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U.S. Nuclear Regulatory Commission
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Calvert Cliffs Nuclear Power Plant, Units 1 and 2
Renewed Facility Operating License Nos. DPR-53 and DPR-69
Docket Nos. 50-317 and 50-318

Subject: Revised - Final Response to Generic Letter 2004-02

References: 1. Final Response to Generic Letter 2004-02, dated August 13, 2018.

2. Supplement to Final Response to Generic Letter 2004-02, dated October 10, 2018.

3. Calvert Cliffs Nuclear Power Plant, Units 1 and 2 – Regulatory Audit RE: Risk-Informed Approach to License Amendment Request for Closure of Generic Issue-191 (EPID L-2018-LLA-0222 and EPID L-2018-LLE-0013), dated December 21, 2018.

By letters dated August 13, 2018 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML18226A189)(Reference 1), as supplemented by letter dated October 10, 2018 (ADAMS Accession No. ML18283A034) (Reference 2), Exelon Generation Company, LLC (Exelon) submitted a License Amendment Request (LAR), exemption request, and updated response to Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized Water Reactors," dated September 13, 2004 (ADAMS Accession No. ML042360586), for Calvert Cliffs Nuclear Power Plant, Units1 and 2 (Calvert Cliffs).

By letter dated December 21, 2018 (ADAMS Accession No. ML18345A194) (Reference 3), the NRC staff informed Exelon of its intention to perform a regulatory audit to support its review of the LAR. The audit was conducted at Calvert Cliffs in Lusby, MD, on January 29 - 31, 2019.

This letter documents Exelon's response to the audit questions. This letter forms Exelon's final response to Generic Letter 2004-02 and supplements the previously submitted correspondence (Reference 1).

The revised original attachments are included with revision bars to clearly identify the changes. Attachments 2, 4 and 5 have not been revised, and therefore, are not included. Additionally, Enclosure 1-2.2 of Attachment 1 has been deleted and it is also not included.

Exelon has reviewed the original information supporting a finding of No Significant Hazards consideration and concludes that the additional information provided in this letter does not affect the bases for concluding that the proposed license amendment does not involve a significant hazards consideration. Furthermore, the additional information provided in this letter does not affect the bases for concluding that neither an environmental impact statement nor an environmental assessment needs to be prepared in connection with the proposed amendment.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 7th day of June 2019.

If you should have any questions regarding this submittal, please contact Enrique Villar at 610-765-5736.

Respectfully,

James Barstow
Director - Licensing & Regulatory Affairs
Exelon Generation Company, LLC

Attachments:

1. Supplemental response to Generic Letter 2004-02
   - 1-1 Introduction
   - 1-2 Deterministic (Approved Methodologies) Bases
     Enclosure 1-2.1 ECCS and CSS System Figures
   - 1-3 Risk-Informed Bases
   - 1-4 Defense in Depth and Safety Margin

3. License Amendment Request for Calvert Cliffs Risk-informed Approach to Closure for GSI-191
   - 3-1 Technical Specification Page Markups
   - 3-2 Technical Specifications Bases Page Markups (Information Only)
   - 3-3 Calvert Cliffs UFSAR Page Markups (Information Only)

cc:		
cc:	NRC Regional Administrator, Region I	w/attachments
	NRC Senior Resident Inspector, CCNPP	"
	NRC Project Manager, NRR, CCNPP	"
	D. A. Tancabel, State of Maryland	"

ATTACHMENT (1)

SUPPLEMENTAL RESPONSE TO GENERERIC LETTER 2004-02

Calvert Cliffs Units 1 and 2 Risk-Informed Approach to Closure for GSI-191

1-1 Introduction

This attachment provides the Calvert Cliffs methodology for a risk-informed approach to addressing Generic Safety Issue (GSI)-191 issues and responding to Generic Letter (GL) 2004-02 [Reference (1)], as discussed in SECY Paper [Reference (2)]. The Calvert Cliffs risk-informed approach is intended to be applied to Calvert Cliffs Units 1 and 2.

The Calvert Cliffs risk-informed methodology addresses the effects of debris accumulation on the Emergency Core Cooling System (ECCS) and Containment Spray System (CSS) Containment Emergency Sump strainer during long-term core cooling in the recirculation mode of operation. In this simplified risk-informed methodology, the effects of debris on the strainer that are bounded by the plant-specific testing, and the downstream effects of system and component blockage(plugging, and wear and core flow blockage and other in-vessel effects) of debris that bypasses the strainer are addressed deterministically in accordance with Nuclear Regulatory Commission (NRC)-accepted methodologies for resolution of GL 2004-02.

Breaks that are not bounded by the plant-specific testing are conservatively assumed to result in core damage and potential large early release of radionuclides. A full spectrum of postulated break sizes. types (longitudinal, circumferential), and locations are analyzed up to and including double-ended guillotine breaks (DEGB) of the largest pipe in the reactor coolant system (RCS). The changes to Core Damage Frequency (CDF) and Large Early Release Frequency (LERF) associated with GSI-191 concerns are quantified by applying the LOCA frequencies published in NUREG-1829 [Reference (3)], and then compared to RG 1.174 [Reference (4)] acceptance criteria guidelines. The Calvert Cliffs analysis shows that the contribution to risk from the breaks that cannot be mitigated using existing NRC approved methodologies is very small and within Regulatory Guide (RG) 1.174 Region III. A detailed description of the Calvert Cliffs simplified risk-informed methodology is provided to NRC for review in Attachment 1-3.

The Licensing Basis with regard to the effects of debris is that there is an acceptably high probability that the effects of LOCA debris will be mitigated based on successful plant-specific prototypical testing using approved assumptions and analyses. The risk from breaks that could generate debris that is not bounded by the testing is very small and acceptable in accordance with the guidelines of RG 1.174.

Implementation of the new licensing basis requires justification in accordance with 10CFR50.12 of an exemption to the relevant regulation; i.e. 10CFR50.46(a)(1). The exemption is complemented by amendments to the Calvert Cliffs Unit 1 and Unit 2 operating licenses to allow for the change in analysis methodology per 10CFR50.59, to change ECCS Technical Specifications, and to add a new Containment Emergency Sump Technical Specification.

The following sections of this introduction are presented in the same layout as the Staff Regulatory Guidance section of draft RG 1.229 [Reference (5)].

1.0 SYSTEMATIC RISK ASSESSMENT OF DEBRIS

As described in RG 1.174, the systematic risk assessment should consider all hazards, initiating events, and plant operating modes. However, a screening process can be used to eliminate scenarios that are not relevant, not affected by debris, or have an insignificant contribution.

Calvert Cliffs performed a systematic risk assessment considering all accident sequences leading to a demand for recirculation. This includes the entire spectrum of LOCAs, Reactor Coolant Pump (RCP) seal

LOCA, secondary system high energy line breaks, and accident sequences leading to once-through-core-cooling (feed & bleed). As presented in Attachment 1-3, only very large weld failures in the main reactor coolant piping generate sufficient debris to threaten strainer performance. Fire and other external events are not capable of inducing large LOCAs.

The Calvert Cliffs simplified risk informed approach considered the following debris-related failure modes:

a. Excessive head loss at the strainer leads to loss of net positive suction head (NPSH) margin for adequate operation of the pumps;
b. Excessive head loss at the strainer causes mechanical collapse of the strainer;
c. Excessive head loss at the strainer lowers the fluid pressure, causing release of dissolved gases (i.e., deaeration or flashing); and
d. Debris prevents adequate flow to the strainer or prevents the strainer from attaining adequate submergence.

The Calvert Cliffs risk-informed approach did not consider the following debris-related failure modes:

a. Debris in the system downstream of the strainer exceeds ex-vessel limits (e.g., blocks small passages in downstream components or causes excessive wear);
b. Debris results in core blockage and decay heat is not adequately removed from the fuel; and
c. Debris buildup on cladding results in inadequate decay heat removal.

These failure modes are addressed in Attachment 1-2 using existing NRC approved methodologies.

1.1 Hazards, Initiating Events, and Plant Operating Modes

1.1.1 <u>Hazards and Initiating Events</u>

Hazards and initiating events considered in the risk assessment are random weld failures in piping systems, pressure retaining component failures, water hammer, seismic, fire, and other external events. The following plant operating modes and hazards were screened from the risk assessment as described in Attachment 1-3:

1. Operating Modes with RCS Pressure <1750 psia,
2. Breaks downstream of normally closed valves,
3. Secondary System Breaks,
4. Non-Piping LOCA Initiators,
    a. Steam Generator Primary Manway Covers,
    b. Valves,
    c. Reactor Head Penetrations,
5. Water hammer induced piping failures,
6. Seismically induced piping failures, and
7. Other external events.

The initiating events addressed in the Calvert Cliffs simplified risk-informed approach are limited to internal event LOCAs in the primary reactor coolant system.

1.1.2 Plant Operating Modes

Each Calvert Cliffs Unit is a two train ECCS and CSS plant with a single emergency recirculation suction strainer. The risk assessment considered plant operating Modes 1, 2; and Mode 3 with pressurizer pressure ≥ 1750 psia. Since a single Containment Emergency Sump strainer is used to supply both trains, two train operation is the limiting operating scenario as it maximizes the recirculation flow rate and strainer head loss.

As presented in Attachment 1-3, only very large weld failures in the main reactor coolant piping generate sufficient debris to threaten strainer performance. Mode 3 with pressurizer pressure < 1750 psia and Mode 4, 5, and 6 LOCAs have been screened out because these lower pressure plant conditions do not support generation or transport of comparable quantities of debris to those of very large breaks.

1.2 Risk Attributable to Debris

The risk attributable to debris was quantified in terms of the change in core damage frequency (ΔCDF) and the change in large early release frequency (ΔLERF) compared to a hypothetical plant condition without any debris. This was done using a best-estimate approach to compute mean ΔCDF and ΔLERF values with conservatisms applied to some of the inputs.

The risk quantification was performed using the Nuclear Accident Risk-WeigHted AnaLysis (NARWHAL) software to calculate the ΔCDF and ΔLERF values. The Calvert Cliffs PRA model of record was used as the source of the base CDF and LERF values and to screen secondary system breaks and breaks downstream of normally closed valves. The Calvert Cliffs PRA model has been peer reviewed against RG 1.200 [Reference (7)] and is therefore appropriate to use for risk-informed applications. The Calvert Cliffs PRA model was not modified to incorporate events for GSI-191 sump strainer or core blockage failures. Therefore, the risk quantification was performed outside the PRA model.

1.3 Technical Adequacy of the Calvert Cliffs Probabilistic Risk Assessment (PRA) Model.

The Calvert Cliffs PRA model is used in a limited way to support the risk-informed GSI-191 analysis:

1) A sensitivity analysis was developed to determine CDF and LERF frequencies from Containment Emergency Sump clogging due to Main Steam and Main Feedwater line breaks in the containment.
2) A CDF-to-LERF multiplier was developed to determine a ΔLERF value for the GSI-191 analysis, based on the calculated ΔCDF value.
3) A valve failure probability was developed to support the screening of breaks downstream of normally closed valves.
4) The overall Internal Events CDF and LERF values are presented.

For the GSI-191 analysis, the Internal Events PRA model is appropriate for supporting probabilistic analysis and sensitivity cases:

- The ΔCDF value is calculated from LOCA pipe breaks in the containment that result in a quantity of debris that may cause the maximum allowable strainer head loss to be exceeded. LOCAs are internal event PRA initiating events.
- The sensitivity analysis for Main Steam and Main Feedwater pipe breaks are based on internal event PRA initiating events.
- The CDF-to-LERF multiplier is based on Large Break LOCA accident progressions. Large-Break LOCAs are internal events PRA initiating events.

- Valve failure probabilities are based on the data analysis in the internal events PRA.

In June 2010, a full-scope internal events PRA peer review [Reference (8)] was conducted to determine compliance with the American Society of Mechanical Engineers (ASME) PRA Standard, RA-S-2008, including the 2009 Addenda A [Reference (6)] and RG 1.200, Revision 2 [Reference (7)]. Subsequently, in January 2017, a PRA Finding Level Fact and Observation (F&O) Technical Review (i.e, F&O Independent Assessment) and Focused-Scope Peer Review was performed [Reference (9)]. The F&O independent assessment determined that all but one finding-level F&O's were resolved. Also, one new finding-level F&O was identified. These finding-level F&Os are presented in Table 1.

As discussed in Table 1, both open finding-level F&Os are documentation issues related to the flood analysis, and these F&Os would not impact GSI-191 analyses.

Table 1: Open Internal Events PRA Findings

F&O ID	SR	Finding/Observation	Status	Disposition
1-18 (from 2010 peer review)	IFSO-A4 IFEV-A7	Examined Internal Flooding Notebook (C0-IF-001, Rev. 1) Section 3.3 and 5.3. Consideration of human-induced mechanisms as potential flood sources not clear. Regarding human-induced impacts on the flood frequency, Section 5.3 of the IF report states that they were included, but their inclusion should be better documented or referenced from IF (e.g., a sample calculation showing human contribution would be helpful) (This F&O originated from SR IFSO-A4 Capability Category 1-3 is MET	Partially Resolved with Open Documentation (IFSO-A4) Resolved (IFEV-A7)	This is an internal flood documentation finding. This issue does not affect GSI-191 analysis. See Note 1 below.
IFFS-01 (finding from 2017 focused scope peer review)	IFEV-B1 IFEV-B2	The Internal Flood Notebook assembled in performing the upgrade to the internal flood PRA was judged not to satisfy the requirement that it document the internal flood-induced initiating events in a manner that facilitates PRA applications, upgrades, and peer review. Essential inputs to the calculation of flood frequencies associated with pipe ruptures is distributed among a variety of files, some of which are not formally stored with other PRA information. Reconstructing the initiating frequencies was impossible without the assistance of members of the IFPRA team. NOT MET Capability Category I-III.	Open	This is an internal flood documentation finding. This issue does not affect GSI-191 analysis. See Note 2 below.

Note 1 - In the Calvert PRA, human-induced mechanisms as potential flood sources are considered, including doors left inadvertently open that alter flood propagation paths, flow-diversion of flow through openings created by disassembly or removal of components to perform maintenance, accidental actuation of fire suppression systems, and overfilling of tanks and vessels. In the Calvert PRA, there are no human-induced mechanisms as flood sources inside of the containment. Such floods would be screened-out of the PRA internal flood analysis. As discussed in Attachment (1-3) Section 1.1.3.3, containment components are designed to operate in a LOCA environment and the containment floor and sump would accommodate support system flooding without submerging any important equipment.

Note 2: - The frequencies for Main Steam and Main Feedwater pipe breaks are derived from Idaho National Laboratory initiating event data for high-energy line breaks, and then updated to reflect plant-specific data using a Bayesian process. In the Calvert PRA, internal flood frequencies are calculated starting with pipe failure and rupture data developed by EPRI, and consider factors such as aging, human-induced floods, and successful isolation of flood sources. However, as discussed in Note 1 above and Attachment (1-3) Section 1.1.3.3, internal flood-induced initiating events in the containment are screened-out of the PRA internal flood analysis.

1.4 Engineering Calculations and Tests

The risk evaluation relies on many engineering calculations and tests that have been developed and conducted for Calvert Cliffs over the last several years to address GSI-191 and GL 2004-02. These calculations and tests are described in detail in Attachment 1-2.
These calculations and tests have been performed in accordance with the Exelon Quality Assurance Topical Report and are maintained in the Fleet Configuration Management System document storage application.

1.5 Small Risk Increase

The GSI-191 risk quantification for Calvert Cliffs shows that the overall risk associated with debris (CDF, LERF, ΔCDF, and ΔLERF) is very small as defined by Region III of RG 1.174.

A total baseline CDF/LERF, which includes contributions from internal events, fire, seismic, and high winds are presented in the tables below:

Unit 1 Baseline CDF	
Source	**Contribution**
Internal Events PRA	9.5E-06
Fire PRA	4.2E-05
Seismic	1.1E-06
High Winds	3.3E-07
Other External Events	No significant contribution
Total Unit 1 CDF	**5.3E-05**

Unit 1 Baseline LERF	
Source	**Contribution**
Internal Events PRA	1.2E-06
Fire PRA	3.2E-06
Seismic	1.1E-07
High Winds	1.6E-08
Other External Events	No significant contribution
Total Unit 1 LERF	**4.5E-06**

Unit 2 Baseline CDF	
Source	**Contribution**
Internal Events PRA	9.6E-06
Fire PRA	4.0E-05
Seismic	1.1E-06
High Winds	5.4E-07
Other External Events	No significant contribution
Total Unit 2 CDF	**5.1E-05**

Unit 2 Baseline LERF	
Source	**Contribution**
Internal Events PRA	1.2E-06
Fire PRA	3.4E-06
Seismic	1.1E-07
High Winds	2.9E-08
Other External Events	No significant contribution
Total Unit 2 LERF	**4.8E-06**

This information has previously been submitted and reviewed by the NRC. The above table was extracted from the Calvert TSTF-505 LAR [15]. Subsequently, the models were updated, and in response to TSTF-505 RAI #5 [16], it was confirmed that the updated plant-specific total CDF and LERF remained less than 1E-4/year and 1E-5/year, respectively. Finally, in the final NRC-approved TSTF-505 amendment in October 2018 [17], the NRC acknowledges that the estimated total CDF and LERF meets the 1E-4/year CDF and 1E-5/year LERF criteria of RG 1.174 [4].

The Calvert Cliffs maximum CDF is 5.3×10^{-5} and the ΔCDF is 6.3×10^{-8} using the "End-of-Plant-License Estimate (40 year) geometric mean LOCA frequencies from NUREG-1829. As shown in Figure 1 this demonstrates that the risk-significance of pipe breaks that produce higher strainer head loss than allowable is very small and falls within Region III of Regulatory Guide 1.174 as shown below.

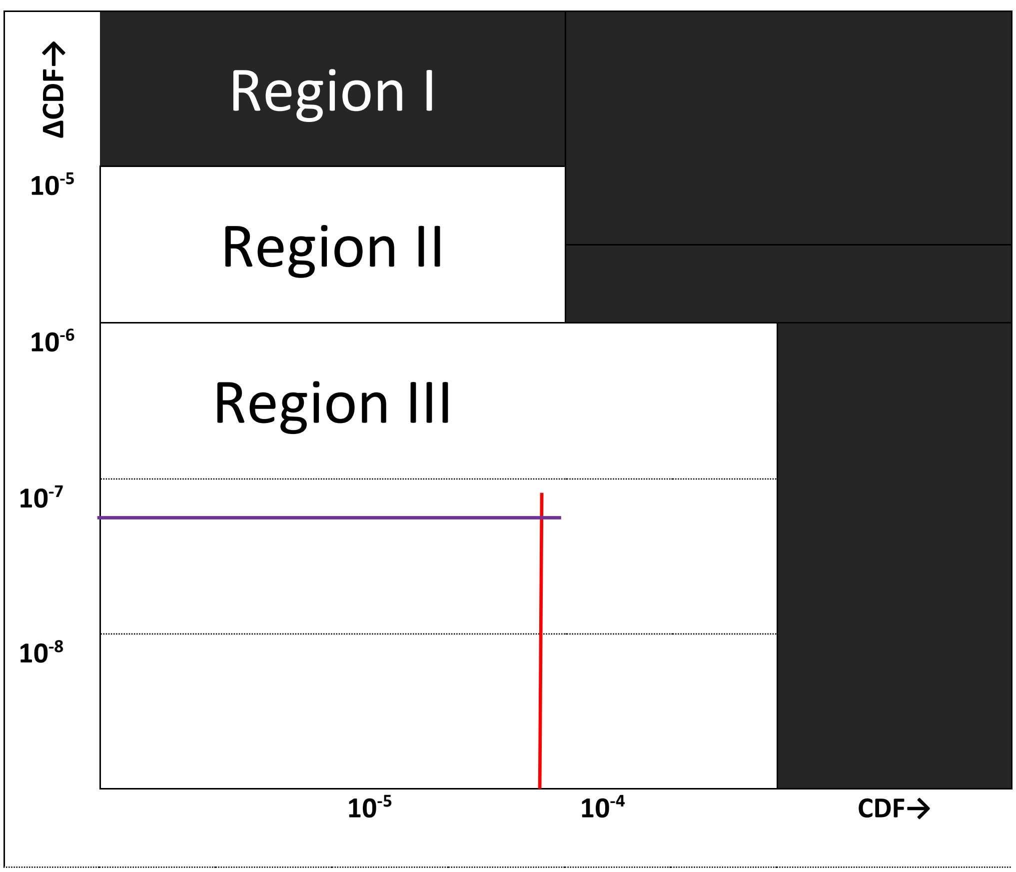


Figure 1: Regulatory Guide 1.174 Acceptance Criteria for CDF

The Calvert Cliffs maximum LERF is 4.8 x 10^{-6} and the ΔLERF is 3.8 x 10^{-9} using the "End-of-Plant-License Estimate (40 year) geometric mean LOCA frequencies from NUREG-1829. As shown in Figure 2, this demonstrates that the risk-significance of pipe breaks that produce higher strainer head loss than allowable is very small and also fall within Region III of Regulatory Guide 1.174.

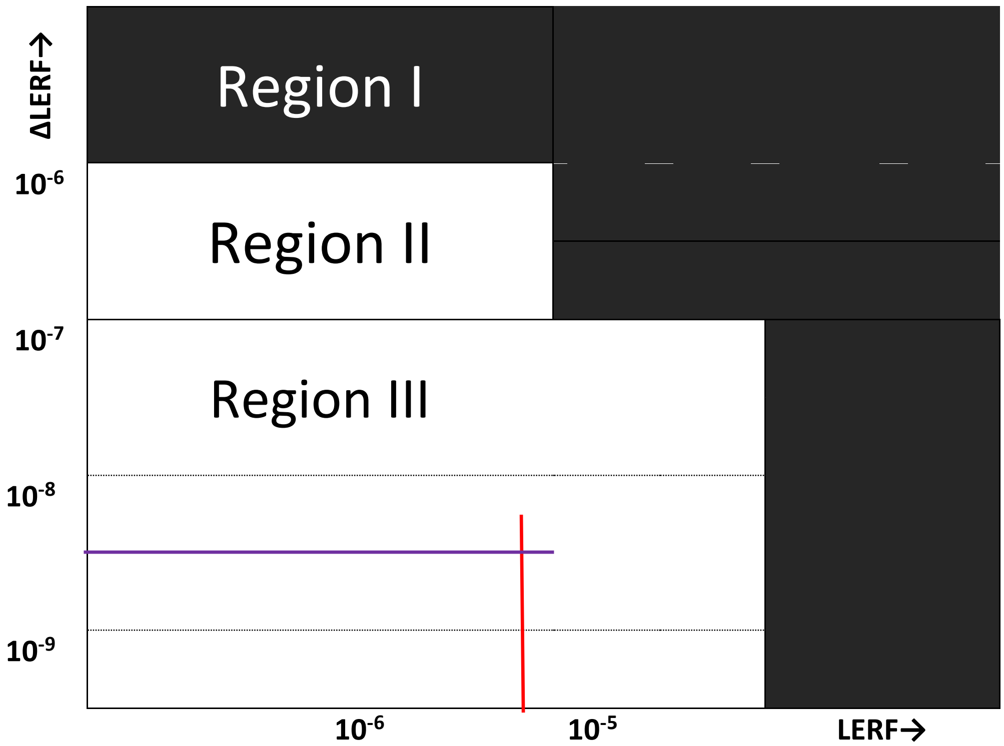


Figure 2: Regulatory Guide 1.174 Acceptance Criteria for LERF

2.0 INITIATING EVENT FREQUENCIES

The initiating events addressed in the Calvert Cliffs simplified risk-informed approach are limited to internal event LOCAs in the primary reactor coolant system. LOCA frequencies for the Calvert Cliffs simplified risk-informed analysis were taken from NUREG-1829.

2.1 Break Locations

Break locations were considered at all welds in ASME Class 1 piping upstream of normally closed valves. Breaks downstream of normally closed valves, and non-piping LOCA initiators including steam generator primary manway covers, valves, and reactor head penetrations were screened as described in Attachment 1-3.

2.2 LOCA Frequency Aggregation Method

The LOCA frequencies in the base PRA model are based on the geometric mean aggregation in NUREG-1829. The uncertainty associated with the use of the geometric mean aggregation for LOCA frequencies was assessed by performing a sensitivity analysis using the arithmetic mean aggregation.

The geometric mean is the most appropriate method for combining the results of the NUREG-1829 elicitation. As stated in NUREG-1829, Section 5.5, "… *the AM (arithmetic mean) of individual estimates is*

often not a good measure of the median group opinion when the individual estimates are widely varying. In this case, the AM is dominated by the one or two largest results and cannot be fairly described as a group estimate".

"There is support for the use of the median or GM (geometric mean) in the literature. In previous NRC applications (…), the median was used as a group estimate when the individual estimates varied by several orders of magnitude… , Meyer and Booker state: "To overcome the influence of extreme values when forming an aggregation estimate, use the median or geometric mean" (...)…, von Winterfeldt and Edwards recommend averaging probabilities (⋯). However, they conclude: "The only context in which we have any reservations about this conclusion is that of very low probabilities - - - - - for such extreme numbers, we would prefer averaging log odds to averaging probabilities." For very low probabilities, averaging log odds is equivalent to using the GM. Taking these considerations into account, and noting that a sensitivity study showed that there is little difference between using the median or the GM to aggregate the study results (⋯), the GM was chosen as the most appropriate group estimate which utilizes all the individual estimates."

2.3 Interpolation of NUREG-1829 LOCA Frequencies

A semi-log interpolation scheme, in which linear interpolation between break sizes and log interpolation between frequencies was used to interpolate between NUREG-1829 LOCA categories. This is acceptable since the break sizes are generally within an order of magnitude; the frequencies span several orders of magnitude; and there is approximately a one half order of magnitude difference between successive LOCA categories.

2.4 Apportionment of LOCA Frequencies

As presented in Attachment 1-3, only large weld failures in the main reactor coolant piping generate sufficient debris to threaten strainer performance. The NUREG-1829 LOCA frequencies were apportioned equally across the welds in the main reactor coolant piping as a function of the break size considered at the weld.

2.5 Parametric Uncertainty

Parametric uncertainty refers to the variability in input parameters that are used in the risk assessment. Parametric uncertainty was addressed through the performance of parametric sensitivity cases. Sensitivity cases were run to identify the worst-case combination of inputs that are bounding for strainer and/or pump failures.

2.6 Applicability of NUREG-1829 LOCA Frequencies

The NUREG-1829 LOCA frequencies represent generic, or average, estimates for the commercial fleet and are not meant to represent a specific site or design. The experts developed these generic estimates using representative assumptions about important variables such as material conditions, plant geometry, degradation mechanisms, loading, and maintenance practices. The experts also assumed normal plant operational cycles and loading histories (e.g., pressure, thermal, residual). Finally, the experts assumed that plant construction and operation comply with all applicable codes and standards required by regulation and technical specifications.

Calvert Cliffs used the "End-of-Plant-License Estimate (40 year) LOCA frequencies from NUREG-1829 Table 7.19. The 40 year estimates are appropriate as both units are in the early portion of the extended operating periods of the renewed licenses.

The Calvert Cliffs Nuclear Steam Supply System (NSSS) for both Units is identical, utilizing pressurized water reactors supplied by Combustion Engineering, Inc. (CE). The NSSS includes two steam generators (SGs), two reactor coolant loops and four RCPs. The reactor coolant loops are very similar to those in the Palisades Plant (Docket number 50-255).

The only weld failures that produce sufficient debris to threaten strainer performance at Calvert Cliffs are breaks in the large primary reactor coolant system piping. Three different types of welds are present in this piping:

1. ASME Section XI Category B-J similar metal longitudinal and butt welds performed in the shop by the pipe supplier (Combustion Engineering),
2. ASME Section XI Category B-F bimetallic (dissimilar) metal butt welds performed in the shop by CE, and
3. ASME Section XI Category B-J similar metal butt welds performed in the field.

The RCS piping is fabricated of low allow steel (SA516, GR70), clad internally with Type 304L stainless steel. The reactor coolant pumps (RCP) are constructed of high alloy CF8M (Cast 316) cast stainless steel. The RCS piping attached to the RCPs is provided with A-352, GRCF8M stainless steel safe ends. The RCS piping was shop fabricated and shop welded into subassemblies to the greatest extent practicable to minimize the amount of field welding. Fabrication of piping and subassemblies was done by shop personnel experienced in making large heavy wall welds. Welding procedures and operations met the requirements of ASME B&PV Code, Section IX. All welds were 100% radiographed and liquid penetrant tested and all reactor coolant piping penetrations were attached in accordance with the requirements of ANSI B31.7. Cleanliness standards consistent with nuclear service were maintained during fabrication and erection.

Field welding was also done by personnel experienced in making large heavy wall welds. Welding procedures and operations were reviewed and approved by CE and met the requirements of ASME B&PV Code, Section IX. All welds were 100% radiographed and liquid penetrant tested in accordance with the requirements of ANSI B31.7. Cleanliness standards consistent with nuclear service were maintained during erection and welding.

2.6.1 <u>B-J Longitudinal and Butt Shop Welds</u>

ANSI B31.7 - 1969 requires these welds to be post-weld heat treated at 1100°F for a minimum of 1 hour per inch of material thickness.

These welds are subject to design and construction defects but no other degradation mechanisms. These welds are included in the Calvert Cliffs ASME Section XI In-Service Inspection Program which includes periodic volumetric, surface, and/or visual examinations and leakage tests to identify evidence of degradation.

2.6.2 <u>B-F Butt Shop Welds</u>

These represent the Inconel buttering on the RCS cold legs to which the eight (8) safe-end welds for welding to the suction and discharge nozzles of the RCPs are attached. These welds were performed using CE controlled welding procedures and post-weld heat treatment in accordance with ANSI B31.7 - 1969 which requires these welds to be post-weld heat treated at 1100°F for a minimum of 1 hour per

inch of material thickness. Inconel is not subject to heat sensitization. The safe-ends were not attached until after final heat treatment stress relief. The stainless steel safe end was welded to the Inconel buttering on the alloy steel and the weld made using Inconel weld wire which precludes heat sensitization of the safe-end material.

These Inconel butter welds are not subject to the Primary Water Stress Corrosion Cracking (PWSCC) degradation mechanism due to the temperature at which they operate. These welds are subject to design and construction defects degradation mechanism. These welds are included in the Calvert Cliffs ASME Section XI In-Service Inspection Program which includes periodic volumetric, surface, and/or visual examinations and leakage tests to identify evidence of degradation.

2.6.3 B-J Butt Field Welds

This represents the majority of field welds performed in the RCS at Calvert Cliffs. These welds were performed using Bechtel controlled welding procedures that were approved by CE. The welds were post-weld heat treated at temperatures of 1125°F ± 25°F. The portion of the pipe adjacent to the heated band and extending for a distance 18 inches along the pipe was insulated with 3 inch thick fiberglass insulation.

These welds are subject to design and construction defects but no other degradation mechanisms. These welds are included in the Calvert Cliffs ASME Section XI In-Service Inspection Program which includes periodic volumetric, surface, and/or visual examinations and leakage tests to identify evidence of degradation.

2.6.4 Summary

The Calvert Cliffs plants, similar to other nuclear power plants constructed in the United States at the time, were designed, constructed, and operated in compliance with the applicable industry codes and standards required by NRC regulations at the time. Calvert Cliffs is not an outlier plant and the NUREG-1829 LOCA frequencies are applicable.

2.7 Site-Specific LOCA Contributors

2.7.1 Seismically-Induced LOCA

Successful long-term core and containment cooling requires a number of the systems at the plant to function. This includes first and foremost the Refueling Water Tank (RWT). If the RWT is failed, then there is no safety injection beyond safety injection tank (SIT) water to provide for core cooling and no containment spray water for containment cooling.

In IPEEE Table 3-4, the RWT was assigned a high confidence low probability of failure (HCLPF) of 0.15 g. This is a much lower fragility than that of the RCS with a HCLPF of 0.4 g. If the RWT does provide injection and recirculation is required, then that water must be cooled. That water can either be cooled by the service water system (SRW) or the component cooling water system (CCW). Containment cooling is also provided by SRW to the containment air coolers.

CCW and SRW are closed loop limited inventory systems. Small, seismically induced line breaks anywhere in these systems would quickly deplete the head tanks resulting in complete loss of the

systems. CCW was assigned a HCLPF of 0.3 g and SRW was assigned a HCLPF of 0.12g. CCW and SWR are expected to fail due to seismic loading well before large RCS piping.

The support systems for core and containment cooling are expected to fail in a seismic event before RCS piping and will not be available. With the support systems unavailable ECCS will be unable to prevent core damage whether debris is generated and transported to the strainer or not. Therefore, the delta risk associated with GSI-191 during a seismic event is negligible. Seismic events were screened from the risk-informed GSI-191 evaluation.

2.7.2 Water Hammer

As presented in Section 2.5 of Attachment 1-3, only large weld failures in the main reactor coolant piping generate sufficient debris to threaten strainer performance. Calvert Cliffs has over 80 years of operating experience between both Units with no water hammers occurring in the main reactor coolant piping. The reactor coolant system is not susceptible to water hammer. Water hammer events were screened from the risk-informed GSI-191 evaluation.

2.8 Fire and Other External Events

As presented in Section 2.5 of Attachment 1-3, only large weld failures in the main reactor coolant piping generate sufficient debris to threaten strainer performance. Fire and other external events that contribute to the CDF and LERF in the Calvert Cliffs PRA do not lead to large break LOCAs. Therefore, fire and other external events were screened from the risk-informed GSI-191 evaluation.

3.0 DEFENSE IN DEPTH AND SAFETY MARGINS

As described in RG 1.174, sufficient defense-in-depth and safety margin must be maintained. Both of these aspects were evaluated in detail as described in Attachment 1-4.

4.0 UNCERTAINTY

Uncertainty quantification is a key requirement in RG 1.174 for a risk-informed evaluation. As defined in RG 1.174 and explained in more detail in NUREG-1855 [Reference (10)] and two corresponding EPRI reports [References (11) and (12)], there are three types of uncertainty that should be addressed:

1) Parametric uncertainty
2) Model uncertainty
3) Completeness uncertainty

Parametric uncertainty refers to the variability in input parameters that are used in the risk assessment. Due to the wide range of plant-specific post-LOCA conditions related to GSI-191 phenomena, this is a very important aspect for understanding the overall uncertainty.

Model uncertainty refers to the potential variability in an analytical model when there is no consensus approach. A consensus approach is a model that has been widely adopted or accepted by the NRC for the application for which it is being used. For example, the use of a spherical zone of influence (ZOI) to model the debris quantity generated by a high energy line break is a consensus model that has been

widely adopted and accepted by the NRC [References (13) and (14)]. In general, Calvert Cliffs is using standard models that have been widely accepted for deterministic evaluations (e.g., accepted insulation and qualified coatings ZOI sizes and prototypical strainer module testing for head loss and penetration). By using these consensus approaches, model uncertainty is minimized.

Completeness uncertainty refers to 1) the uncertainty associated with scenarios or phenomena that are excluded from the risk evaluation, and 2) the uncertainty associated with unknown phenomena. Although it may not be practical to quantify the uncertainty associated with factors that are not explicitly modeled, their potential impact can be qualitatively assessed. Uncertainties associated with unknown phenomena, on the other hand, cannot even be qualitatively assessed. Uncertainties associated with unknown phenomena are the reason that it is important to maintain defense-in-depth and safety margins.

Because all of the cases that were evaluated for model uncertainty and parametric uncertainty resulted in a ΔCDF less than $1x10^{-6}$ (see Section 4.1 and Section 4.2 below), it can be concluded with high confidence that the risk associated with GSI-191 is very small as defined by the acceptance guidelines in RG 1.174.

4.1 Parametric Uncertainty

To quantify parametric uncertainty, sensitivity cases were run to identify the worst-case combination of inputs that are bounding for strainer failures. Table 2 shows a high-level summary of the important input parameters with the bounding direction for strainer failures. It also summarizes the inputs used for the base case and the changes in inputs used for the worst-case strainer failure sensitivity cases.

There are competing factors associated with pool volume, and either a minimum or maximum could end up being more conservative with respect to strainer failures since the pool volume affects the amount of chemical precipitate in the sump. Therefore, both conditions were analyzed. Similarly, either a minimum or maximum sump pool temperature could be more conservative. However, since the parametric sensitivity analysis showed that higher temperature is more conservative, the maximum bounding temperature profile was used for the sensitivity cases.

The design flow rate for the ECCS pumps was used for the base case, but was increased to use the maximum flow rate for the bounding strainer failure cases. For both the base case and the sensitivity cases, the ECCS/CS switchover timing is calculated in NARWHAL as a function of the pump flow rates and RWT water volume. The combined High Pressure Safety Injection (HPSI), Low Pressure Safety Injection (LPSI), and CSS pump flow rate is slightly higher for the sensitivity cases, which results in an earlier switchover time for the cases evaluating a minimum pool volume.

Conservative inputs were used in the base case for strainer head loss and the various strainer and pump acceptance criteria. Therefore, the same inputs were used in the sensitivity cases.

Table 2: Worst Case Conditions for Strainer Failure

Parameter	Bounding Direction	Base Case Input	Sensitivity Case Input
Insulation Debris Quantity	Maximum	Consensus (Maximum)	Same as Base Case
Qualified Coatings Debris Quantity	Maximum	Consensus (Maximum)	Same as Base Case
Unqualified Coatings Debris Quantity	Maximum	Consensus (Maximum)	Same as Base Case
Latent Debris Quantity	Maximum	Consensus (Maximum)	Same as Base Case
Miscellaneous Debris Quantity	Maximum	Consensus (Maximum)	Same as Base Case
Debris Transport Fractions	Maximum	Consensus (Maximum)	Same as Base Case
Pool Volume/Level	Minimum or Maximum	Minimum	Minimum and Maximum
Containment Pressure	Minimum	Consensus (Minimum)	Same as Base Case
Pool Temperature	Minimum or Maximum	Design Basis (Maximum)	Same as Base Case
ECCS Flow Rate	Maximum	Design Basis	Maximum
CSS Flow Rate	Maximum	Maximum	Same as Base Case
ECCS/CSS Switchover Time	Minimum	Function of Water Volume and Flow Rates	Same as Base Case
Core Flush Switchover Time	N/A	Procedural Step (Minimum)	Same as Base Case
Secure CSS Time	Maximum	Maximum	Same as Base Case
pH	Maximum	Mean values	Maximum
Head Loss	Maximum	Consensus (Maximum)	Same as Base Case
Structural Margin	Minimum	Design (Minimum)	Same as Base Case
NPSH Margin	Minimum	Available - Required	Same as Base Case
Strainer Void Fraction Limit	Minimum	Minimum	Same as Base Case
Penetration	Minimum	No penetration	Same as Base Case
LOCA Frequency Value	Maximum	Nominal (mean)	Maximum (95th percentile)

Since minimum and maximum inputs were considered for the pool volume inputs, 2 simulations were required for the bounding strainer failure cases. The differences in each of these cases compared to the base case are summarized below.

1. Strainer Failure Case 1 (Minimum Water Volume)
    a. Minimum Water Volume (Base Case Inputs)
    b. Maximum HPSI Flow Rate
    c. Maximum LPSI Flow Rate
    d. Maximum CSS Flow Rate (Base Case – conservatively skewed toward maximum)
    e. Maximum pH Profile
    f. Maximum LOCA Frequency (95^{th} Percentile)

2. Strainer Failure Case 2 (Maximum Water Volume)
    a. Maximum Water Volume (Max RWT value)
    b. Maximum HPSI Flow Rate
    c. Maximum LPSI Flow Rate
    d. Maximum CSS Flow Rate (Base Case – conservatively skewed toward maximum)
    e. Maximum pH Profile
    f. Maximum LOCA Frequency (95^{th} Percentile)

Table 3 and Figure 3 show the results of the parametric uncertainty quantification. Table 3 shows the ΔCDF for each of the parametric uncertainty cases. Figure 3 illustrates the change in ΔCDF for each of the parametric uncertainty cases in comparison to the base case. Note that although the description only mentions one variable, each parametric uncertainty case changed several variables. These variables include the water volume inputs, sump and spray pH profiles, and LOCA Frequency aggregation. The results of this evaluation show that the parametric uncertainty is low.

Table 3: Bounding Strainer Failure Cases

Case	Description	ΔCDF	Change in ΔCDF from Base Case
1	Bounding conditions with maximum pH profile and minimum water volume	1.9E-07	1.3E-07
2	Bounding conditions with maximum pH profile and maximum water volume	1.9E-07	1.3E-07

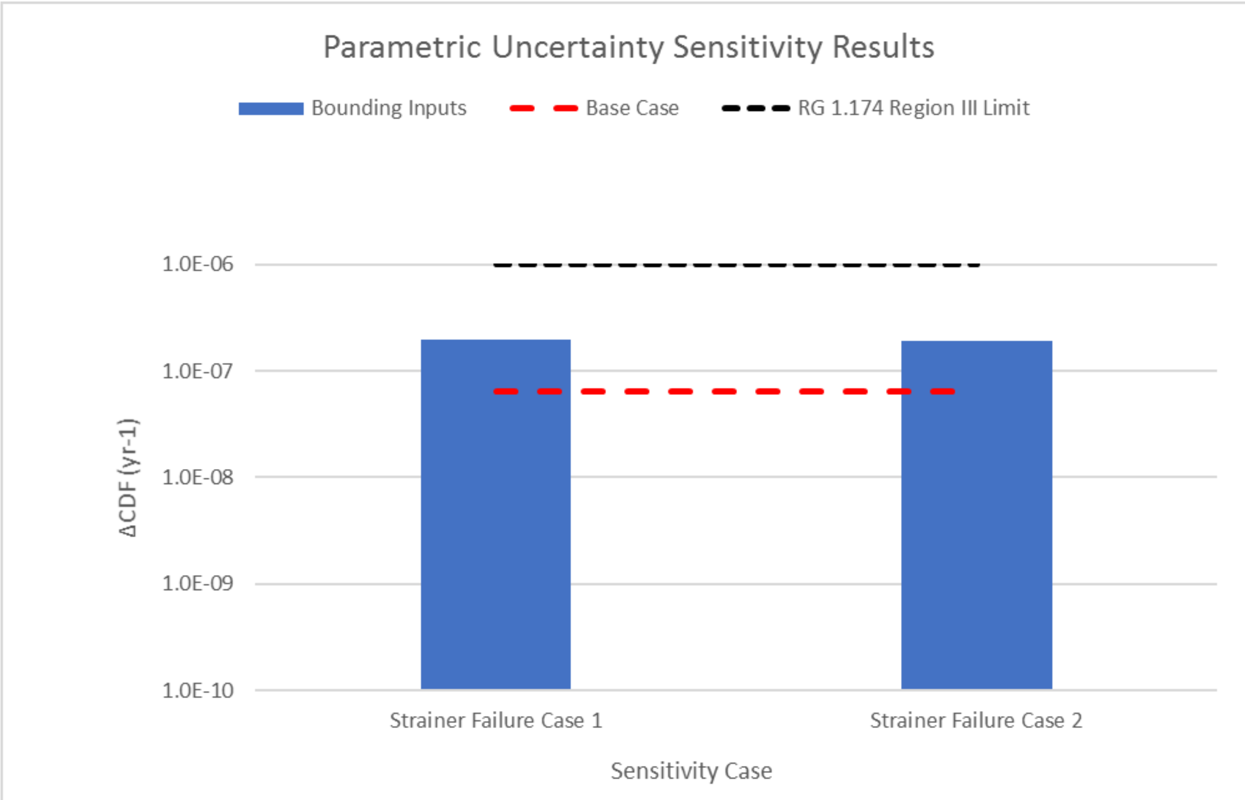


Figure 3: Comparison of Parametric Uncertainty Sensitivity Cases to the Base Case

4.2 Model Uncertainty

To meet the guidance in NUREG-1855, model uncertainty must be addressed for any models or approaches for which no consensus exists. Most of the GSI-191 models used for the Calvert Cliffs evaluation are consensus models that have been widely used by the industry and accepted by the NRC. However, the following models used for Calvert Cliffs are not consensus models and therefore are included in the model uncertainty evaluation:

- Break model
- LOCA frequencies
- LOCA frequency allocation to individual welds
- LBLOCA size range discretization
- Time-step size
- Precipitation Solubility Option

To address the uncertainty in these models, alternative models were evaluated.
In addition to the sensitivities mentioned above, an additional sensitivity case was performed to investigate the effects of using strainer head loss Test #1 which included small pieces of fibrous debris, demonstrated prototypical non-uniform debris deposition on the strainer, and resulted in significantly lower strainer head loss than the other tests.

Table 4 and Figure 4 show the results from the model uncertainty quantification. Table 4 shows the ΔCDF for each of the model uncertainty cases. Figure 4 illustrates the change in ΔCDF for each one of the model uncertainty cases in comparison to the base case. These results show that the model uncertainty is low and the resulting ΔCDF for each of the parametric sensitivity cases is within RG 1.174 Region III.

Note that a sensitivity was performed to verify that the Calvert Cliffs Unit 1 model bounded Unit 2 with respect to GSI-191. Because the ΔCDF is lower for Unit 2, this confirms that Unit 1 is bounding with respect to GSI-191.

Table 4: Results of Model Uncertainty Quantification

Model with No Consensus	Sensitivity Case	ΔCDF	Change in ΔCDF from Base Case
Continuum Break Model	DEGB-Only Model	1.8E-07	1.2E-07
NUREG-1829 40-year Geometric Mean LOCA Frequencies	NUREG-1829 40-year Arithmetic Mean LOCA Frequencies	7.7E-07	7.0E-07
	NUREG-1829 60-year Geometric Mean LOCA Frequencies	2.4E-07	1.8E-07
Top-Down LOCA Frequency Allocation to Welds	Hybrid Allocation Methodology: Skewed to High Rupture Probability Welds	6.3E-08	0.00E+00
	Hybrid Allocation Methodology: Skewed to High and Medium Rupture Probability Welds	6.3E-08	0.00E+00
	Hybrid Allocation Methodology: Spread Equally Across all Welds (top-down)	6.3E-08	0.00E+00
	Hybrid Allocation Methodology: Lower Weight on Longitudinal Welds	6.1E-08	-2.4E-09
	Hybrid Allocation Methodology: Higher Weight on Longitudinal Welds	8.5E-08	2.2E-08
LBLOCA Size Range Discretization (14-18, 18-30 and 30-60 inches)	Bias 1 (14-18 and 18-60 inches)	6.6E-08	2.9E-09
	Bias 2 (14-30 and 30-60 inches)	8.0E-08	1.7E-08
Time Step Size	2 minutes	6.3E-08	0.00E+00
	3 minutes	6.4E-08	5.5E-10
	4 minutes	6.3E-08	-3.5E-10
	5 minutes	6.7E-08	3.1E-09
	15 minutes	7.1E-08	7.2E-09
Precipitation Solubility Option	ANL Solubility Equation; Precipitation forced at 24 hours	6.3E-08	0.00E+00
Head Loss Tests with Fines Only	Head loss data with prototypical non-uniform debris deposition	1.1E-08	-5.3E-08
Unit 1 Debris Quantities	Unit 2 Debris Quantities	5.2E-08	-1.1E-08

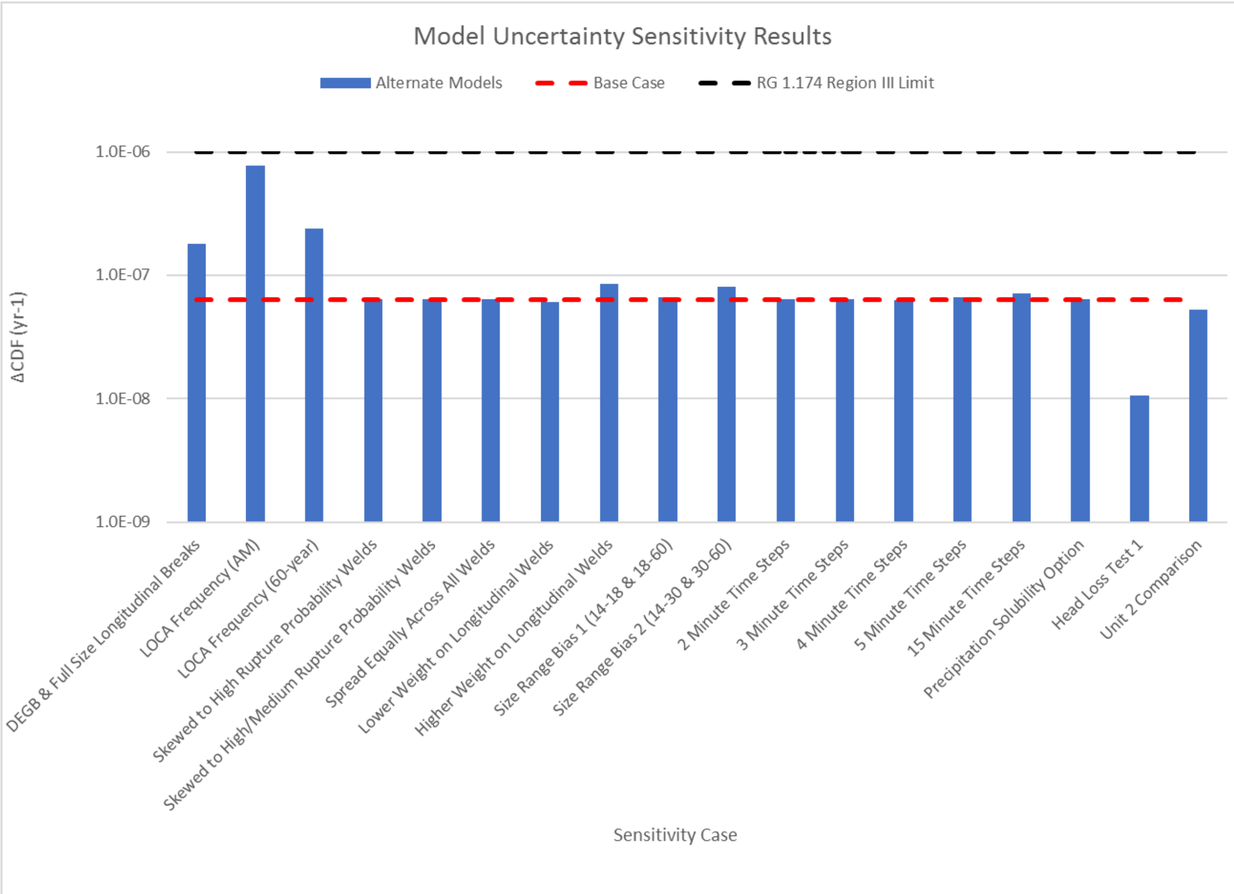


Figure 4: Comparison of Model Uncertainty Sensitivity Cases to the Base Case

4.3 Completeness Uncertainty

Completeness uncertainty was qualitatively determined to be low. As described below, the Calvert Cliffs risk-informed evaluation was rigorous and comprehensive, and the areas that were not explicitly evaluated have a low potential for any significant risk impact:

- The range of hazards, initiating events, and plant operating modes were considered as described in Attachment 1-3.
- LOCAs were directly evaluated in the risk quantification as described in Attachment 1-3.
    - The LOCA evaluation included pipe breaks on every weld within the Class 1 pressure boundary inside the first isolation valve.
    - The LOCA evaluation included an analysis of longitudinal weld breaks spaced no more than one (1) pipe ID apart along each weld.
    - Break sizes ranging from ½-inch to a full DEGB were postulated on each weld.
    - Partial breaks (i.e., breaks smaller than a DEGB) were evaluated in 45-degree increment orientations around the pipe for each break size.
    - Debris quantities were calculated for breaks on welds outside the first normally closed isolation valve, and there is no significant difference between the type and quantity of debris generated for these breaks compared to similar size breaks inside the first isolation valve. Due to the low probability of isolation valve failure to remain closed,

    breaks outside the first isolation valve are insignificant with respect to GSI-191 risk at Calvert Cliffs as described in Attachment 1-3.
  - Non-pipe LOCAs were shown to be reasonably represented or bounded by adjacent pipe breaks as described in Attachment 1-3.
  - Bounding equipment configurations were explicitly evaluated.
- The risk of seismic and water hammer-induced LOCAs was shown to be low as described in Attachment 1-3.
- As described in Attachments 1-2 and 1-3, all known GSI-191 phenomena and debris failure mechanisms were evaluated either in a bounding manner for phenomena not explicitly included in the Calvert Cliffs risk-informed analysis model or in a reasonably conservative manner for phenomena that were included in the risk-informed analysis.

Although there is also some uncertainty associated with unknown phenomena, this uncertainty is judged to be small. The nuclear industry has been actively addressing GSI-191 concerns for PWRs for well over a decade. In addition, the boiling water reactor (BWR) strainer performance issue dates back to 1992, and unresolved safety issue (USI) A-43 dates back to 1979. Numerous tests have been performed by the NRC and industry, as well as regulators and utilities around the world over the last 35 years to resolve issues related to debris and strainer performance. This testing has investigated nearly every aspect of GSI-191 including insulation and coatings destruction from break jets; unqualified coatings failure; blowdown and washdown debris transport; containment pool settling, tumbling, and lift-over-curb debris transport; debris erosion; chemical release, solubility, and precipitation; strainer head loss, vortexing, and bypass; ex-vessel component wear; and in-vessel core blockage and boron precipitation. Based on the extensive research that has been performed, it is unlikely that there are unidentified phenomena that would significantly increase the risk of GSI-191 related failures.

5.0 MONITORING PROGRAM

- Calvert Cliffs has implemented procedures and programs for monitoring, controlling, and assessing changes to the plant that have a potential impact on plant performance related to GSI-191 concerns. These provide the guidance to inspect the condition of the sump strainers, refueling pool cavity drains and trash racks, and the ability to assess impacts to the inputs and assumptions used in engineering analysis that support the proposed change. Programmatic requirements ensure that the potential for debris loading on the sump does not materially increase to unacceptable debris quantities. In addition, programs and procedures have been implemented to evaluate and control potential sources of debris in containment. Examples of existing programs include the following:
- Programs and procedures evaluate and control potential sources of debris in containment.
- Technical Requirements Manual requirements implemented by Calvert Cliffs procedures require visual inspections of all accessible areas of the containment to check for loose debris, and the containment sump to check for debris.
- The Calvert Cliffs GSI-191 Engineering Standard will identify control of aluminum in containment as a critical parameter.
- The Calvert Cliffs Engineering Change Process procedure includes provisions for managing potential debris sources such as insulation, qualified coatings, addition of aluminum or zinc, and potential effects of post-LOCA debris on recirculation flow paths and downstream components. The procedure requires engineering changes that involve any work or activity inside the containment to be evaluated for the potential to affect the following:

    - Reactor coolant pressure boundary integrity.
    - Accident or post-accident equipment inside containment.
    - Quantity of metal inside containment.
    - Quantity or type of coatings inside containment.
    - Thermal insulation changed or added.
    - Post-LOCA recirculation flow paths to the emergency recirculation sump.
    - Post-LOCA recirculation debris impact on internals of fluid components.
    - Addition or deletion of cable.
- Programs are in place to ensure that Service Level 1 protective coatings used inside containment are procured, applied, and maintained in compliance with applicable regulatory requirements.
- Procedures govern the use of signs and labels inside containment.
- As part of the Calvert Cliffs Corrective Action Process, issue reports are written due to adverse conditions identified during the containment inspections or containment emergency recirculation sump and strainer surveillances.
- The Calvert Cliffs Maintenance Rule program includes performance monitoring of functions associated with ECCS and CS. The inclusion of the ECCS and CS into the Maintenance Rule program and the assessment of acceptable system performance provide continued assurance of the availability for performance of the required functions.

6.0 QUALITY ASSURANCE

All calculations, engineering evaluation, technical reports, and tests have been performed in accordance with the Exelon Quality Assurance Topical Report and are maintained in the Fleet Configuration Management System.

- The Calvert Cliffs QA program is implemented and controlled in accordance with the Operations Quality Assurance Plan and is applicable to SSCs to an extent consistent with their importance to safety, and complies with the requirements of 10CFR50, Appendix B and other program commitments as appropriate.
- The QA Program is implemented with documented instructions, procedures, and drawings which include appropriate quantitative and qualitative acceptance criteria for determining that prescribed activities have been satisfactorily accomplished. Procedures control the sequence of required inspections, tests, and other operations when important to quality. To change these controls, the individual procedure must be changed, and a similar level of review and approval given to the original procedure is required. Such instructions, procedures, and drawings are reviewed and approved for compliance with requirements appropriate to their safety significance.
- QA program controls are applied to safety-related SSCs to provide a high degree of confidence that their safety function will be performed. The rigorous controls imposed by the QA program provide adequate quality control elements to ensure system component reliability for the required functions.

7.0 PERIODIC UPDATE OF RISK-INFORMED ANALYSIS

The risk-informed GSI-191 analysis will be updated within 48 months following initial NRC approval or since the last update. This update will include all parts of the risk-informed evaluation including the systematic risk assessment, consideration of defense-in-depth, and consideration of safety margin. The

update will also include any new information from Calvert Cliffs PRA updates and on LOCA frequencies that may be developed.

8.0 REPORTING AND CORRECTIVE ACTION

Calvert Cliffs will take corrective action in the event that the risks of debris exceed the RG 1.174 design bases criteria or in the event that defense-in-depth or safety margins have decreased so as to impact the operability of the Containment Emergency Sump. These issues will be tracked to completion in accordance with Calvert Cliffs corrective action program. The risk of debris is defined in terms of ΔCDF and ΔLERF and is listed in the Calvert Cliffs UFSAR. Defense-in-depth measures and safety margin are specifically defined in Attachment 1-4.
Reportability for Containment Emergency Sump related issues will be in accordance with the requirements of 10 CFR 50.72 and 50.73, and applying the criteria established contained in NUREG-1022.

9.0 LICENSE AMENDMENT REQUEST

The Calvert Cliffs license amendment request is presented in Attachment 3.

10.0 REFERENCES

(1) Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," USNRC, September 13, 2004.

(2) SECY-12-0093, "Closure Options for Generic Safety Issue - 191, Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance," July 9, 2012.

(3) NUREG-1829, "Estimating Loss-of-Coolant Accident (LOCA) Frequencies Through the Elicitation Process," April 2008.

(4) Regulatory Guide 1.174. "An Approach for Using Probabilistic Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis," Revision 2, May 2011.

(5) Regulatory Guide 1.229 (ML16062A016 & ML17025A060), "Risk-Informed Approach for Addressing the Effects of Debris on Post-Accident Long-Term Cooling," Revision 0, DRAFT.

(6) ASME/ANS RA-Sa-2009, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," Addendum A to RAS-2008, ASME, New York, NY, American Nuclear Society, La Grange Park, Illinois, February 2009.

(7) Regulatory Guide 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities," Revision 2, March 2009.

(8) LTR-RAM-II-10-055, "RG 1.200 PRA Peer Review Against the ASME PRA Standard Requirements for The Calvert Cliffs Nuclear Power Plant Probabilistic Risk Assessment," Westinghouse, November 23, 2010.

(9) CCNPP PRA Finding Level Fact and Observation Technical Review & Focused-Scope Peer Review, Report No. 032299-RPT-001 Revision 0.

(10) NUREG-1855, "Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decision Making," Revision 1, March 2017.

(11) EPRI Report 1016737, "Treatment of Parameter and Model Uncertainty for Probabilistic Risk Assessment," Final Report, December 2008.

(12) EPRI Report 1026511, "Practical Guidance on the Use of Probabilistic Risk Assessment in Risk-Informed Applications with a Focus on the Treatment of Uncertainty," Technical Update, December 2012.

(13) NEI 04-07 Volume 1, "Pressurized Water Reactor Sump Performance Evaluation Methodology, Nuclear Energy Institute Guidance Report," Revision 0, December 2004.

(14) NEI 04-07 Volume 2, "Pressurized Water Reactor Sump Performance Evaluation Methodology, Volume 2 - Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02," Revision 0, December 6, 2004.

1-2 Deterministic Basis

The deterministic basis is addressed using the Revised Content Guide for Generic Letter 2004-02 Supplemental Responses, November 2007.

OVERALL COMPLIANCE

***NRC Issue* 1:**

Provide information requested in GL 2004-02, "Requested Information." Item 2(a) regarding compliance with regulations. That is, provide confirmation that the ECCS and CSS recirculation functions under debris loading conditions are or will be in compliance with the regulatory requirements listed in the Applicable Regulatory Requirements section of this generic letter. This submittal should address the configuration of the plant that will exist once all modifications required for regulatory compliance have been made and this licensing basis has been updated to reflect the results of the analysis described above.

Response to Issue 1:

This submittal proposes a change associated in the methodology used to show compliance with 10 CFR 50.46. The proposed new methodology uses a risk-informed approach to evaluate the effects of Loss of Coolant Accident (LOCA) debris on emergency recirculation sump strainer performance instead of a traditional deterministic approach. The details of the approach are provided in Attachment 1-3 of this submittal.

The debris load on the Containment Emergency Sump was predicted for pipe breaks of varying sizes at all welded joints in non-isolable reactor coolant system (RCS) piping. Breaks that generated debris loads that are postulated to result in strainer head losses exceeding acceptable limits, as determined by strainer head loss testing, were considered to result in failure of the emergency core cooling system (ECCS) and containment spray system (CSS). The deterministic current licensing basis (CLB) will continue to apply to LOCA break sizes that generate strainer debris loads that are predicted to result in acceptable strainer head loss. The proposed methodology change will apply for LOCA break sizes that result in greater than the acceptable strainer head loss.

NUREG 1829 (“Estimating Loss-of-Coolant Accident Frequencies through the Elicitation Process”) is used to determine the break frequency for those break sizes for which ECCS failure is predicted and uses that frequency to calculate the ΔCDF for comparison to the criteria in RG 1.174. The results of the evaluation show that the risk from the proposed change is “very small” in that it is in Region III of RG 1.174. The methodology includes conservatisms in the plant-specific testing.

The Calvert Cliffs simplified risk-informed approach to the effects of LOCA debris replaces the existing deterministic approach described in the Calvert Cliffs licensing basis and consequently requires an amendment to the Calvert Cliffs Unit 1 and Unit 2 operating licenses to incorporate the revised methodology per the requirements of 10CFR50.59. This proposed amendment to the Renewed Facility Operating License is described in Attachment 3 of this submittal.

In addition, Calvert Cliffs proposes to amend the Unit 1 and Unit 2 Operating Licenses to revise the Technical Specifications (TS) for the ECCS and the Containment Systems. The changes proposed for these TS would add a new Limiting Condition for Operation (LCO), required action, and completion time specific to the effects of debris to TS 3.6.9, “Containment Emergency Sump”. The proposed TS changes

will align the TS with the risk-informed methodology change. The proposed LCO is based on the amount of debris tested in the Calvert Cliffs plant-specific testing so that the determination of operability is performed without needing a risk assessment, which makes the process consistent with NRC guidance on operability determinations.

At Calvert Cliffs, a Containment Emergency Sump is provided for each unit. Each Containment Emergency Sump serves both trains of the ECCS and the Containment Spray System. In response to the Nuclear Regulatory Commission (NRC) Generic Letter (GL) 2004-02, Calvert Cliffs has significantly increased the filtration capacity and improved the design of the Containment Emergency Sump strainer which was designed, manufactured and tested by Control Components, Incorporated (CCI) of Winterthur, Switzerland. This system has a strainer surface area of 6,060 ft^2. The sump strainer system ensures the NPSH available exceeds the pump requirements following a LOCA, thereby supporting the operability of the ECCS and Containment Spray Systems.

The Containment Emergency Sump strainer was installed in Unit 2 during the Spring 2007 refueling outage and in Unit 1 during the Spring 2008 refueling outage. Structural upgrades were performed on the Unit 2 sump in 2009 and in Unit 1 sump in 2010 to provide additional strength. The system has three strainer module rows utilizing 33 strainer modules connected to a central water duct that discharges directly into the sump pit, which houses the two ECCS/Containment Spray pump suction headers. Each strainer module has a series of strainer cartridges constructed of perforated stainless steel plate. Following a LOCA event, all liquid used for recirculation must pass through these strainer cartridge perforations or similar sized strainer system gaps prior to entering the sump. The Containment Emergency Sump strainer has been tested for multiple debris loads. The debris loads that result in strainer head loss which exceeds the allowable head loss value has been shown to be of such low probability that the risk of these LOCA events is “very small” and in Region III of RG 1.174.

For all but a small number of low-frequency pipe breaks the Containment Emergency Sump strainer system installed at Calvert Cliffs provides sufficient strainer capability during recirculation to allow the ECCS to perform its required function of cooling the nuclear core and maintaining its temperature acceptably low enough for the extended period required by the long-lived radioactivity remaining in the core. Furthermore, the Containment Spray System is also provided with sufficient flow during recirculation from the Containment Emergency Sump strainer so that adequate containment heat removal and atmosphere clean-up is provided. Calvert Cliffs is in compliance with the regulatory requirements listed in the Applicable Regulatory Requirements section of Generic Letter 2004-02 through implementation of the simplified risk-informed approach described in Attachment 1-3 and the License Amendment Request (LAR) presented in Attachment 3.

In addition to strainer and sump modifications, Calvert Cliffs has further reduced the potential impact of chemical effects head loss by employing targeted modifications to reduce the amount of aluminum inside containment. Aluminum is a primary precipitant for chemical effects at Calvert Cliffs. Aluminum scaffolding materiel is no longer stored in containment. The aluminum scissors lift on the polar crane was removed from both units in the 2012 and 2013 RFOs. Significant amounts of mineral wool insulation were replaced with stainless steel reflective metal insulation (RMI) for both units during the 2013 and 2014 RFOs. The scaffolding materiel, scissors lift and mineral wool insulation constituted the majority of aluminum sources inside containment.

Calvert Cliffs has undertaken a significant effort to reduce the fibrous insulation debris source term. Reducing the amount of fiber decreases strainer head loss and reduces the chemical effects source term. In the 2013/2014 RFOs, multiple sections of insulated piping were re-insulated with RMI. The RMI used at Calvert Cliffs is constructed of stainless steel, and does not fail in a manner that contributes to strainer head loss.

Furthermore, during the 2012 and 2013 RFOs, Calvert Cliffs implemented a modification to increase from 1" to 8" the drain flow path from the two refueling pool cavities to the lower level of containment. This eliminates potential water sequestration in the refueling pool cavities, raises the post-LOCA sump water level, and provides additional margin for ECCS and Containment Spray System pump net positive suction head (NPSH) and strainer deaeration. A trash rack strainer is installed over each drain entrance to prevent large debris from clogging either of the drains.

The responses that follow present a number of conservatisms. They are summarized below:

- The Calvert Cliffs debris generation analysis was performed in accordance with the approved methodology of NEI 04-07 ("Pressurized Water Reactor Sump Performance Evaluation Methodology") that includes multiple levels of conservatism:
    - The debris generation calculation analyzed a full spectrum of break sizes. The likelihood of a large rupture in pressurized water reactor coolant piping is less than 1.6x10-6 per year. Estimates for the frequency of a full double-ended rupture of the main coolant piping are on the order of 1x10-8 per year. Smaller piping ruptures, while still unlikely, provide a better measure of expected behavior.
    - Break opening time and full offset displacement for double-ended guillotine breaks are instantaneous. The non-physical assumption of an instantaneous opening of a fully offset double-ended rupture leads to a significant overestimation of the debris generation potential for a postulated break. Even conservative estimates of minimum break opening times for large bore piping preclude formation of damaging pressure waves. The wide recognition that a large RCS pipe is more likely to leak and be detected by the plant's leakage monitoring systems long before cracks grow to unstable sizes is referred to as leak before break and is an accepted part of regulatory compliance with General Design Criterion 4.
    - Full destruction of materials within a conservatively determined zone of influence is based upon a conservative extrapolation of limited test data performed under non prototypical conditions, with limiting configurations. The sparse database on insulation destruction testing has forced the use of bounding results. For example: results based on aluminum jacketed insulation are applied to stainless steel jacketed insulation; all insulation is presumed to have a worst-case seam orientation relative to the break. The zone of influence for insulation materials is expected to be significantly smaller than that predicted by the NRC guidance due to real factors including the absence of a damaging pressure wave, greater structural integrity than tested materials, and non-limiting seam orientations.
- The Calvert Cliffs debris transport evaluation was performed in accordance with NEI 04-07, that includes multiple levels of conservatism:
    - All debris is assumed to wash down to the sump pool with no holdup on structures. Although fine debris could be carried by draining containment spray flow, a significant quantity of fines would likely be retained on walls and structures above the containment

sump pool due to incomplete spray coverage and hold up on structures. Even in areas that are directly impacted by containment spray flow, some amount of fines would agglomerate together and settle prior to reaching the strainer.

- All fine debris is assumed to transport to the surface of the strainer. Debris present or generated at the beginning of the event will generally be pushed by break and containment spray flows into quiescent regions in the sump pool, and will reside as debris piles. At the start of containment sump recirculation, to cause movement of these piles of debris, it would take substantially higher flow rate than what would actually occur. Even if these piles of debris were to move, there are numerous obstacles (e.g. supports, equipment, and curbs) that would prevent debris from reaching the strainer.
- Approved guidance calls for uniform debris transport to and deposition on the strainer surfaces. Testing shows that debris transport to the surface of complex strainers will not be uniform, unless it is artificially induced in the testing. Some settling and uneven debris distribution is prototypical, which results in lowered head loss across the strainers.

- The Calvert Cliffs strainer head loss testing was performed in accordance with the NRC March 2008 guidance [Reference (13)] that includes multiple levels of conservatism:
  - During head loss testing, only fiber fines were used to conservatively bound head loss as it was observed that small pieces of fiber dramatically reduced strainer debris bed head loss. Actually, should large quantities of debris be generated and transported to the strainer, it would be a mixture of fiber fines and small pieces.
  - During head loss testing, fiber fines produced by erosion are assumed to arrive at the strainer at time t = 0, instead of hours or days later when strainer performance margin is greater. Fiber fines created by erosion will arrive at the strainer over a period of hours or even days. A significant portion of these fines will arrive after performance margin has increased.
  - During head loss testing, a full 30 day chemical precipitate load is assumed to arrive at the strainer at the earliest possible time with no credit for settling or nucleation on containment surfaces. The quantity of precipitate arriving at the strainer is expected to be significantly lower than tested amounts. In addition, the precipitate is expected to arrive or form in the debris bed gradually.
  - During head loss testing, all fiber and particulate debris is collected on the strainer prior to addition of chemical precipitates. The chemical precipitate coating on the debris bed observed in head loss testing is not prototypical. In reality it would be less uniform than that achieved during testing since some fiber and particulate debris would arrive along with the precipitates, or the precipitates would form in the debris bed, producing a less uniform deposit. A less uniform deposition of precipitates would yield a lower strainer head loss.
  - During head loss testing, repeated attempts were made to get debris that had settled in the immediate vicinity of the strainer back onto the strainer. The conservatism of assuming 100% debris transport to the strainer is clearly demonstrated in testing where non prototypical agitation must be employed to prevent natural settling of debris. Much of the debris that is assumed to transport to the strainer will likely settle in the immediate vicinity of the strainer and not become part of the strainer debris bed.

  - Head loss test procedures were designed to assure uniform debris distribution on the strainer to maximize debris bed head loss. The design and physical layout of the Calvert Cliffs strainer promotes non-uniform debris distribution.
  - During testing, debris materials that were demonstrated to reduce debris bed head loss such as lead shielding blanket fibers and metallic insulation debris were excluded from the tested debris in order to conservatively maximize head loss. The lead shielding blanket fibers and some of the smaller metallic insulation debris will likely transport to the strainer and disrupt formation of a uniform fiber/particulate debris bed. This will result in lower strainer head loss.
  - Metallic insulation debris that is predicted to enter the sump pool but not reach the strainer is excluded from testing to prevent capture of finer debris before it reaches the strainer. Any debris that enters the sump pool but does not transport to the strainer would likely capture some of the fine debris before it reaches the strainer.
- The Calvert Cliffs chemical effects head loss analysis was based on testing in accordance with WCAP-16530 [Reference (12)] that includes multiple levels of conservatism:
  - WCAP-16530 relies largely upon short-term release rates (hours) for the determination of long-term releases (30 days). Long-term release rates of constituent materials are expected to be significantly lower than that predicted by design basis models due to surface passivation and formation of surface films.
  - One hundred percent of chemical species of interest are assumed to precipitate. When solubility limits are taken into account, the predicted precipitation is reduced by one to two orders of magnitude.
  - The current models call for chemical precipitate formation in a form readily transported to the sump screen. A significant portion of precipitate formation will occur on large surface areas in containment, and in settled debris, all of which are remote from the strainer, and will not then be readily transported to the strainer.
  - The approved testing methodology results in the chemical precipitates being pre-formed and overlaid upon the strainer debris bed as a whole, after debris and particulates are placed into the test. This is conservative. Some chemical precipitates typically form in the debris bed itself on the fiber surfaces, instead of laying over the exterior surface of the strainer debris bed as a whole. This will result in lower strainer head loss.
- For in-vessel effects, the flow rate through the Calvert Cliffs core can range from less than 2.3 gpm per fuel assembly to 6.8 gpm per fuel assembly, which is significantly lower than the approximately 44.7 gpm per fuel assembly used for fuel assembly blockage testing as described in WCAP-16793-NP [Reference (19)]. This provides for a significant margin above the bounding 15g/fuel assembly established in the WCAP.
- No temperature corrections to head loss based on viscosity variations dependent on temperature were credited.
- No containment accident pressure is credited beyond that required to maintain the pressure consistent with the sump fluid temperature at or above saturation conditions of 212°F.
- Assumption of the latent debris quantity based on the larger quantity from the two units.
- Wear analyses were performed in accordance with WCAP-16406-P-A [Reference (8)] using bounding debris quantities and assuming no hold-up of particulate would occur in various

locations. These locations include the fiber bed, the reactor vessel, and the refueling canals and reactor cavity.

- The wear analysis also assumed no particulate depletion for the entire 30 day mission time.
- The Calvert Cliffs design incorporates one of the largest strainers in the PWR fleet, along with one of the lowest strainer recirculation flow rates. The resultant low approach velocity will limit the amount of debris transported to the strainer filtration surface.
- Analyses assume that 100% of the unqualified coating debris fail at time of accident.

GENERAL DESCRIPTION OF AND SCHEDULE FOR CORRECTIVE ACTIONS

***NRC Issue 2*:**

Provide a general description of actions taken or planned, and dates for each. For actions planned beyond December 31, 2007, reference approved extension requests or explain how regulatory requirements will be met as per "Requested Information" Item 2(b). That is provide a general description of and implementation schedule for all corrective actions, including any plant modifications, that you identified while responding to this generic letter. Efforts to implement the identified actions should be initiated no later than the first refueling outage starting after April 1, 2006. All actions should be completed by December 31, 2007. Provide justification for not implementing the identified actions during the first refueling outage starting after April 1, 2006. If all corrective actions will not be completed by December 31, 2007, describe how the regulatory requirements discussed in the Applicable Regulatory Requirements section will be met until the corrective actions are completed.

Response to Issue 2:

In response to GL 2004-02, Calvert Cliffs has completed the following actions for Calvert Cliffs Units 1 and 2.

- Performed walk downs to sample and characterize latent debris, including other debris sources, e.g., labels – Completed September 2010.
- Performed comprehensive debris generation analyses and conservative debris transport assumptions in accordance with approved methods presented in NEI 04-07 – Multiple revisions of these calculations from 2004 to 2018.
- Performed as-built verification walk downs of insulation in Calvert Cliffs Units 1 and 2 Containments – Completed 2012
- Replaced a simple geometry strainer that had a filtering surface area of approximately 150 ft^2, and had a gross mesh, with a complex geometry strainer having a filtering surface area of 6,060 ft^2 and a finer mesh – Completed Unit 2 during the spring 2007 refueling outage and in Unit 1 during the spring 2008 refueling outage.
- Performed head loss analysis for replacement strainers – Completed May 2009.
- Performed bypass testing for replacement strainers – Completed October 2007.
- Performed vortex testing and analysis – Completed May 2009.
- Performed head loss testing for the replacement strainers (including chemical effects) – Completed October 2010.
- Completed detailed structural analysis of the new strainers – Completed September 2014.
- Performed High pressure safety injection (HPSI) cyclone separator blockage testing – Completed June 2008.
- Performed HPSI cyclone separator replacement – Completed June 2008.

- Implemented calcium-silicate pipe insulation removal or banding – Completed March 2008.
- Replaced trisodium phosphate containment buffering agent with sodium tetraborate – Completed March 2009.
- Removed the telescoping aluminum ladder from the polar crane in containment to reduce the aluminum content in containment – Completed March 2013.
- Replaced significant amount of mineral wool insulation with stainless steel RMI to reduce the amount of aluminum inside containment – Completed March 2014.
- Replaced significant amount of fibrous insulation with RMI – Completed March 2014.
- Performed a comprehensive chemical effects head loss experimental and test program – Completed November 2014.
- Enlarged the reactor refueling cavity drains to reduce post-loss-of-coolant accident water holdup and increase strainer submergence – Completed March 2013.
- Installed blow-out panels in the reactor cavities ventilation ducting to allow early failure of the ventilation duct should it fill with water. This reduced post-loss-of-coolant accident water holdup and increased strainer submergence – Completed March 2011.
- Participated in the South Texas Project Risk-Informed Generic Safety Issue 191 (GSI-191) Resolution Pilot Project – Completed July 2017.
- Prepared this simplified risk-informed response to GL 2004-02 and resolution of GSI-191 – Submitted August 2018.

In addition to implementation of the proposed changes to the Technical Specifications and the UFSAR associated with the LAR included in this application, Calvert Cliffs is revising the Emergency Operating Procedures (EOPs) to assure the flow rate through the strainer does not exceed 2,900 gpm prior to the recirculation mode of operation.

SPECIFIC INFORMATION REGARDING METHODOLOGY FOR DEMONSTRATING COMPLIANCE

***NRC Issue 3a*:**

Break Selection

The objective of the break selection process is to identify the break size and location that present the greatest challenge to post-accident sump performance.

1. *Describe and provide the basis for the break selection criteria used in the evaluation.*
2. *State whether secondary line breaks were considered in the evaluation (e.g., main steam and feedwater lines) and briefly explain why or why not.*
3. *Discuss the basis for reaching the conclusion that the break size(s) and locations chosen present the greatest challenge to post-accident sump performance.*

*Response to Issue 3a*1:

The debris generation analysis evaluated LOCA breaks at all weld locations in American Society of Mechanical Engineers (ASME) Class 1 piping. This included circumferential butt welds and longitudinal welds along the length of the reactor coolant piping. Breaks in longitudinal welds were considered at positions along the weld at distances no greater than the pipe inside diameter apart. This is more conservative than the 5 ft. criterion allowed by Reference (1). The debris generation analysis considered the following pipe breaks:

1) Breaks in the primary RCS 42" hot leg, 30" crossover leg, and 30" cold leg piping with the largest amount of debris in the zone of influence (ZOI).
2) Large breaks in the RCS with two or more different types of debris.
3) Break locations with the most direct path to the recirculation strainer.
4) Break locations with the largest potential particulate to fiber mass ratio.
5) Break locations at all welds in ASME Class 1 piping in containment.

The simplified risk informed approach used the BADGER (Break Accident Debris Generation EvaluatoR) software program to perform the debris generation analysis at each break location. BADGER automates the ZOI debris generation and analyzes each circumferential butt weld location for double-ended guillotine break spherical ZOI destruction, as well as partial-break hemispherical ZOI destruction and along the longitudinal welds for full and partial break hemispherical ZOI destruction. Fiber, particulate, and metallic debris generation from insulation, radiation shielding blankets, and fire barrier materials at each location and for each break size is compiled in a database.

A three-dimensional computer aided design (CAD) model of the Calvert Cliffs containment building reflecting the as-built insulation configuration was assembled and used with the BADGER software to calculate debris quantities for each break. Calvert Cliffs Units 1 and 2 are mirror image plants of the same design. However, there are differences in the as-built insulation configuration between the units. The CAD model was developed for both Unit 1 and Unit 2. The debris generation analysis confirmed that the Unit 1 insulation configuration bounded the Unit 2 configuration with respect to GSI-191 issues.

Response to Issue 3a2:

The risk-informed approach evaluated Feedwater line and Main Steam line break sequences that lead to recirculation in the Calvert Cliffs PRA. This is discussed in Attachment 1-3 of this submittal.

Response to Issue 3a3:

The risk informed analysis used the NARWHAL software to evaluate the acceptability of the strainer debris loads generated at each ASME Class 1 weld location, including longitudinal welds, inside the first closed valve from the RCS. The resultant break point spacing was much smaller than the 5 ft criterion allowed by Reference (1). Varying break sizes are evaluated at each weld location. In all, almost 14,000 breaks were evaluated. This comprehensive approach ensured that all possible break locations that could present a challenge to post-accident sump performance were evaluated.
As shown in Attachment 1-3 only very large breaks in the primary RCS loop piping generate sufficient debris to result in strainer failure. .

***NRC Issue 3b*:**

Debris Generation/Zone of Influence (zone of influence) (excluding coatings)

The objective of the debris generation/zone of influence process is to determine, for each postulated break location: (1) the zone within which the break jet forces would be sufficient to damage materials and create debris; and (2) the amount of debris generated by the break jet forces.

1. *Describe the methodology used to determine the zone of influences for generating debris. Identify which debris analyses used approved methodology default values. For debris with zone of influences not defined in the guidance report (GR)/safety evaluation (SE), or if using other than default values, discuss method(s) used to determine zone of influence and the basis for each.*

2. *Provide destruction zone of influences and the basis for the zone of influences for each applicable debris constituent.*
3. *Identify if destruction testing was conducted to determine zone of influences. If such testing has not been previously submitted to the NRC for review or information, describe the test procedure and results with reference to the test report(s).*
4. *Provide the quantity of each debris type generated for each break location evaluated. If more than four break locations were evaluated, provide data only for the four most limiting locations.*
5. *Provide total surface area of all signs, placards, tags, tape, and similar miscellaneous materials in Containment.*

Response to Issues 3b1 and 3b2:

The ZOI for generated debris was determined using approved methodologies presented in NEI 04-07 and the associated NRC safety evaluation, Reference (1), for most materials.

Transco RMI

The ZOI for Transco reflective metal insulation (RMI) used the approved methodology default value of 2.0 [Reference (1), page 30].

Marinite Board Fire Barrier

The ZOI for Marinite board was based on testing. References (5) and (6) document testing performed in order to determine realistic jet impingement destruction data for Marinite board. Reference (5) documents that of a total of 13 destruction tests performed with Marinite with ZOIs ranging from 13.3D to 3.4D, only three of the tests generated visible debris. The visible debris was generated at ZOIs of 5.5D, 4.5D, and 3.4D. Calvert Cliffs increased the ZOI to 17D to conservatively address concerns about the nozzle size used in the jet impingement testing.

Nukon and Thermal Wrap Insulation

The ZOI for Nukon insulation used the approved methodology default value of 17.0 [Reference (1), page 30]. Based on similarity of design, this ZOI was applied to Thermal Wrap insulation also. The debris size distributions for these insulation materials were modified from that provided on page 38 of Reference 1 as described below.

Using an analysis approach consistent with the methodology of Appendix II of Reference (1), Air Jet Impact Test (AJIT) data was used to compute refined size distributions for low-density fiberglass insulations (i.e., Nukon, Thermal Wrap, generic fiberglass). Table 1a provides the results of this analysis where it is seen that based on the Average Centroid Distance from the break to the target different expressions are used to compute the fraction of debris which is fines, small pieces, large pieces, and intact blankets.

The average centroid distance (C) from the break location to all the piping and components having a given insulation type (e.g., Nukon) is computed in the BADGER software, and then during the post-processing of the BADGER results the appropriate column from Table 1a is used to determine the fraction of debris that is fines, small pieces, large pieces, and intact blankets.

Table 1a: Nukon & Thermal Wrap Debris Size Distribution Using BADGER

Debris Size	Average (Centroid) Distance from Break Location to Target		
	0D – 4D ZOI	**4D – 15D ZOI**	**15D – 17D ZOI**
Fines Fraction (F_{fines})	$F_{fines} = 0.2$	$F_{fines} = -0.01364 \times C + 0.2546$	$F_{fines} = -0.025 \times C + 0.425$

Small Pieces Fraction (F_{smalls})	$F_{smalls} = 0.8$	$F_{smalls} = -0.0682 \times C + 1.0724$	$F_{smalls} = -0.025 \times C + 0.425$
Large Pieces Fraction (F_{large})	$F_{large} = 0$	$F_{large} = 0.0393 \times C - 0.157$	$F_{large} = -0.215 \times C + 3.655$
Intact Pieces Fraction (F_{intact})	$F_{intact} = 0$	$F_{intact} = 0.0425 \times C - 0.170$	$F_{intact} = 0.265 \times C - 3.505$

Similar to Table 1a, an analysis approach consistent with the methodology of Appendix II of Reference (1), Air Jet Impact Test (AJIT) data was used to compute refined size distributions for low-density fiberglass insulations (i.e., Nukon, Thermal Wrap, generic fiberglass) as shown in Table 1b. Table 1b is to be used as an alternative to Table 1a for non-BADGER debris generation calculations. Table 1b is applied slightly differently than Table 1a in that all of the insulation within a given ZOI range from the break has the debris size distribution fractions from Table 1b applied to it, and the results from the three sub-ZOIs are summed together to compute the total for each debris size category.

Table 1b: Nukon & Thermal Wrap Debris Size Distribution for Non-BADGER Calculations

Material Size	0-7 L/D	7-11.9 L/D	11.9-17 L/D
Fines	20%	13%	8%
Small Pieces (< 6" on a side)	80%	54%	7%
Large Pieces (> 6" on a side)	0%	16%	41%
Intact (Covered) Blankets	0%	17%	44%

Calcium Silicate (Cal-Sil) Insulation
Using the same approach applied to Nukon and Thermal Wrap insulation discussed above, the debris size distribution was refined based on the applicable AJIT data. This refined size distribution separates Cal-Sil debris generated in a 6.4D ZOI into intact pieces which remain on the target, smalls, and fines. For Cal-Sil, the piecewise functions are summarized in Table 2a below and will be used as an alternative with the previously approved size distribution data in the BADGER debris generation calculation.

Table 2a: Cal-Sil Debris Size Distribution

Debris Size	**Average (Centroid) Distance from Break Location to Target**		
	0D – 1.5D ZOI	**1.5D – 5D ZOI**	**5D – 6.4D ZOI**
Fines Fraction (F_{fines})	$F_{fines} = 0.5$	$F_{fines} = -0.06571 \times C + 0.5986$	$F_{fines} = -0.1929 \times C + 1.2345$
Small Pieces Fraction (F_{smalls})	$F_{smalls} = 0.5$	$F_{smalls} = -0.1043 \times C + 0.6614$	$F_{smalls} = -0.0971 \times C + 0.6155$
Intact Pieces Fraction (F_{intact})	$F_{intact} = 0$	$F_{intact} = 0.17 \times C - 0.26$	$F_{intact} = 0.29 \times C - 0.85$

An alternate approach is to conservatively simplify the above table by assuming 50% fines and 50% small pieces in the entire 0-6.4D ZOI.

Temp-Mat Insulation
The ZOI for Temp-Mat insulation used the approved methodology default value of 11.7 given on page 30 of Reference 1. The debris size distributions for Temp-Mat insulation was modified from that provided on page 38 of Reference 1 as described below.

Using an analysis approach consistent with the methodology of Appendix II of Reference (1), Air Jet Impact Test (AJIT) data was used to compute refined size distributions for Temp-Mat. Table 2b provides the results of this analysis where it is seen that based on the Average Centroid Distance from the break to the target different expressions are used to compute the fraction of debris which is fines, small pieces, large pieces, and intact blankets.

The average centroid distance (*C*) from the break location to all the piping and components having Temp-Mat insulation is computed in the BADGER software, and then during the post-processing of the BADGER results the appropriate column from Table 2b is used to determine the fraction of debris that is fines, small pieces, large pieces, and intact blankets.

Table 2b: Temp-Mat Debris Size Distribution for BADGER Calculations

Debris Size	Average (Centroid) Distance from Break Location to Target		
	0D – 2D ZOI	**2D – 8D ZOI**	**8D – 11.7D ZOI**
Fines Fraction (F_{fines})	F_{fines} = 0.333	F_{fines} = -0.03050 × C + 0.3940	F_{fines} = -0.0405 × C + 0.474
Small Pieces Fraction (F_{smalls})	F_{smalls} = 0.667	F_{smalls} = -0.0945 × C + 0.856	F_{smalls} = -0.0271 × C + 0.316
Large Pieces Fraction (F_{large})	F_{large} = 0	F_{large} = 0.0601 × C – 0.120	F_{large} = -0.0974 × C + 1.140
Intact Pieces Fraction (F_{intact})	F_{intact} = 0	F_{intact} = 0.0649 × C – 0.130	F_{intact} = 0.165 × C – 0.930

Similar to Table 2b, an analysis approach consistent with the methodology of Appendix II of Reference (1), Air Jet Impact Test (AJIT) data was used to compute refined size distributions for Temp-Mat insulation as shown in Table 2c. Table 2c is to be used as an alternative to Table 2b for non-BADGER debris generation calculations. Table 2c is applied slightly differently than Table 2b in that all of the insulation within a given ZOI range from the break has the debris size distribution fractions from Table 2c applied to it, and the results from the three sub-ZOIs are summed together to compute the total for each debris size category.

Table 2c: Temp-Mat Debris Size Distribution for Non-BADGER Calculations

Material Size	0-3.7 L/D	3.7-11.9 L/D
Fines	20%	7%
Small Pieces (< 6" on a side)	80%	27%
Large Pieces (> 6" on a side)	0%	32%
Intact (Covered) Blankets	0%	34%

Mineral Wool Insulation

The mineral wool at Calvert Cliffs was provided by Transco Products and is encapsulated in stainless steel cassettes. The mineral wool cassettes are virtually identical to that of the original Transco RMI installed at Calvert Cliffs but with a different filler material, i.e. mineral wool fibers instead of stainless steel foils. Based on the robust nature of these cassettes, the ZOI for the Transco mineral wool is closer to that of Transco RMI than that of low density fiber glass.

The Transco stainless steel cassette system includes inner and outer sheaths, slotted end panels, and latch and strike closure buckles similar to the cassettes tested in the air jet impact testing that resulted in the approved ZOI for Transco RMI of 2.0D, Reference (1). The tested cassettes contained metal foil and produced none or very little transportable debris. The contained material contributes no strength

to the cassettes. Therefore, the destruction pressure for the Transco mineral wool cassettes and RMI cassettes are considered equal. However, to account for the difference in filler material, the ZOI for the mineral wool cassettes will be conservatively increase by a factor of 2 from 2.0D to 4.0D.

Generic Fiberglass Insulation

Like Nukon and Thermal Wrap, the generic fiberglass insulation at Calvert Cliffs is another low-density fiberglass; therefore a ZOI 17.0 [Reference (1), page 30] is applied to it as well.

The generic fiberglass at Calvert Cliffs is molded into shape using heavy density resin bonded inorganic glass fibers with 0.010" stainless steel jacketing fitted around it and secured by rivets. This fiberglass has a bulk density generally greater, but no lower than Nukon and Thermal Wrap. Based on insulation density, Calvert Cliffs assumes the same debris size distribution for generic fiberglass that is being used for Nukon and Thermal Wrap. The comparison of debris damage for three insulation types with differing densities shown in Figure II-8 of Reference 1, supports the assumption of less material damage for a higher density material. This assumption was also accepted in Reference (4) by the NRC. As was the case for the plant in Reference 4, there is substantially less generic fiberglass than Nukon and Thermal Wrap at Calvert Cliffs; therefore, the assumed size distribution for generic fiberglass is acceptable.

The generic fiberglass at Calvert Cliffs does not have a cloth jacket that the Nukon and Thermal Wrap insulations have. Therefore, there are no intact pieces of insulation for generic fiberglass, and all insulation that would have been characterized as "intact pieces" based on Table 1a and 1b will be assumed to be "large" pieces.

Lead Shielding Blankets

The lead shielding blankets potentially exposed to high energy line break jet are both free-hanging blankets hung adjacent to piping and wrapped around piping or components. Typically, there are two lead blankets between the piping and the surrounding area. Blast testing of lead blankets similar to those used at Calvert Cliffs has been performed with both air jets and steam jets. The air jet testing conducted as part of the AJITs [Reference (2)] is included in the Boiling Water Reactor Utility Resolution Guidance for ECCS Suction Strainer Blockage. The steam jet testing was performed by Wyle and is documented in WCAP-16727-P, [Reference (3)].

The Wyle testing is not used to quantify ZOI information. This testing is used to show that open back (freely hanging) blankets will be torn from their grommets and not generate fine debris when near a break jet and that open back blankets are less likely to generate debris than those installed in a strong back configuration. Furthermore, the inner and outer cover and lead wool on the break side of a lead blanket are sacrificial and provide protection to the inner and outer cover on the opposite side of the blanket.

The AJITs subjected rubberized cloth coated lead shielding blankets to a range of surface pressures up to a maximum pressure of 40 psig. The lead blankets were wrapped around a 12 inch pipe in these tests, not a free hanging, open-back configuration. This configuration is similar to the strong back configuration discussed in the Wyle testing, even though the backing in this test was a pipe, not a flat plate.

No debris was generated in any of these tests. Since these tests were performed with an air jet, the damage pressures are reduced by 40% to account for potentially enhanced debris generation in a two-phase jet, consistent with Reference (1). Therefore, a ZOI corresponding to a damage pressure of 24 psig [=(1-0.4)*40] is applicable to the lead blankets wrapped around piping and components and it is conservative for the free-hanging lead blankets since the blankets at Calvert Cliffs have an open-back configuration. This damage pressure corresponds to a PWR ZOI of 5.4 D.

Lead Wool
Although lead wool debris may be generated, it will not transport to the strainer due to the high density of lead.

Lead Blanket Covers
In the AJITs, no lead blanket debris was generated for surface pressures corresponding to a ZOI of 5.4 D. In order to determine the size distribution for the lead blanket cover debris which could potentially be generated inside of 5.4 D, other tests performed as part of the AJITs were used.

The cloth cover used on NUKON blankets is similar to the lead blanket Alpha Maritex cover materials, except that the NUKON cover uses a plain weave while the Alpha Maritex 3259-2-SS and 8459-2-SS covers use a 4-harness and 8-harness satin weave, respectively. The NUKON cover cloth is made of 18 oz/yd^2 E-glass. Both Alpha Maritex 3259-2-SS and 8459-2-SS are made with G37 fiberglass yarn, which is also E-glass. The density of Alpha Maritex 3259-2-SS (the inner cover) is 17.5 oz/yd^2 while the density of Alpha Maritex 8459-2-SS (the outer cover) is 34 oz/yd^2.
The primary difference between the NUKON cover and the Alpha Maritex products is the weave type. Typically, a plain weave is the least tear resistant since it has a very tight construction which has the least amount of internal slippage/yarn mobility. In addition, only one yarn bears the load in a plain weave when the fabric is torn. However, satin weaves have fewer yarn interlacings per area (less tight weave) and therefore allow more internal slippage. Furthermore, multiple yarns bear the load in a satin weave when the fabric is torn. This results in satin weaves, used in the Alpha Maritex covers, being much more tear resistant than plain weaves, used in NUKON cloth covers.
Although the materials of construction are similar for the NUKON cloth cover and the Alpha Maritex products, the plain weave utilized in the NUKON cloth cover is less tear resistant than the satin weave utilized in the Alpha Maritex covers. Therefore, the fiberglass cover used for NUKON is less robust than the lead blanket inner and outer covers. Thus, the debris generation properties for the NUKON cover are conservative for Alpha Maritex 3259-2-SS and Alpha Maritex 8459-2-SS.
The AJITs subjected unjacketed NUKON blankets installed on a 12 inch pipe to a range of pressures with the maximum pressure being 190 psig. In all of these tests, the cloth cover and scrim failed in large intact sections and was determined to be non-transportable. Since these tests were performed with an air jet, the damage pressure is reduced by 40% to account for potentially enhanced debris generation in a two-phase jet. An air jet damage pressure of 190 psig corresponds to a two-phase damage pressure of 114 psig [=(1-0.4)*190], which corresponds to a ZOI of 2.1 D. Therefore, lead blanket cover debris generated beyond 2.1 D is considered to be large or intact pieces.
Within a ZOI of 2.1 D, the lead blanket covers on the break side of the lead wool in the blankets closest to the break are considered to become 20% fines and 80% small pieces. As the lead blanket covers are more robust than NUKON blanket covers, this approach is conservative.
The lead blanket covers on the opposite side of the lead wool in the blankets closest to the break are considered to form large pieces or remain intact, as are the lead blanket covers on the 2nd outboard set of lead blankets where two blankets are essentially "stacked" next to each other. These covers are shielded from the break by the innermost lead wool and inner and outer covers. This approach is reasonable since the lead blankets are freely hanging, and therefore would be torn from their grommets and projected away from the pipe in the event that a break occurs.

The size distributions and sub-zone ZOIs for lead shielding blankets are shown in Table 3.

Table 3: Lead Shielding Blanket Debris Size Distribution

Debris Type	Size	Size Distribution	
		2.1D ZOI	2.1D – 5.4D ZOI
Lead Blanket Cover Layers Closest to Pipe Break (Open Back Configuration)	Fines	20%	0%
	Small Pieces	80%	0%
	Large/Intact Pieces	0%	100%
Remaining Lead Blanket Cover Layers (Open Back Configuration)	Fines	0%	0%
	Small Pieces	0%	0%
	Large/Intact Pieces	100%	100%
Wrapped Lead Blanket Cover Layers (Strong Back Configuration)	Fines	20%	0%
	Small Pieces	80%	0%
	Large/Intact Pieces	0%	100%

Response to Issue 3b3:

Destructive testing was not conducted to determine the zones of influence for materials. Where destructive test results were used, these tests had been previously reviewed by the NRC.

Response to Issue 3b4:

The Calvert Cliffs Debris Generation calculation presents the methodology used to calculate the amount of debris generated from double-ended guillotine breaks (DEGBs) and partial breaks at all ASME Class 1 welds in the reactor coolant and attached piping systems. A three-dimensional CAD model of the Calvert Cliffs containment building reflecting the as-built insulation configuration was assembled and used with the BADGER software to calculate debris quantities for each break.

The insulation types in containment include steel jacketed generic fiberglass, banded Cal-Sil, RMI, steel encapsulated mineral wool, Temp-Mat, and steel jacketed Thermal Wrap and Nukon which are installed within cloth blankets/jacketing. The debris generation analysis also addressed permanent lead shielding blankets and Marinite fire barriers on cable trays. High energy line break locations were considered at all ASME Class 1 welds and the resulting ZOIs were used to calculate the quantity of debris for each break.

Table 4 presents the Large Break Loss-of-Coolant-Accident (LBLOCA) debris generation quantities for the most limiting break with respect to total fiber mass. Note that the unqualified coating quantities, and Nuke Tape quantities shown in the table are applicable to all breaks, and all other debris quantities, including qualified coatings, are break specific.

All fine debris (including fines from erosion) were assumed to transport to the strainer. Therefore, for all fine debris (fiber and particulate) the transport fraction is 100%.

An erosion fraction of 10% was used for the small and large pieces of fiberglass debris (Nukon, Thermal Wrap, Temp-Mat, Generic Fiberglass). An erosion fraction of 17% was used for small pieces of Cal-Sil, and small and large pieces of Marinite.

It was assumed that small and large pieces of insulation debris would not transport to the strainer. This is an acceptable assumption because it was shown in head loss testing that small and large pieces of insulation debris reduce the strainer head loss. Therefore, for all small and large pieces of insulation debris the transport fraction is 0%.

Table[GVV1][GVV2] 4: Summary of LOCA Generated Debris

Debris Type	Debris Size	Debris Quantity Generated @ Weld 42-RC-11-4
Nukon	Fines	213.1 lbm
	Small Pieces (<6")	786.4 lbm
	Large Pieces (>6")	188.7 lbm
	Intact Pieces (>6")	203.8 lbm
Thermal Wrap	Fines	360.9 lbm
	Small Pieces (<6")	1262.2 lbm
	Large Pieces (>6")	519.1 lbm
	Intact Pieces (>6")	560.8 lbm
Generic Fiberglass	Fines	158.8 lbm
	Small Pieces (<6")	565.0 lbm
	Large Pieces (>6")	418.1 lbm
Temp-Mat	Fines	224.5 lbm
	Large Pieces	149.7 lbm
Mineral Wool	Fines	82.6 lbm
RMI	Small Pieces (<4”)	192.8 ft^2
	Large Pieces (>4”)	64.3 ft^2
Cal-Sil	Fines	0.0 lbm
	Small Pieces	0.0 lbm
	Remains on Target	0.0 lbm
Marinite	Fines / Particulate	0.139 ft^3
	Small Pieces (1/2”-<2")	0.052 ft^3
	Large Pieces (>2”-4”)	0.287 ft^3
	Remains on Target	10.141 ft^3
Lead Blankets	Cover Fines	0.9 lbm
	Cover Small Pieces	3. 6 lbm
	Large/Intact Pieces	414.9 lbm
	Lead Wool Fines	Note 1
Nuke Tape Fiber (lbm)	Fines	1.25 lbm
Nuke Tape Particulate (ft^3)	Fines	0.022 ft^3
Latent Fiber (lbm)	Fines	22.5 lbm
Dirt/Dust (lbm) (ft^3)	Particulate	127.5 lbm or 0.754 ft^3
Unqualified Alkyds (ft^3)	Particulate	2.02 ft^3

Debris Type	Debris Size	Debris Quantity Generated @ Weld 42-RC-11-4
Unqualified Epoxy (ft^3)	Particulate	3.47 ft^3
Unqualified IOZ (ft^3)	Particulate	0.46 ft^3
Unqualified Organic Zinc (ft^3)	Particulate	0.079 ft^3
Degraded Qualified Epoxy (ft^3)	Chips	1.097 ft^3
Degraded Qualified IOZ (ft^3)	Particulate	0.55 ft^3
Qualified Epoxy (ft^3)	Particulate	1.14 ft^3
Qualified IOZ (ft^3)	Particulate	0.76 ft^3

Note 1: The quantity of lead wool fines was not explicitly computed as this debris source does not contribute to chemical effects or debris bed head loss.

Response to Issue 3b5:

Walkdowns were performed in the Spring 2009 refueling outage to ensure the amount of labels, signs, placards, tape and tags in containment were completely investigated. The total surface area of this type of debris is less than 300 ft^2. The strainer design allows for 375 ft^2 of sacrificial surface area. After an average mean packing ratio of 0.75 (Reference 1, page 49) is applied to the 375 ft^2 the total allowable surface area for this type of debris is 500 ft^2.
In addition, valve tag labels are made of materials that will sink intact, and procedures require that all placards be chained so they won't transport to the sump strainer.

***NRC Issue 3c*:**

Debris Characteristics

The objective of the debris characteristics determination process is to establish a conservative debris characteristics profile for use in determining the transportability of debris and its contribution to head loss.

1. *Provide the assumed size distribution for each type of debris.*
2. *Provide bulk densities (i.e., including voids between the fibers/particles) and material densities (i.e., the density of the microscopic fibers/particles themselves) for fibrous and particulate debris.*
3. *Provide assumed specific surface areas for fibrous and particulate debris.*
4. *Provide the technical basis for any debris characterization assumptions that deviate from NRC-approved guidance.*

Response to Issue 3c1:

A detailed discussion of the size distribution assumed for Nukon, Thermal Wrap, generic fiberglass, Temp-Mat, calcium-silicate insulations and lead shielding blankets was provided in the response to Issue 3b1/3b2.

Table 5 provides the debris size distribution assumed for the remaining types of debris.

Table 5: Debris Size Distribution

Material	Small Fines	Small Pieces	Large Pieces	Intact Pieces	Particulate	Chips
Mineral Wool	100%	0%	0%	0%	0%	0%
RMI	0%	75%	25%	0%	0%	0%
Marinite	1.3%	0.5%	2.7%	95.5%	0%	0%
Latent Fiber Debris	100%	0%	0%	0%	0%	0%
Dirt/Dust	0%	0%	0%	0%	100%	0%
All Coatings in ZOI	0%	0%	0%	0%	100%	0%
Qualified Coatings Outside ZOI	0%	0%	0%	0%	0%	0%
Degraded Qualified IOZ Coatings Outside ZOI	0%	0%	0%	0%	100%	0%
Degraded Qualified Epoxy Coatings Outside ZOI	0%	0%	0%	0%	0%	100%
Never Qualified Coatings Outside ZOI	0%	0%	0%	0%	100%	0%

Response to Issue 3c2:

The bulk densities of material and destroyed debris are listed in Table 6 below. These values are obtained from the NRC-approved methodology or vendor specific information (in the case of lead shielding blankets and coatings).

Table 6: Debris Densities

Material Type	Density of Individual Fiber or Particle (lb_m/ft^3)	Density of a Blanket of Product (lb_m/ft^3)
Nukon	159	2.4
Transco Thermal Wrap	159	2.4
Generic fiberglass	159	5.5
Temp-Mat	162	11.8
Mineral wool	90	8
Cal-Sil	144	14.5
Lead Blanket Inner Cover	81	N/A
Lead Blanket Outer Cover	76.6	N/A
Latent Fiber	94	2.4
Dirt/Dust	169	N/A
Marinite[1]	144	14.5

Coating Material	Material Density (lb_m/ft^3)	Characteristic Size (ft)
Inorganic zinc	300	$3.2x10^{-5}$
Alkyd coating	98	$3.2x10^{-5}$

Topcoats

Vendor	Trade Name	Dry Film Density (lb/gal)	Dry Film Density (lb/ft^3)
Carboline	Carboguard 890	14.72	111
Ameron	Amercoat 66	14.04	105
Ameron	Amercoat 90	14.80	111
Valspar	89 Series	16.60	124

Primers

Vendor	Trade Name	Dry Film Density (lb/gal)	Dry Film Density (lb/ft^3)
Carboline	Carboguard 890	14.7	111
Carboline	Starglaze 2011 S	19.4	145
Ameron	Dimetcote 6	40.1	300
Ameron	Nu-Klad 110AA	20.1	150
Ameron	Amercoat 71	16.6	126
Valspar	13-F-12	40.1	300
Shermin Williams	Epolon II	16.8	126
Wasser	MC-Miozinc	36.1	270

Note 1: Particle density for Cal-Sil applied to Marinite

Response to Issue 3c3:

Since the head loss across the ECCS strainers is determined via testing, specific surface areas for fibrous and particulate debris are not used to determine debris head loss. Therefore, these values are not provided as part of this response.

Response to Issue 3c4:

The Calvert Cliffs debris generation, transport, and head loss analyses have used the debris characterization assumptions provided in Reference 1. Specifically, the size of particulates is consistent with 10 microns for coatings particulate. Coatings that were installed as qualified, but have subsequently been classified as unqualified based on inspections are assumed to have failure distribution consistent with that reported in Reference 23. In general, Reference 23 concludes that degraded-qualified epoxy topcoated systems fail as chips when exposed to design basis accident environments, while degraded-qualified inorganic zinc primers fail in pigment size (i.e., 10 microns). For downstream effect evaluations, the size distribution of unqualified coatings was assumed to be that in the Linear Mass Fraction column of Table I-1 of Reference 8.

Qualified coatings in the ZOI, degraded qualified IOZ coatings, and never-qualified coatings are assumed to fail as particulate.
See Issue 3m for the debris size distribution used in the downstream effect evaluations

***NRC Issue 3d*:**

Latent Debris

The objective of the latent debris evaluation process is to provide a reasonable approximation of the amount and types of latent debris existing within the Containment and its potential impact on sump screen head loss.

1. *Provide the methodology used to estimate quantity and composition of latent debris.*
2. *Provide the basis for assumptions used in the evaluation.*
3. *Provide results of the latent debris evaluation, including amount of latent debris types and physical data for latent debris as requested for other debris under c. above.*
4. *Provide amount of sacrificial strainer surface area allotted to miscellaneous latent debris.*

Response to Issue 3d1:

The Containment was sampled via a walkdown performed to collect latent debris samples from the various surfaces in Containment. The surface types sampled included: 1) containment liner, 2) floor, 3) stair grating, 4) walls, 5) horizontal cable trays, 6) vertical cable trays, 7) horizontal piping, 8) vertical piping, 9) horizontal ducting, 10) vertical ducting, 11) horizontal equipment, and 12) vertical equipment. A minimum of four samples were taken from each surface type. The area of each sample was recorded along with the weight of latent debris in the sample area. The average and maximum weight per unit surface area were recorded. The averages were then multiplied by the horizontal and vertical surface areas that might have latent debris accumulate on them which resulted in the latent debris loading for Containment. The latent debris load results used the maximum sample for each surface type with the exception of the non-stair grating where it was assumed that the latent debris load was the same as the floor.

Response to Issue 3d2:

Debris was assumed to be normally distributed for a given sample type. This assumption was supported by the walkdown observation that latent debris was uniform for a given surface type. Averaging the latent debris for surface types having multiple samples is consistent with the sampling approach taken to estimate the amount of latent debris inside Containment.

Response to Issue 3d3:

Latent debris includes dirt, dust, lint, fibers, etc., that are present inside the Containment and could be transported to the emergency sump strainer. This debris could be a contributor to head loss across the strainer. In accordance with recommendations in Reference 13, latent debris samples were collected to estimate the actual mass of latent debris inside of Containment. A latent debris load of 150 lbs was computed. The latent debris was described as dust with no fiber in any sample. However, it is assumed that 15% of the latent debris is fibrous and 85% is particulate.

Response to Issue 3d4:

Latent debris (in the form of dust) is accounted for in test and analysis by including it in the debris mix. Therefore, no specific sacrificial area needs to be allocated to it. Therefore, Calvert Cliffs does not provide an amount of sacrificial strainer surface area allotted to miscellaneous latent debris other than that allocated for stick-on labels (see Response to Issue 3b5 above).

***NRC Issue 3e*:**

Debris Transport

The objective of the debris transport evaluation process is to estimate the fraction of debris that would be transported from debris sources within Containment to the sump suction strainers.

1. *Describe the methodology used to analyze debris transport during the blowdown, washdown, pool-fill-up, and recirculation phases of an accident.*
2. *Provide the technical basis for assumptions and methods used in the analysis that deviate from the approved guidance.*
3. *Identify any computational fluid dynamics codes used to compute debris transport fractions during recirculation and summarize the methodology, modeling assumptions, and results.*
4. *Provide a summary of, and supporting basis for, any credit taken for debris interceptors.*
5. *State whether fine debris was assumed to settle and provide basis for any settling credited.*
6. *Provide the calculated debris transport fractions and the total quantities of each type of debris transported to the strainers.*

Response to Issue 3e1:

Calvert Cliffs conservatively assumed that 100% of the debris that did not remain on the target transported to the containment pool. No debris hold-up on structures, gratings or in quiescent pools was credited.

For the blowdown phase, it was assumed that 100% of the debris was blown into the recirculation pool. This is a conservative assumption, as it ensures that the entire debris load was available for production of chemical precipitates and transport during recirculation.

The washdown phase of transport was not evaluated, as it was conservatively assumed that all debris was blown directly into the recirculation pool, maximizing the potential for production of chemical precipitates and transport to the strainer.

For the pool-fill phase of transport, the potential for debris to transport to inactive cavities was evaluated and determined to not be significant. Therefore, no credit is taken for debris transport to inactive cavities.

Calvert Cliffs uses the size distribution for fiber and particulates provided in response to Issue 3c1 and assumes that, with the exception of lead wool, all fines, including fines eroded from small and large pieces of fiberglass insulation, particulate, and precipitate debris transport to the sump strainer during the recirculation phase of transport. Small and large pieces of debris were conservatively assumed to not transport to the strainers as these sizes of debris were demonstrated to reduce strainer head loss in plant-specific strainer head loss testing.

Response to Issue 3e2:

Erosion of low density fiberglass insulation is the only area where the debris transport analysis deviates from the approved guidance. The approved guidance specifies that an erosion fraction of 90% should be used for fiberglass debris.
To quantify the recirculation pool erosion fractions for Calvert Cliffs, 30 day erosion testing was performed. Based on this testing an erosion fraction of 10% was used for fiberglass debris except for that which is contained in an intact blanket/jacket [Reference (11)].
Calvert Cliffs includes debris from permanent lead shielding blankets in the debris source term. The debris from the lead shielding blankets is assumed to not erode in the recirculation pool because the jacket material used on these permanent lead shielding blankets is specifically designed for high temperature with improved resistance to abrasion, flexing, tear and puncture. This assumption is consistent with approved guidance where jacketed pieces of fiberglass insulation are not susceptible to erosion in the recirculation pool.

Response to Issue 3e3:

No computational fluid dynamics codes were used by Calvert Cliffs.

Response to Issue 3e4:

No credit is taken for debris interceptors.
Response to Issue 3e5:

Based on observations from head loss testing where fines from the cover on lead shielding blankets did not transport to the strainer even when using artificial agitation, it is concluded that the cover material of the lead shielding blankets would not transport to the strainer during sump recirculation. Calvert Cliffs did not credit the settling of any other fine debris in the transport calculations.

Response to Issue 3e6:

Table 7a lists the debris transport fractions used for Calvert Cliffs as well as the quantities of each type of debris transported to the strainer for the break that produces the largest quantity of fine fibrous debris. Erosion factors are given under Item Section 3b4.

Table 7a: Bounding Debris Quantity at Emergency Sump Strainer for Calvert Cliffs

Debris Type	Debris Size	Transport Fraction to Pool	Transport Fraction to Strainer	Debris Quantity Transported to Strainer
Reflective Metal Insulation (RMI)	Small Pieces	100%	0%	0 ft^2
	Large Pieces		0%	0 ft^2
Nukon & Thermal Wrap	Fines	100%	100%	574.0 lbm
	Small Pieces		0%	0 lbm
	Small Pieces Eroded to Fines		100%	204.9 lbm
	Large Pieces		0%	0 lbm
	Large Pieces Eroded to Fines		100%	70.8 lbm
	Intact Pieces		0%	0 lbm
Generic Fiberglass	Fines	100%	100%	158.8 lbm
	Small Pieces		0%	0 lbm
	Small Pieces Eroded to Fines		100%	56.5 lbm
	Large Pieces		0%	0 lbm
	Large Pieces Eroded to Fines		100%	41.8 lbm
Temp-Mat	Fines	100%	100%	224.5 lbm
	Large Pieces		0%	0 lbm
	Large Pieces Eroded to Fines		100%	15.0 lbm
Mineral Wool	Fines	100%	100%	82.6 lbm
Marinite	Fines	100%	100%	0.139 ft^3
	Small Pieces		0%	0 lbm
	Small Pieces Eroded to Fines		100%	0.009 ft^3
	Large Pieces		0%	0 lbm
	Large Pieces Eroded to Fines		100%	0.049 lbm
	Remains on Target	0%	0%	0 lbm
Cal-Sil	Fines	100%	100%	0.00 lbm
	Small Pieces		0%	0 lbm
	Small Pieces Eroded to Fines		100%	0.00 lbm
	Remains on Target	0%	0%	0 lbm
Lead Shielding Blankets	Inner/Outer Cover Fines	100%	100%	0.89 lbm
	Inner/Outer Cover Small Pieces		0%	0 lbm
	Inner/Outer Cover Large Pieces		0%	0 lbm
	Inner/Outer Cover Intact Pieces		0%	0 lbm
	Lead Wool Fines		0%	0 lbm
Qualified Epoxy in ZOI	Particulate	100%	100%	1.14 ft^3
Qualified IOZ in ZOI	Particulate	100%	100%	0.76 ft^3
Degraded Qual Epoxy	Chips (Note: Analysis conservatively assumed fines with 100% transport)	100%	0%	1.097 ft^3
Degraded Qual IOZ	Particulate	100%	100%	0.549 ft^3
Unqualified Alkyd	Particulate	100%	100%	2.02 ft^3
Unqualified Epoxy	Particulate	100%	100%	3.47 ft^3
Unqualified IOZ	Particulate	100%	100%	0.459 ft^3
Unqual Organic Zinc	Particulate	100%	100%	0.0788 ft^3
Latent Fiber	Fines	100%	100%	22.5 lbm
Dirt/Dust	Fines	100%	100%	0.754 ft^3
Nuke Tape Fiber	Fines	100%	100%	1.25 lbm
Nuke Tape Particulate	Particulate	100%	100%	0.022 ft^3

The transported debris quantities (fiber fines and particulate) of the most limiting break given above with respect to fiber mass (at Weld-42-RC-11-4) are computed using the erosion factors given in Item 3b4 with the results presented in Table 7b below.

Table 7b Total Fines and Particulate at Strainer for Limiting Break

Break Location	Total Fiber Fines Quantity (lbm)	Total Particulate Quantity (ft^3)
42-RC-11-4	1455	10.6

***<u>NRC Issue 3f</u>*:**

Head Loss and Vortexing

The objectives of the head loss and vortexing evaluations are to calculate head loss across the sump strainer and to evaluate the susceptibility of the strainer to vortex formation.

1. *Provide a schematic diagram of the emergency core cooling system (ECCS) and containment spray systems (CSS).*
2. *Provide the minimum submergence of the strainer under small-break loss-of-coolant accident (SBLOCA) and large-break loss-of-coolant accident (LBLOCA) conditions.*
3. *Provide a summary of the methodology, assumptions and results of the vortexing evaluation. Provide bases for key assumptions.*
4. *Provide a summary of the methodology, assumptions, and results of prototypical head loss testing for the strainer, including chemical effects. Provide bases for key assumptions.*
5. *Address the ability of the design to accommodate the maximum volume of debris that is predicted to arrive at the screen.*
6. *Address the ability of the screen to resist the formation of a "thin bed" or to accommodate partial thin bed formation.*
7. *Provide the basis for the strainer design maximum head loss.*
8. *Describe significant margins and conservatisms used in the head loss and vortexing calculations.*
9. *Provide a summary of the methodology, assumptions, bases for the assumptions, and results for the clean strainer head loss calculation.*
10. *Provide a summary of the methodology, assumptions, bases for the assumptions, and results for the debris head loss analysis.*
11. *State whether the sump is partially submerged or vented (i.e., lacks a complete water seal over its entire surface) for any accident scenarios and describe what failure criteria in addition to loss of net positive suction head (NPSH) margin were applied to address potential inability to pass the required flow through the strainer.*
12. *State whether near-field settling was credited for the head-loss testing and, if so, provide a description of the scaling analysis used to justify near-field credit.*
13. *State whether temperature/viscosity was used to scale the results of the head loss tests to actual plant conditions. If scaling was used, provide the basis for concluding that boreholes or other differential-pressure induced effects did not affect the morphology of the test debris bed.*

14. *State whether containment accident pressure was credited in evaluating whether flashing would occur across the strainer surface, and if so, summarize the methodology used to determine the available containment pressure.*

Response to Issue 3f1:

Diagrams of the Calvert Cliffs ECCS and CS system for Units 1 and 2 are provided in Enclosure (1-2.1) to the submittal.

Response to Issue 3f2:

Calculations for minimum containment flood level have demonstrated that, for a small break LOCA (SBLOCA) and large break LOCAs (LBLOCA), the emergency sump strainer will be completely submerged at the time of switchover to containment sump recirculation. The minimum calculated submergence level (level over the maximum strainer pocket) which occurs after the initiation of recirculation, is presented in Table 8.

Table 8: Emergency Recirculation Sump Strainer Submergence

Break Size	Sump Water Temperature (°F)	Strainer Submergence (feet)
DEGB of Hot Leg/Cold Leg or Equivalent Size Longitudinal Breaks	$120 \le T_{sump} \le 140$	2.21
	$140 < T_{sump} \le 220$	2.09
Other Break Sizes > 0.08 ft2	$120 \le T_{sump} \le 140$	1.89
	$140 < T_{sump} < 220$	1.77
Break Sizes ≤ 0.08 ft2	$120 \le T_{sump} \le 140$	1.47
	$140 < T_{sump} \le 220$	1.35

<u>Response to Issue 3f3</u>:

Calvert Cliffs has completed vortex testing and analysis. CCI performed generic vortex testing for their strainer design in March 2005. The test results from those tests are used in the analysis which shows that vortexing is not possible at the design flows for the Calvert Cliffs strainers. Specifically, the Froude number for the Calvert Cliffs strainers is about 0.0025 (Fr = flow speed squared divided by the product of gravitational constant times the submergence depth) and the submergence of the strainer is 1.35 feet minimum. Under such conditions, air ingestion via vortex development is not possible.

Additionally, vortexing was investigated at both minimum LOCA submergence depths, 1.35 feet for a SBLOCA and 1.77 feet for a LBLOCA. The flow rates investigated range from 80% of the design flow rate to more than 500% of the design flow rate. No vortexing was seen in any design basis head loss test. The large range in flow rates with no evidence of vortexing provides assurance that variations in flow across the strainer will not result in vortexing.

Vortex development may arise due to flow disturbances. Borehole formation most likely is due to stochastic structural anomalies in the debris accumulated in and around the strainer pocket which has the borehole. The resulting flow disturbances due to the altered flow field around the borehole can lead to vortexing. Once the bore hole forms, the strainer differential pressure causes a large increase in flow speed through the newly formed borehole. This flow speed change itself is a perturbation of the flow field (a change from before the borehole formed to as it forms to after formation). CCI testing for this phenomenon includes local vortex formation. Based on CCI test results including tests specific for Calvert Cliffs, the critical Froude number for borehole induced vortexing is 62. The Froude number is defined as follows: Fr = 2 × measured head loss ÷ submergence depth. Based on the maximum head loss from testing in Table 10 and the minimum submergence from Table 8, the plant Froude number is:

$$2 \times 3.31' \div 1.35' = 4.9$$

This is lower than the critical Froude number for the submergence depth. Therefore, the strainer will not ingest air via vortices caused by boreholes.
Additional information on vortexing was provided in response to Request for Additional Information (RAI) 17 [Reference(20)].

Response to Issue 3f4:

Calvert Cliffs used the strainer supplier, CCI, to perform plant specific strainer head loss testing. Four different test campaigns were performed and two different test loop configurations were utilized for the Calvert Cliffs head loss testing, as follows:

1. Large Scale Test Loop Facility in Winterthur, Switzerland;
2. Multi Functional Test Loop (MFTL) at CCIs facility in Winterthur, Switzerland.

In each test one or more full-size strainer cartridges are placed in a test tank and are subsequently loaded with the amount of debris computed to transport to this portion of the overall strainer. The volumetric flow rate is scaled so that the average velocity through the strainer cartridges corresponds to the expected average flow speed through the strainer installed in the plant during a large break LOCA.

Debris is introduced into the tank approximately 5 feet upstream of the test strainer. Fiber debris is shredded and diluted in water to minimize agglomeration of fines. Chemical precipitates are generated in separate tanks according to the methods described in Reference (12).

The first three test campaigns were run from August 2006 to January 2009. Calvert Cliffs redesigned the strainer head loss test program based on experience gained in the three test campaigns and NRC guidance [Reference (13)] and ran new tests in the summer of 2010.
The CCI MFTL is a closed recirculation loop as shown in Figure 1. The water recirculation in the loop occurs by means of a centrifugal pump with a flow rate capacity up to 125 m^3/h and a flow meter capacity of 200 m^3/h. The flow rate is adjustable by controlling the speed of the pump motor via a frequency based variable speed controller. Additionally, the flow rate can be pre-adjusted by means of a valve in the downstream line. The water flow rate is measured using a KROHNE magnetic inductive flow meter. The temperature of the water is measured using a Ni-CrNi Thermocouple Type K.

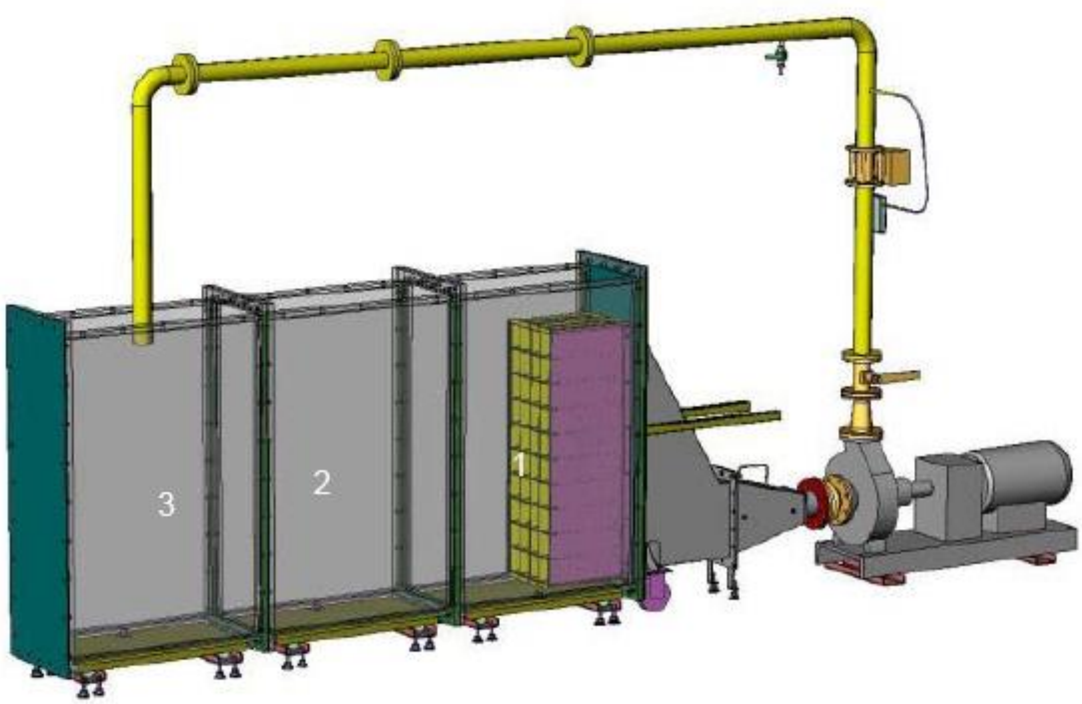


Figure 1: Outline of MFTL for Calvert Cliffs testing (3 modules shown)

A CCI strainer segment with 36 representative pockets was placed in the Plexiglas channel before the loop was filled with water. The test module is shown in Figure 2. The 36 pocket prototype had a vertical orientation while the water flow was horizontal into the pockets. The prototype was 9 pockets high (90 mm height per pocket) by 4 pockets wide (84 mm per pocket) and the pockets were 200 mm deep. The distance of the test pockets above the floor was approximately 5 cm. Side plates (200 mm long), top and bottom sealing plates were made from solid, non-perforated steel plate. The hole diameter in the perforated strainer pockets was 1.6 mm (1/16") and the test cartridge plate thickness was 1.25 mm.

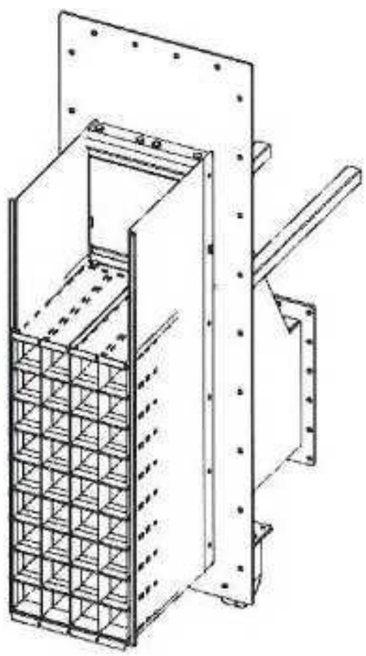


Figure 2: Strainer Test Module

After preparation and addition of the fiber, particulate and precipitate test debris mixtures into the test loop, the head loss was monitored until it reached a satisfactory stabilization point. Head loss, temperature and flow rate measurements were taken throughout the test.

The test program did not take credit for near field debris settling. The debris was introduced about midway between the sparger and the test strainer module. Agitation with a drill and propeller effectively eliminated debris settling. The chemicals were introduced in the loop close to the sparger via a peristaltic pump. The volume of water in the test loop is approximately 2400 liters.

Some debris settlement occurred in the MFTL testing. Most debris was transported into the strainer pockets by the flume flow but some settled to the floor of the flume. Agitation was used to suspend the settled debris. The agitation methods were successful at resuspending debris but were not successful at moving the settled debris into the pockets. In general, the pockets were full of fibrous and particulate debris prior to addition of chemical precipitate surrogates. The debris that did not enter the strainer pockets was found on the face of the strainer outside of the pockets or at the base of the strainer, within about 30 centimeters of the strainer. Far more debris is postulated to transport to the strainer

than can fit into the strainer pockets. In essence, the strainer is full with debris and consequently is buried under the remaining debris load.

The fibrous insulation debris and Marinite debris used in the test were provided to CCI by Calvert Cliffs from materials identical to plant insulation. Silicon carbide was used as the surrogate for particulate coatings debris. Epoxy coatings chip debris was produced from the same epoxy coating used in containment at Calvert Cliffs. Cal-Sil was not included in the test debris mix due to the insignificant quantity of Cal-Sil generated by large break LOCAs, see Tables 4 and 7a.

The debris preparation and addition methods used by CCI for the Calvert Cliffs tests are identical to those witnessed by the NRC in Spring 2008 at CCI's laboratory in Switzerland.

Fibrous debris for use in tests was prepared by the following method:

Fiber Fines

- The fibers were freed from the jacketing (if jacketed). Then the fibers were baked by placing them in an oven with a regulated temperature of 250°C (480°F) for 24 hours prior to testing. Generic fiberglass insulation was not baked for the tests since it is used at Calvert Cliffs on relatively cool pipes.
- The fibers were hand cut in pieces of approx. 50 x 50 mm (2 in. x 2 in.).
- The dry material was weighed
- The fibers were split in batches of 3 to 4 dm^3 (0.1 to 0.14 ft^3)
- Each batch was soaked in 2 l of water (½ gal) until they appeared saturated
- Their adherence was decomposed by a high pressure water jet with a capacity of 100 bar (1450 psig) and with the jet in a distance of ± 0.05 m (2 in.) to the water surface, during approximately 4 min for each batch.
- It was ensured by visual means that the insulation was decomposed in the water in fine pieces with no clumps of fibers remaining intact and individual fiber pieces were smaller than 8 mm (0.3 in.).

Fiber Small Pieces

- The fibers were freed from the blanket/jacketing (if jacketed). Then the fibers were baked by placing them in an oven with a regulated temperature of 250°C (480°F) for 24 hours prior to testing. Generic fiberglass insulation was not baked for the tests since it is used at Calvert Cliffs on relatively cool pipes.
- The fibers were hand cut in pieces of approx. 50 x 50 mm (2 in. x 2 in.).
- The dry material was weighed
- The fibers were split in batches of 3 to 4 dm^3 (0.1 to 0.14 ft^3)
- The fiber material was run through an electric leaf shredder one time
- Each batch was soaked in several liters of water (preferably using water from the test loop) at no more than a 100 – 200g (3.5 – 7 oz.) fiber smalls per preparation bucket.
- Prior to addition to the loop the fiber smalls were mixed briefly using either the propeller drill bit, hand agitation or some other means to prevent fiber smalls agglomeration. Caution was used to prevent breaking the small pieces into fines.
- The fibers small pieces were used in their respective sizes once saturated

Marinite

Marinite was pulverized using mechanical means to a powder form. The Marinite was combined with the Silicon Carbide particulate debris bucket.

Degraded Qualified Epoxy Coatings Outside ZOI

- Epoxy coating was applied to a plastic sheet and allowed to cure.
- The cured epoxy coating was removed from the plastic sheet and disintegrated into large chips which were placed in a bucket.
- The large chips were further disintegrated into smaller chips using a drill machine with an agitating propeller.
- The small chips were then sieved to obtain the proper size.

Particulate and fibrous materials were prepared and maintained separately. Neither type was mixed together; there were no mixed mode suspensions during preparation and addition. Both debris types were further diluted during the addition process. The normal test sequence was to alternate particulate and fibrous insulation additions during a single batch add. That is, one batch might consist of several containers of particulate debris and several of fibrous debris; additions of each type would be alternated until the entire batch was added. Particulate was added before fiber as CCI experience showed that this resulted in higher head loss. Paint chips were added after all particulate and fibrous debris was added.

The particulate and fibrous debris was added to the flume approximately midway between the return pipe opening and the strainer face, approximately 1.5 meters (5 ft.) from the strainer face. The coatings chips were added immediately upstream of the strainer face as the chips would not transport along the flume. Care was taken to assure uniform distribution of debris across the strainer face. Care was also taken to add the debris slowly, avoiding water disturbance that might disturb the debris bed.

Mechanical agitation was used to suspend debris that settled in the flume. Debris at the base of the strainer was allowed as long as this debris appeared as a natural slope with no visible humps away from the slope. Agitation was performed provided particulate and fibrous debris was free in the flume or had settled to the flume floor in a mass greater than approximately 50 cm (20 in.) away from the upstream strainer face. Guidance was provided to not force debris onto the strainer face through this agitation. This guidance was violated in one test (Test 6).

After all non-chemical debris was added to the flume, head loss was allowed to stabilize. The head loss stabilization criterion was less than a 1% increase per hour for head loss values >60 mbar (2 ft-water) or ≤0.6 mbar (0.25 in.-water) increase per hour for head loss values ≤60 mbar (2 ft-water).

Chemical precipitate formation does not need to be considered until the containment pool cools to 140°F. Multiple containment response analyses show that when the containment pool cools to 140°F the containment pressure is less than 2.2 psig. The Calvert Cliffs Emergency Operating Procedure for LOCA directs the operators to secure one containment spray pump when containment pressure drops below 4.0 psig. This action is credited in reducing strainer flowrate prior to the formation of chemical precipitates.

Calvert Cliffs prepared GOTHIC containment response calculations to verify that sufficient time was available to assure one CS pump could be secured and strainer flow rate reduced before the

containment pool temperature reduces to 140°F. These calculations used assumptions and inputs that maximized containment cooldown rates and considered maximum instrument uncertainty to delay operator action. The results of these calculations showed that for maximum cooldown conditions, containment pressure reduces to 3.68 psig (4 psig indicated) about 30 minutes into the event and the containment sump temperature reduces to 140°F more than 24 hours later. See Figure 3.

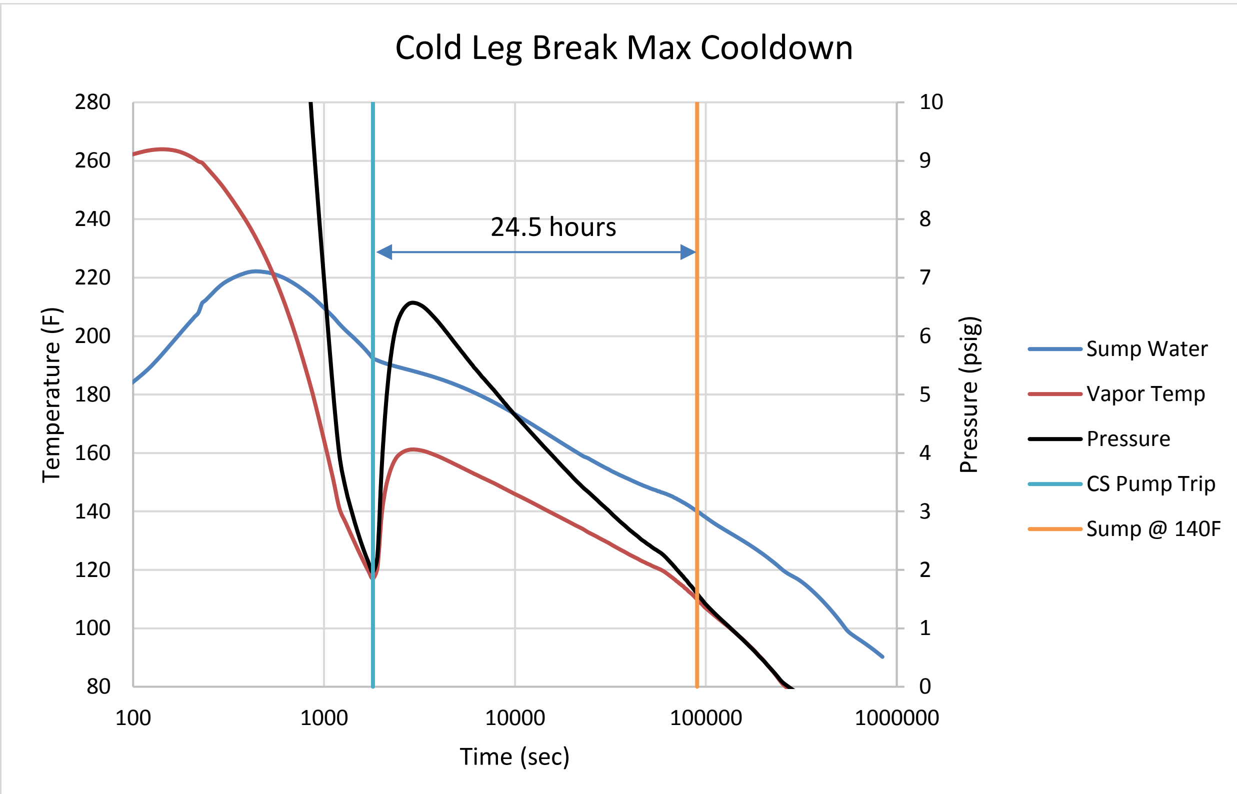


Figure 3: Time from Securing CS pump to Pool Reaching 140°F

Prior to adding chemical precipitates to the test loop, the test flow was reduced to the nominal strainer flow which accounted for securing one division of engineered safeguards (one HPSI and one containment spray pump). The strainer head losses obtained at this reduced flow rate were then scaled to the equivalent flow rate of two HPSI and one containment spray pump.

Chemical addition was performed in a continuous fashion by a peristaltic metering pump and was introduced immediately below the return via a hollow tube. This configuration provided the best chance for the chemical precipitate surrogates to fully mix in the flume flow prior to arrival at the strainer and debris bed.

Agglomeration was not observed. All debris was transported to the strainer module either directly or via resuspension in the flume flow through the action of agitation methods. Calvert Cliffs test methods are conservative in the delivery of material to the strainer.

The abbreviated procedure for performance of the tests is provided below.

1) Prepare fibrous insulation debris.

2) Prepare particulate debris.
3) Prepare chemical precipitate surrogate.
4) Perform clean head loss test from 12% to 200% design flow rate.
5) Fiber / Particulate debris introduction:
   a) Ensure appropriate flow rate and water temperature per test plan.
   b) Starting with particulate, alternate additions of fiber fines, fiber smalls and particulate..
   c) Ensure transport to the strainer by appropriate agitation. Ensure appropriate distribution of debris across the strainer without center weighting.
   d) Add debris for thin bed investigation or for normal bed investigations as required in the test plan.
   e) Maintain water level, flow rate, and temperature within tolerance.
   f) Allow head loss to stabilize in accordance with criteria in test plan.
6) Chemical precipitate introduction.
   a) Adjust flow rate per test plan.
   b) Add sodium aluminum silicate precipitate immediately below the sparger (return of flow from the heater to the test flume) per test plan using a peristaltic pump.
   c) Addition rate is specified in the test plan.
   d) Ensure transport of the debris bed by appropriate agitation.
   e) Maintain water level, flow rate, and temperature within tolerance.
   f) Allow head loss to stabilize in accordance with criteria in test plan.
7) Perform optional flow sweep at the end of the test to demonstrate bed stability:
   a) Reduce flow rate to 80% design.
   b) Increase flow rate in increments to at least 120% of design. A few tests investigated flow rates as high as 250% of design.

The MFTL was heated to between 45-50°C (115 - 125°F) for the Calvert Cliffs tests. The submergence was about 10 cm (~4 in.). The strainer test modules were elevated above the flume floor about 5 cm (~ 2 in.) consistent with the plant installation. The strainer modules tested were identical to those installed in Calvert Cliffs.

Seven head loss tests were performed in the summer of 2010. These tests included head loss for fibrous and particulate debris (conventional debris) as well as head loss with chemical precipitates. This was a test for success campaign based on multiple insulation replacement schemes all of which included 100% replacement of mineral wool. Debris quantities and head loss results are presented in Table 9 and Table 10 below. Further details can be found in Table 3 of Attachment 1-3.

Table 9: Debris Quantities (kg)

	Nukon	Transco Fiber	Temp Mat	Generic Fiber	Paint Chips	Marinite	Silicon Carbide	Precipitate (NAS)
Test 1	1.516	2.681	0.069	0.173	0.254	0.015	2.844	0.088
Test 2	0.336	0	0.070	0.242	0	0.015	3.581	0.096
Test 3	0.644	0.594	0.069	0.394	0.254	0.015	3.581	0.096
Test 4	0.138	0.873	0.069	0.036	0.254	0	2.908	0.077
Test 5	0.339	0.873	0.069	0.046	0.331	0	3.645	0.087
Test 6	0.339	0.873	0.069	0.046	0.331	0	3.645	0.087
Test 7	0.237	0.873	0.069	0	0.254	0.015	2.844	0.091

Table 10: Maximum Recorded Head Loss Results (ft-water)

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Conventional Debris Only	0.11	0.03	0.08	0.05	0.06	0.06	0.05
Conventional and Chemical Debris	0.15	0.05	3.20	0.61	1.23	3.31	0.67

<u>Test 1</u>

The first test in the series was a test with fine and small piece fibrous debris along with particulate. The debris load consisted of an equivalent quantity of 313 ft^3 of fine fibers and 798 ft^3 of small pieces of fiber. The fiber and particulate debris were introduced in five equal batches in the order of particulate, fines, then small pieces. A photograph of the debris loaded strainer after introduction of the chemical precipitates is shown in Figure 4. The maximum debris bed head loss in this test was less than 1.76 inches of water (0.06 psid, 4.4 mbar) as shown in Figure 5. Note that data were not provided between 42.2 and 48.7 hours into the test; however, the incremental rise in head loss shown in Figure 5 can be confirmed by examining the test data recorded in the test report.

The maximum head loss was low, less than 2 inches of water, and the debris bed was non-uniform as shown in Figure 4.

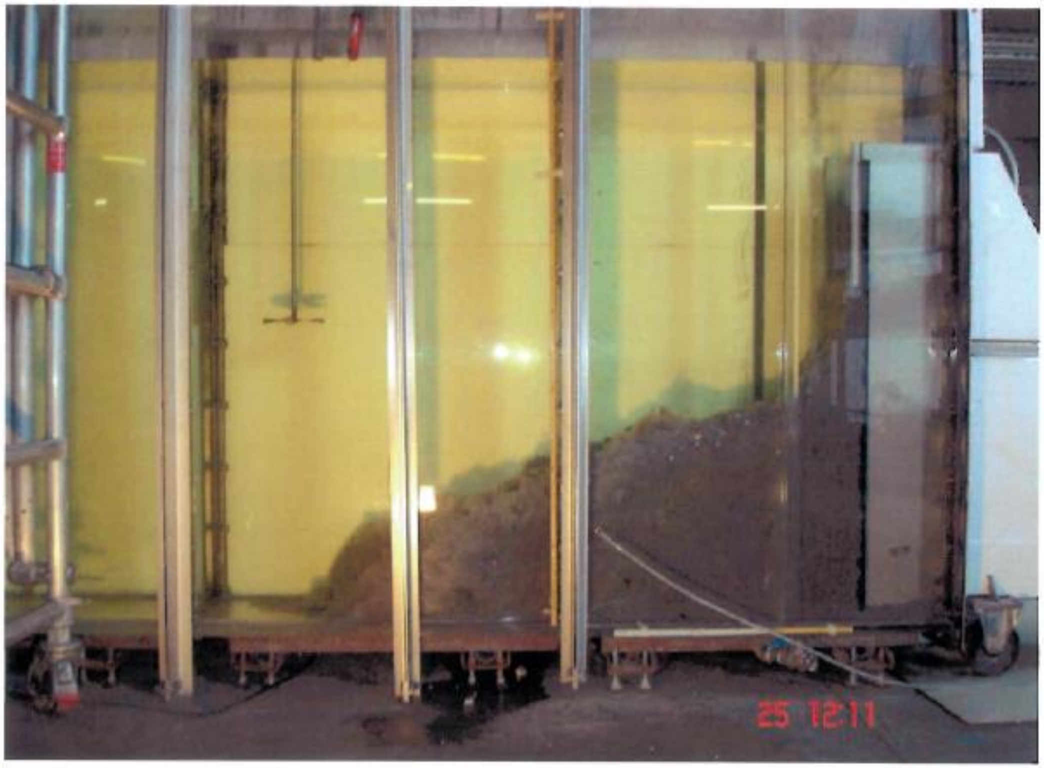


Figure 4: Test 1 Non-Uniform Debris Deposition When Small Fiber Pieces Included

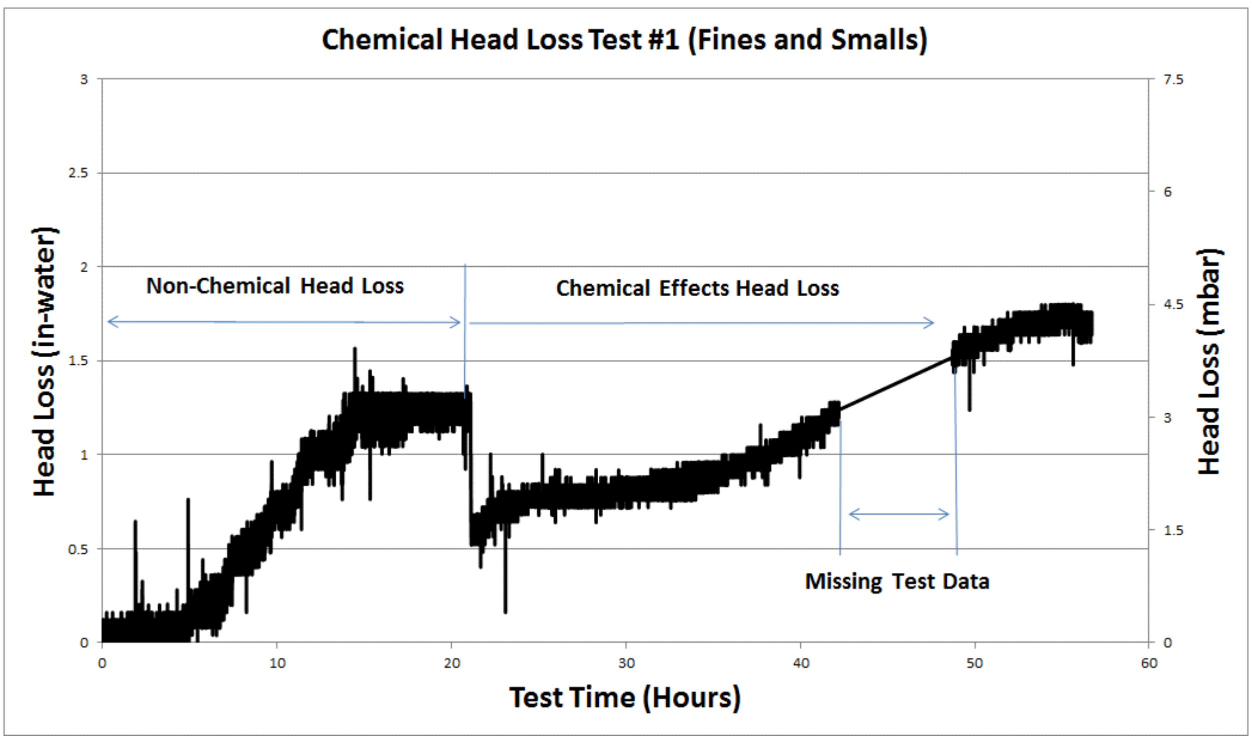


Figure 5: Test 1 Head Loss Data

Two key conclusions were drawn from Test 1:

1) Debris deposition on the strainer for large break LOCA at Calvert Cliffs is non-uniform.
2) Testing with small-pieces of fibrous insulation is potentially non-conservative due to the very low head loss observed.

The decision was made to exclude small pieces of fibrous debris from further head loss testing. Test 5 included a comparable quantity of fine fibers to that of Test 1 and resulted in significantly higher head loss.

Test 2

Test 2 was a thin-bed test. The test alternated the addition of fiber fines and particulate to the loop, starting with particulate. This sequence was chosen due to previous CCI experience which showed this methodology resulted in higher head loss than initially adding all particulate to the loop followed by batching in fiber. This test resulted in debris bed head losses less than 0.6 inch of water (1.5 mbar). A photograph of the debris loaded strainer after introduction of the chemical precipitates is shown in Figure 6. A plot of the head loss data is shown in Figure 7.

Consistent with earlier thin-bed testing attempt, no thin-bed formation was observed. The head loss results were very low. The Calvert Cliffs emergency recirculation strainer is not susceptible to the thin-bed effect.

Figure 6: Debris Deposition in Thin-Bed Test

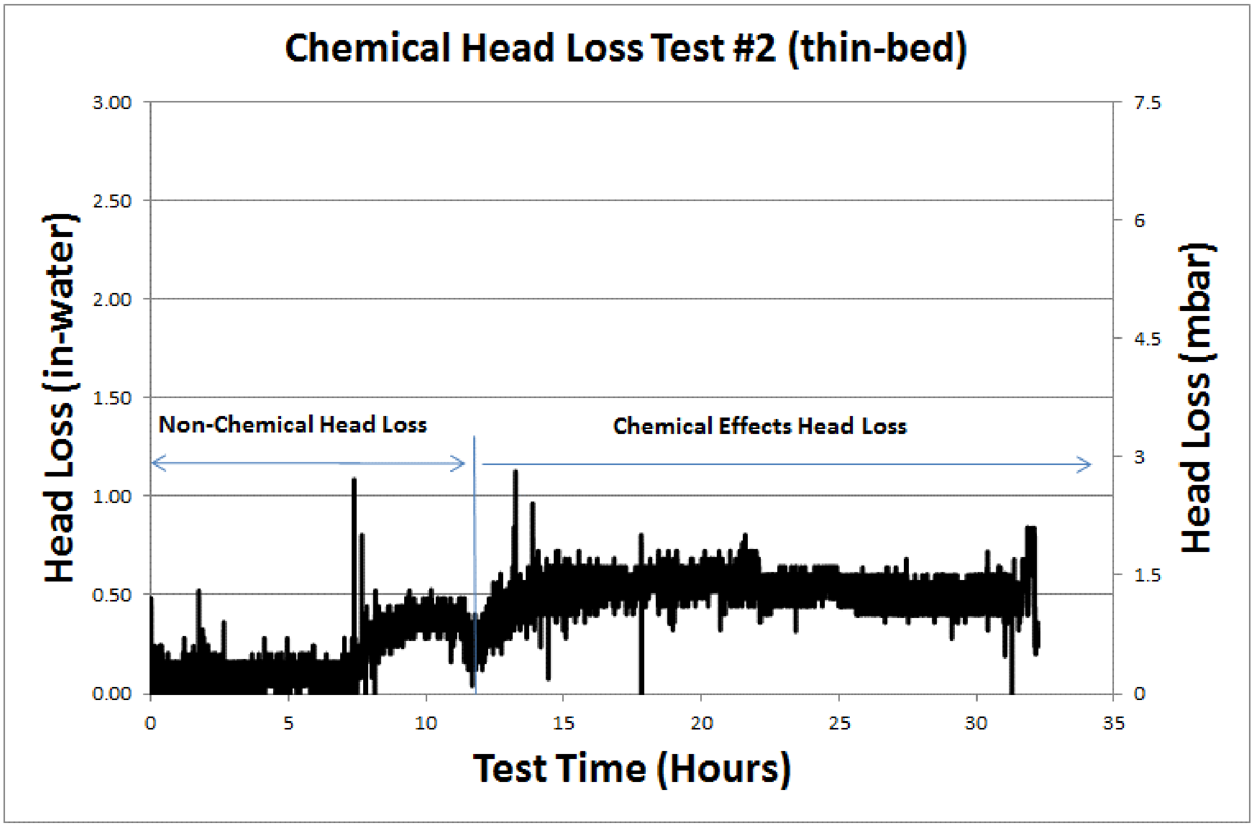


Figure 7: Test 2 Head Loss Data

<u>Test 3</u>

The third test in the series was a test with the equivalent of 369 ft^3 of fine fibrous debris. The maximum debris bed head loss prior to introduction of chemical precipitates was 1 inch of water (2.5 mbar). After introduction of the chemical precipitates, the debris bed head loss climbed to 3.2 feet of water (94.6 mbar) at which time a bore hole formed in the debris bed and the head loss dropped to approximately 0.9 feet of water (27.3 mbar) before leveling off at 1.2 feet of water (35.2 mbar). Photographs of the Test 3 debris bed are shown in Figure 8. A plot of the head loss data is shown in Figure 9.

The debris bed bore hole from test 3 is shown in Figure 10. This is typical of the remaining tests in this series. Each of tests 3 through 7 experienced at least one debris bed break-through after introduction of the chemical precipitate material. The low flow rate at Calvert Cliffs results in the strainer pockets filling with loosely packed fiber followed by the fibrous debris building a debris bed across the face of the strainer. When the chemical precipitates cover the debris bed, the soft bed compresses and eventually ruptures into one pocket which relieves the differential pressure.

Figure 8: Test 3 Debris Bed Before and After Chemical Precipitates

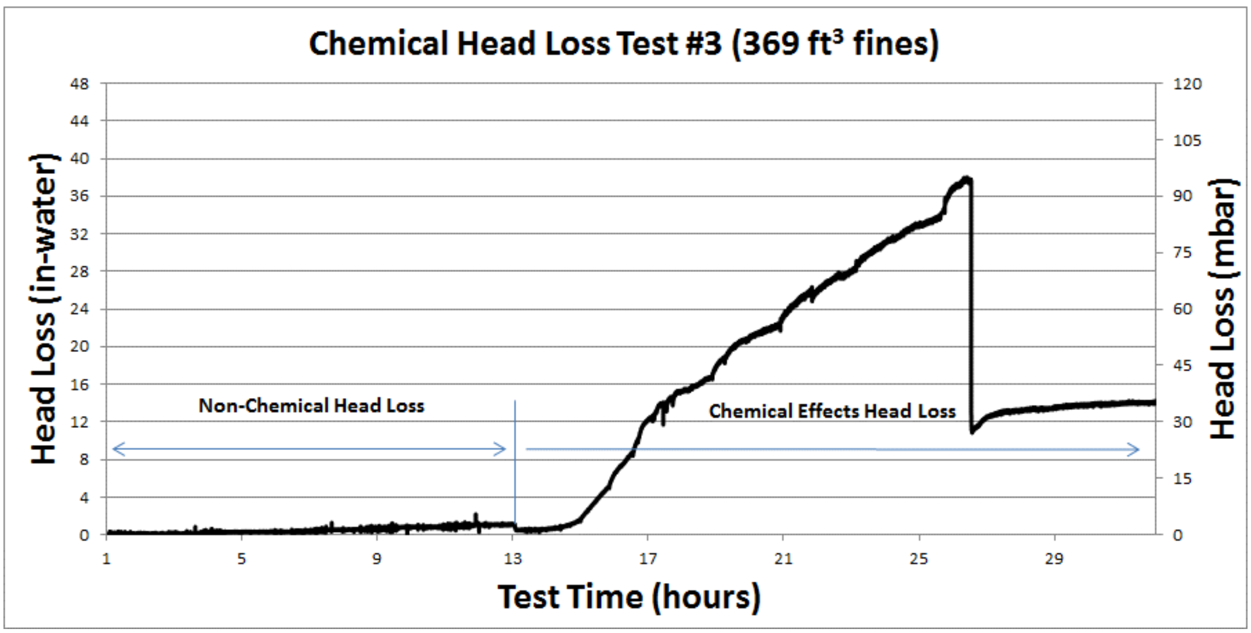


Figure 9:Test 3 Head Loss Data

Figure 10: Test 3 Debris Bed Bore Hole

Each of tests 3 through 7 experienced at least one debris bed break-through after introduction of the chemical precipitate material. The low flow rate at Calvert Cliffs results in the strainer pockets filling with loosely packed fiber followed by the fibrous debris building a debris bed across the face of the strainer. When the chemical precipitates cover the debris bed, the soft bed compresses and eventually ruptures into one pocket which relieves the differential pressure.

<u>Test 4</u>

The fourth test in the series was a test with the equivalent of 270 ft^3 of fine fibrous debris. The maximum debris bed head loss prior to introduction of chemical precipitates was 0.61 inch of water (1.5 mbar). After introduction of the chemical precipitates, the debris bed head loss climbed to 6.1 inches of water at which time a bore hole formed in the debris bed (15.1 mbar). The last of the precipitate was added to the loop and the head loss slowly returned to 7.2 inches of water at which time another bore hole formed in the debris bed (17.9 mbar). The head loss leveled off to approximately 4.1 inches of water (10.3 mbar) at the end of the test. The head loss data from Test 4 is shown in Figure 11.

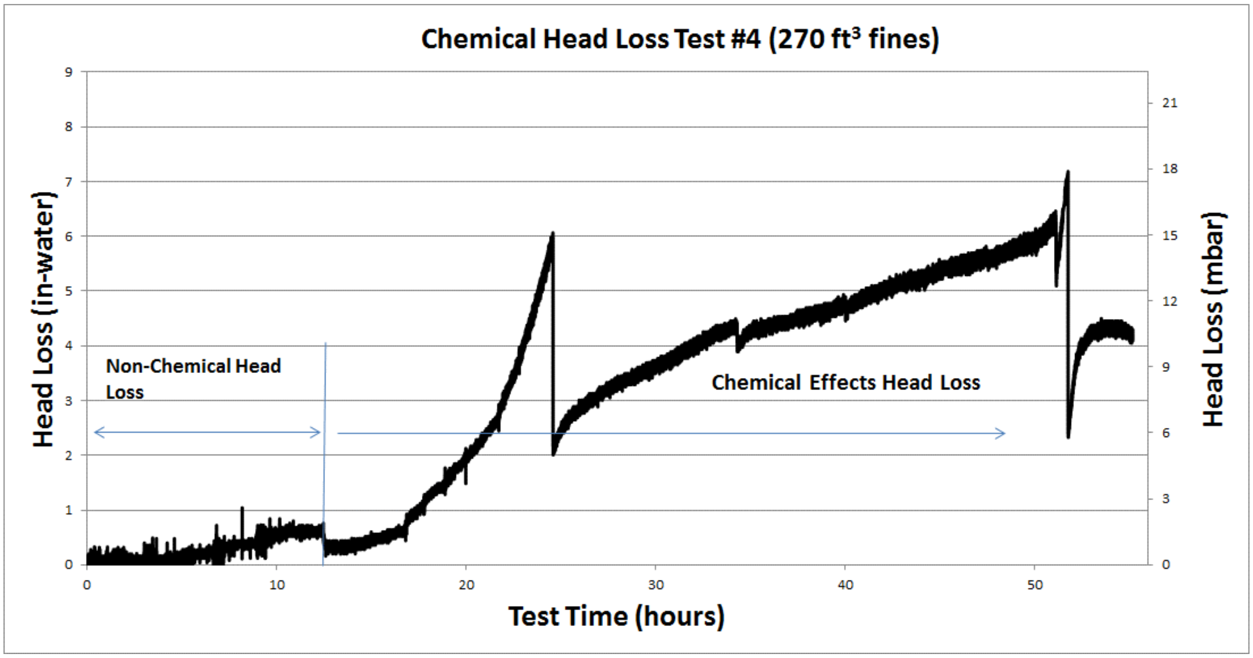


Figure 11: 4 Head Loss Data

Test 5

The fifth test in the series was a test with the equivalent of 323 ft^3 of fine fibrous debris. The maximum debris bed head loss prior to introduction of chemical precipitates was 0.69 inch of water (1.7 mbar). After introduction of the chemical precipitates, the debris bed head loss climbed to approximately 1.2 feet of water (36.2 mbar) at which time a bore hole formed in the debris bed and the head loss dropped to approximately 3.5 inches of water (8.8 mbar). The head loss leveled off at test end to 7.8 inches of water (19.4 mbar). The head loss data from Test 5 is shown in Figure 12.

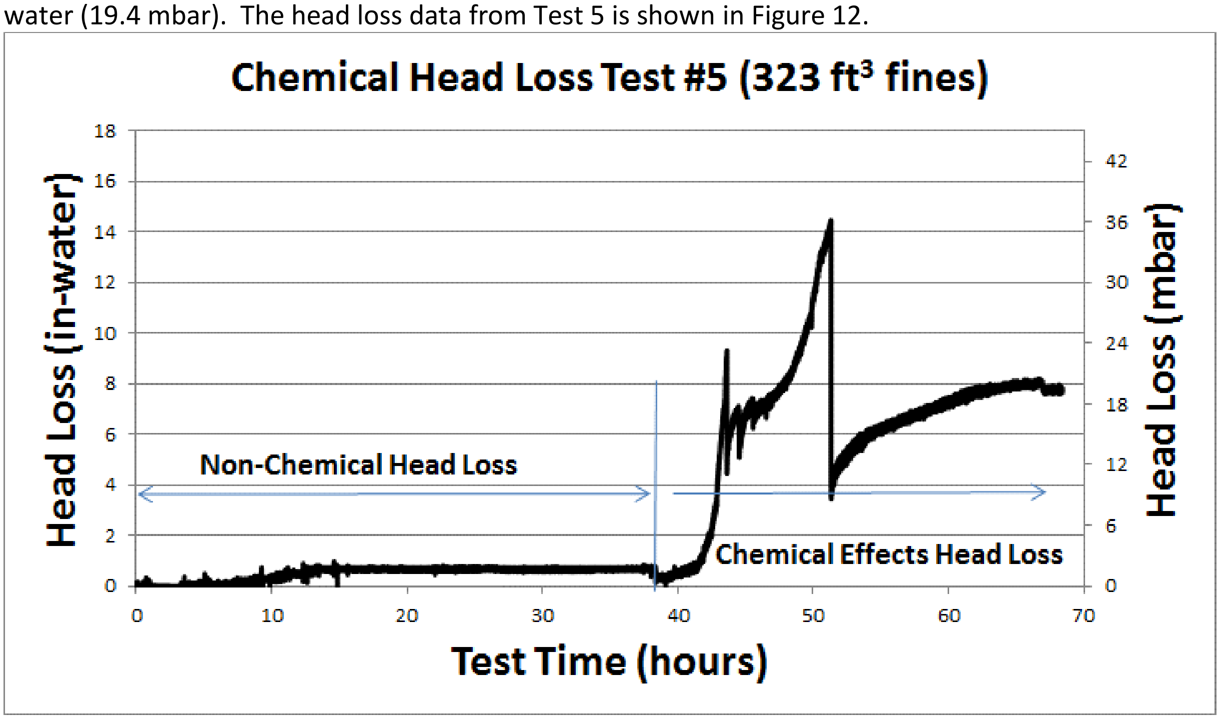


Figure 12: Test 5 Head Loss Data

Test 6

The sixth test in the series was a test using the same debris load as Test 5 with the addition of lead shielding blanket cover broken down as fine as possible. The maximum debris bed head loss prior to introduction of chemical precipitates was approximately 0.73 inch of water (1.8 mbar). After introduction of the chemical precipitates, the debris bed head loss climbed to 3.3 feet of water (97.8 mbar) at which time a bore hole formed in the debris bed and the head loss dropped to 1.1 feet of water. The head loss leveled off at test end to around 2.0 feet of water (58.7 mbar). The head loss data from Test 6 is shown in Figure 13.

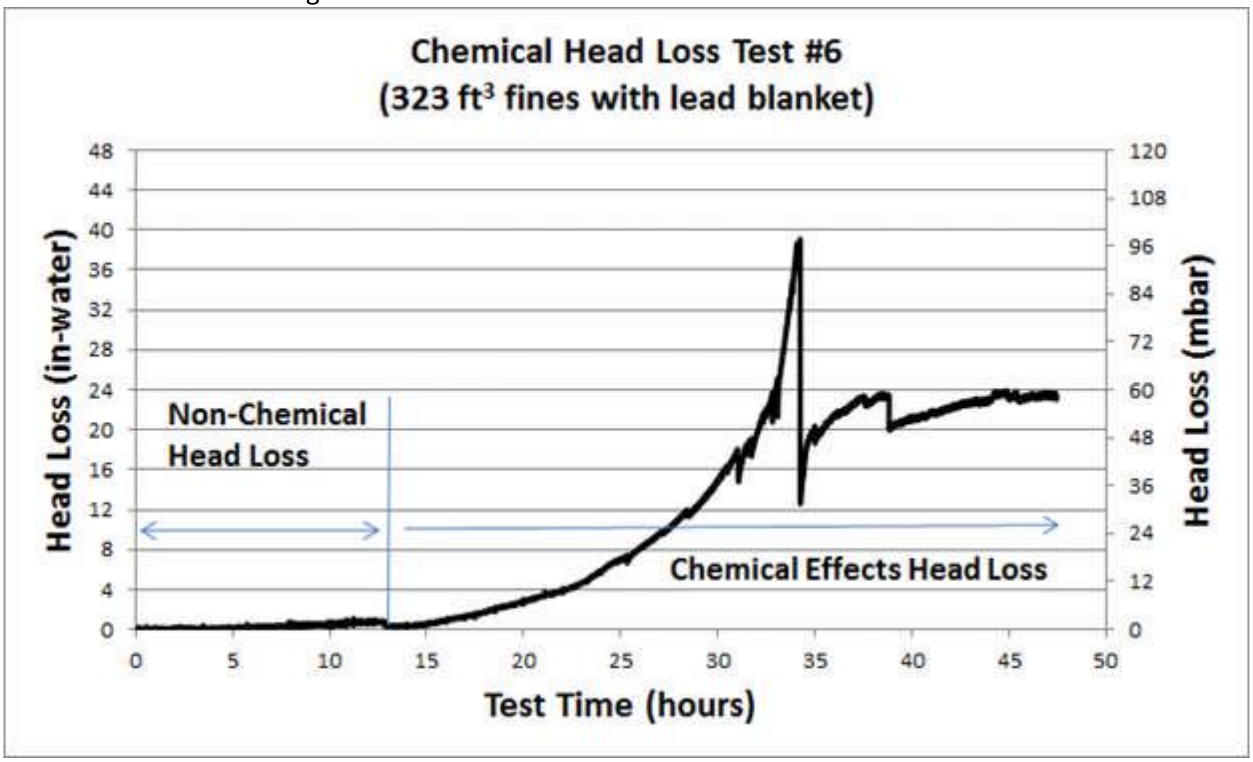


Figure 13: Test 6 Head Loss Data

Test 6 was rejected due to improper agitation of debris in the test flume. The Calvert Cliffs test engineer on duty witnessed agitation where an electric drill driven propeller disturbed the debris on the face of the strainer. The use of the hand-held drill was observed lifting the debris within the debris bed and creating a non-prototypical debris profile that was considered not to be consistent with previous testing. Test 6 was rejected and additional guidance on agitation was provided before proceeding with additional testing.

Test 7

The final test in the series was a test with the equivalent of 292 ft^3 of fine fibrous debris. The maximum debris bed head loss prior to introduction of chemical precipitates was approximately 0.57 inch of water (1.4 mbar). After introduction of the chemical precipitates, the highest debris bed head loss was 7.9 inches of water before an interruption formed in the debris bed (19.6 mbar). The head loss leveled off at

test end around 7.5 inches of water after multiple debris bed interruptions (18.7 mbar). The head loss data from Test 7 is shown in Figure 14.

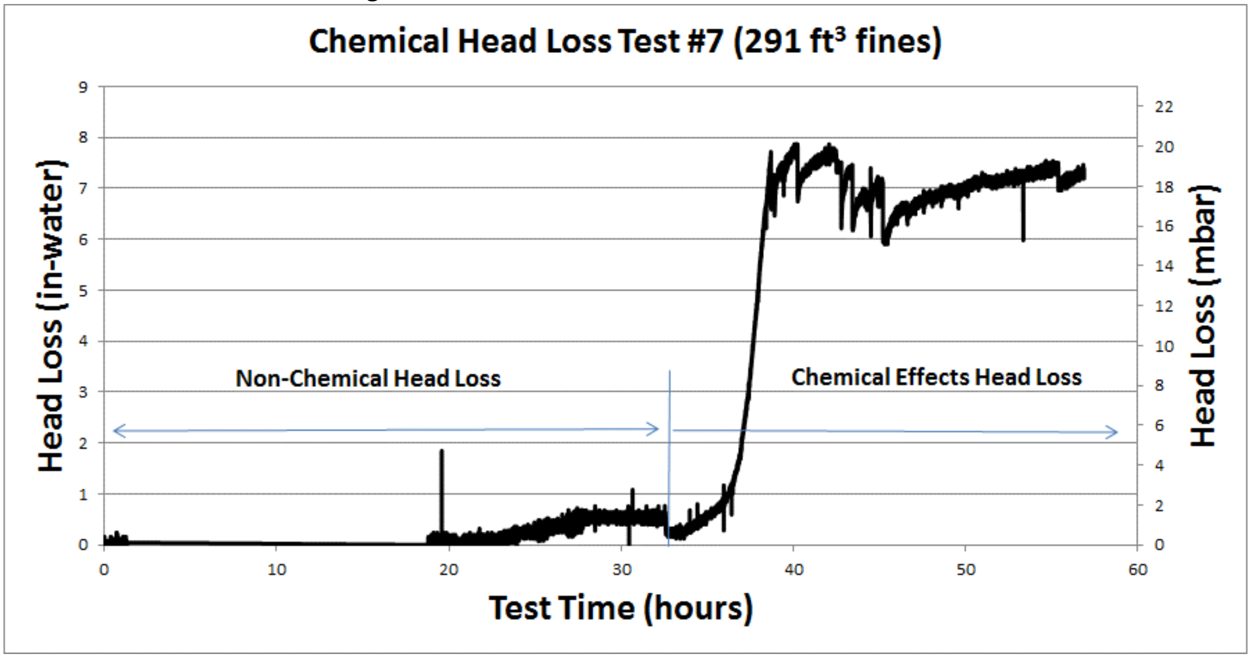


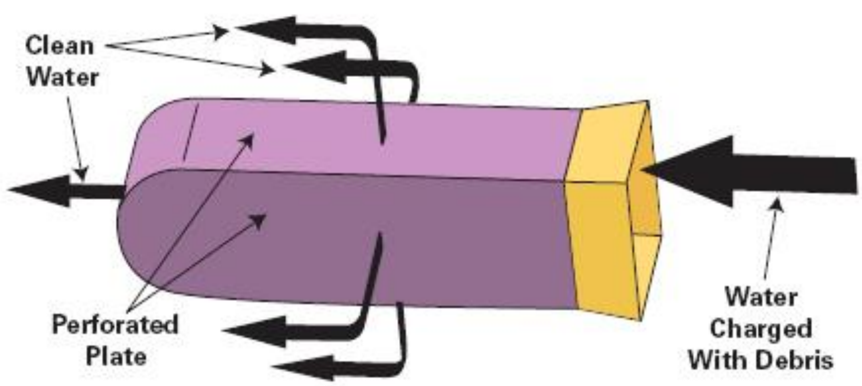
Figure 14: Test 7 Head Loss Data

Response to Issue 3f5:

The pockets in CCIs strainer cassettes are designed to fill with debris with additional debris depositing on the outside of the strainer. The distributed layout of the strainer module rows allows sufficient space for the debris to accumulate and completely envelop the strainer. The low flow velocity into the strainer prevents the strainer pockets from becoming tightly packed with debris. Therefore, complete envelopment of strainer, as demonstrated in strainer head loss testing (Test 1), is acceptable.

Response to Issue 3f6:

The strainer installed at Calvert Cliffs is CCI's pocket cassette type strainer. Figure 15 shows a representative pocket cassette strainer. During the April/May 2008 testing, the October-December 2008 testing, and the June/July 2010 testing at CCIs MFTL, several attempts were made to generate a thin bed using Calvert Cliffs-specific debris. The geometry of the pocket filtration surface is such that it was not possible to have a uniform fiber bed on the filtration surface.



CCI's horizontal cassette pocket with five flow paths

Figure 15: Pocket Cassette Strainer

The April-May 2008 tests used the following thin bed test methodology:

- Add 50% of the particulate and 10% of the fibrous debris (expected bed thickness 0.1 inch). Measure head loss.
- Add 50% of the particulate and 10% of the fibrous debris (expected total bed thickness 0.2 inches). Measure head loss.

The October-December 2008 tests used the following thin bed test methodology:

- Add 50% of the particulate and 10% of the fibrous debris (expected bed thickness 0.1 inch). Measure head loss.
- Add 50% of the particulate and 5% of the fibrous debris (expected total bed thickness 0.15 inches). Measure head loss.
- Add 5% of the fibrous debris (expected total bed thickness 0.2 inches). Measure head loss.
- Add 10% of the fibrous debris (expected total bed thickness 0.3 inches). Measure head loss.
- Add 10% of the fibrous debris (expected total bed thickness 0.4 inches). Measure head loss.
- Add 20% of the fibrous debris. Measure head loss.
- Repeat above step twice more. Final expected bed thickness 1.0 inch.

The June-July 2010 tests used the following thin bed test methodology:

- Add particulate debris, 100% of the Marinite and 20% of the Silicon Carbide, and 20% of the fibrous debris (expected bed thickness 0.125 inch). Observe strainer coverage and measure head loss.
- Add 60% of the Silicon Carbide particulate and 20% of the fibrous debris (expected total bed thickness 0.25 inches). Observe strainer coverage and measure head loss.
- Add remaining 20% of the Silicon Carbide particulate debris (full screen coverage verified). Measure head loss.
- Add chemical precipitate surrogates. Measure head loss.

Calvert Cliffs thin bed testing included beds as thin as 1/16 inch up to a nominal full load of debris and included a wide range of simultaneous particulate loading. This ensures that the maximum head loss condition for the CCI strainers and for the Calvert Cliffs debris loads is identified. Maximum head loss occurs with maximum debris. No significant increase in head loss was seen in any thin-bed test. The Calvert Cliffs strainer exhibits no thin bed effect.

Response to Issue 3f7:

The acceptable maximum strainer head loss is dependent on the limiting strainer failure mode for Calvert Cliffs, deaeration. Incipient deaeration occurs at the downstream side of the debris bed when debris bed head loss exceeds strainer submergence. Strainer submergence is dependent on LOCA size and break location. Smaller LOCAs have less water injected because the Safety Injection Tanks do not inject and the break location for large break LOCAs smaller than a double-ended guillotine break of the RCS loops can retain more water inside the reactor coolant system. The maximum allowable head loss for three different strainer failure modes and three LOCA sizes is presented in Table 11

Table 11 Maximum Allowable Head Loss

Strainer Failure Mode	Break Size	Sump Water Temperature (°F)	Maximum Allowable Head Loss (feet)
Structural	All	$T_{sump} \leq 220$	23.40
$NPSH_a$ Reduction	All	$T_{sump} \leq 140$	28.79
		$140 < T_{sump} \leq 219$	2.42
Deaeration	DEGB of Hot Leg/Cold Leg or Equivalent Size Longitudinal Breaks	$120 \leq T_{sump} \leq 140$	2.21
		$140 < T_{sump} \leq 220$	2.09
	Other Break Sizes > 0.08 ft^2	$120 \leq T_{sump} \leq 140$	1.89
		$140 < T_{sump} < 220$	1.77
	Break Sizes ≤ 0.08 ft^2	$120 \leq T_{sump} \leq 140$	1.47
		$140 < T_{sump} \leq 220$	1.35

The acceptable head loss test is discussed in Section 2.2 of Attachment 1-3.

Response to Issue 3f8:

As described in response to Issue 1, the Calvert Cliffs debris generation and debris transport calculations include multiple levels of conservatism that maximize debris on the strainer. During head loss testing,

only fiber fines were used to conservatively bound head loss as it was observed that small pieces of fiber reduced debris bed head loss (Test 1). In reality, should there be large quantities of LOCA-generated debris then small pieces discharged in the vicinity of the strainer might transport to the screen, and act to form the irregular debris bed that was shown during head loss testing to have a lower maximum head loss than a pure fiber fine debris bed. Also, fiber fines produced by erosion are assumed to arrive at the strainer at time t = 0, instead of hours or days later when flow margin is greater. Fiber fines created by erosion will arrive at the strainer over a period of hours or even days.

Another key conservatism is the assumption that all fines transport to the sump strainer. Strainer head loss testing conducted at approach flow velocities representative of the Calvert Cliffs sump pool recirculation flow rates demonstrated that the majority of the fines settled rather than transported to the sump screen even when the debris was deposited only a few feet from the test screen. The fact that the strainer flow rate is so small that fines tend to settle, even at the inlet to the strainer, indicates a conservative overall design. Only by use of artificial agitation of the test pool water were fines made to transport to the strainer test screen. By use of this artificial pool agitation fine debris was made to transport into the pockets of the test strainer, and once these filled to collect on the face of the test strainer.

Head loss test procedures were designed to ensure uniform debris distribution on the strainer to maximize debris bed head loss; however, the design and physical layout of the Calvert Cliffs strainer promotes non-uniform debris distribution which is conducive to lower head loss.

Debris materials that had been demonstrated to reduce strainer head loss, such as lead shielding blanket and metal reflective insulation, were excluded from strainer head loss testing in order to maximize strainer head loss. Though it is unlikely that lead shielding blanket and metal reflective insulation debris will transport to the strainer in measurable quantities, it is possible that random pieces of this debris might be at the strainer where it could disrupt the formation of a high-head-loss uniform fiber/particulate debris bed. Also, metal reflective insulation debris is excluded from testing to prevent capture of finer debris before it reaches the strainer; however, in actuality metal reflective insulation in the sump pool would likely capture some of the fine debris before it reaches the strainer.

The chemical precipitates used in the strainer head loss testing was prepared and introduced in accordance with WCAP-16530 that includes multiple levels of conservatism. The full 30 day chemical precipitate load was assumed to arrive at the strainer at the earliest possible time with no credit for settling or nucleation on containment surfaces. Also, the quantity of precipitate arriving at the strainer is expected to be significantly lower than tested amounts. In addition, the precipitate is expected to arrive or form in the debris bed gradually and the resultant head loss would be lower and compensated by increased head loss margins as the recirculation flow rate is reduced.

Response to Issue 3f9:

The clean strainer head loss across the filtration surface of the prototypical strainer module as measured in CCI's Large Scale Test Loop Facility was approximately zero. This head loss was confirmed in the demonstration testing performed in the MFTL.

The head loss in the axial flow channel between cartridge modules and in the radial duct is computed using formulas in Reference (14). Flow formulas applicable to turbulent flow are used because the flow velocity in the strainer internals is well within the turbulent range.
Influx flow from the side (i.e., through the cartridges) into the axial flow channel is considered. The friction drag coefficient is developed from the well-known Moody friction curves. A friction factor of 0.025 is used which is conservative for high Reynolds numbers. A relative roughness of 0.001 is used for the smooth stainless steel.
Head loss due to flow obstructions (i.e., seven stabilizer plates within the strainer assembly) and enlargements in the flow stream are considered using equations from Reference (14). The computed analytical head loss for the strainer interior for the design flow rate is approximately 0.288' WC (8.6 millibar).
Additional information on clean strainer head loss was provided in response to RAI 16 [Reference (20)].

Response to Issue 3f10:

The overall strainer head loss consists of a clean strainer head loss (i.e., head loss due to flow through the strainer internals), a head loss due to conventional debris (e.g., fiber and particulate), and a head loss due to chemical precipitates.
The bounding clean strainer head loss (CSHL) of 0.288 ft was used for all breaks (see response to Issue 3f9). Similarly, a bounding conventional debris (fiber and particulate) head loss of 0.08 ft was used for all breaks. Chemical debris (sodium aluminum silicate, SAS) head loss was determined via a lookup table based on the amount of fiber fines, particulate, and chemical debris for each break as shown in Table 12 below. A value of 0 ft of chemical head loss was assigned for debris loads that do not contain any precipitates.

Table 12: Head Loss Due to Chemical Effects

SAS (lbm)	Fiber Fines (lbm)	Particulate (ft^3)	Chemical Head Loss (ft)
0	2,500	15.0	0
47.9	403	11.18	0.05
47.9	695	9.076	0.842
54.1	734	8.877	0.942
54.1	826	11.38	1.74
59.7	1,058.6	11.38	4.61

Response to Issue 3f11:

The emergency sump strainer is fully submerged under all accident scenarios that include recirculation. There is no vent above the water level. For additional information refer to the response to Issue 3f2.

Response to Issue 3f12:

The head loss testing with chemical effects did not credit near-field debris settling. Settling distant from the test strainer was prevented by careful debris addition and agitation in the test loop. All debris added to the test reached the strainer. However, not all debris entered the strainer pockets. The large quantity of fibrous debris exceeded the volume of the strainer pockets. Hence, most of the fibrous debris attached to the front of the strainer. Some debris attached or 'settled' to the lower face of the strainer. See Figure 16 below. A relatively uniform debris mass protrudes from the entrance to the strainer pockets. The lower portion of that mass forms a ramp of debris supported by the test flume floor immediately at the base of the test strainer. The portion that is partially supported by the flume

floor is generally about 10% of the total. The balance is in the pockets or attached to the face of the strainer (about 85%), or has settled on top of the strainer test module (about 5% of the total).

Figure 16: Typical Debris Bed from Testing at CCI

Agitation was used to ensure transport of all forms of debris to the entrance of the strainer. Because of the extensive artificial agitation used to effect debris transport to the strainer during head loss testing the actual amount which might transport during an accident is bounded by that in the head loss testing.

In addition, the artificial agitation in the test facility was conducted with great care to prevent debris bed disturbances. Photographic and video records show that the test debris beds remain undisturbed during agitation.

Response to Issue 3f13:

No scaling via temperature dependent dynamic viscosity was used.

Response to Issue 3f14:

Containment accident pressure is not credited in evaluating whether flashing occurs across the strainer surface. One of the three acceptable head loss criteria was that the overall strainer head loss did not exceed the strainer submergence.

NRC Issue 3g:

Net Positive Suction Head (NPSH)

The objective of the NPSH section is to calculate the NPSH margin for the ECCS and CSS pumps that would exist during a loss-of-coolant accident (LOCA) considering a spectrum of break sizes.

1. *Provide applicable pump flow rates, the total recirculation sump flow rate, sump temperature(s), and minimum containment water level.*
2. *Describe the assumptions used in the calculations for the above parameters and the sources/bases of the assumptions.*
3. *Provide the basis for the required NPSH values, e.g., three percent head drop or other criterion.*
4. *Describe how friction and other flow losses are accounted for.*
5. *Describe the system response scenarios for LBLOCA and SBLOCAs.*
6. *Describe the operational status for each ECCS and CSS pump before and after the initiation of recirculation.*
7. *Describe the single failure assumptions relevant to pump operation and sump performance.*
8. *Describe how the containment sump water level is determined.*
9. *Provide assumptions that are included in the analysis to ensure a minimum (conservative) water level is used in determining NPSH margin.*
10. *Describe whether and how the following volumes have been accounted for in pool level calculations: empty spray pipe, water droplets, condensation and holdup on horizontal and vertical surfaces. If any are not accounted for, explain why.*
11. *Provide assumptions (and their bases) as to what equipment will displace water resulting in higher pool level.*
12. *Provide assumptions (and their bases) as to what water sources provide pool volume and how much volume is from each source.*
13. *If credit is taken for containment accident pressure in determining available NPSH, provide description of the calculation of containment accident pressure used in determining the available NPSH.*
14. *Provide assumptions made which minimize the containment accident pressure and maximize the sump water temperature.*

15. *Specify whether the containment accident pressure is set at the vapor pressure corresponding to the sump liquid temperature.*
16. *Provide the NPSH margin results for pumps taking suction from the sump in recirculation mode.*

Response to Issue 3g1:

A single Containment Emergency Sump supplies inventory to both trains of the Safety Injection and Containment Spray systems. During sump recirculation operation each train consists of a HPSI pump and a Containment Spray pump.

Maximum HPSI pump flow rate = 1055 gpm (two pumps operating)
Maximum CS pump flow rate = 3450 gpm (two pumps operating)
Maximum Total Strainer Flowrate = 1055 gpm + 3450 gpm = 4505 gpm
Strainer design flow = 5000 gpm

The condition of a LPSI pump failure to stop at recirculation actuation signal (RAS) may result in a LPSI pump operating post-RAS. Procedure changes are being implemented to assure that post-RAS LPSI flow is throttled to 600 gpm indicated, which could be as high as 800 gpm maximum, and that one HPSI pump is secured if two HPSI pumps are operating. The flow from the HPSI pump would be throttled per procedure to 600 gpm indicated which ensures decay heat removal requirements are met. Maximum HPSI flow is taken as 645 gpm; therefore, for the Failure of a LPSI Pump to Stop scenario the Maximum Total Strainer Flowrate is:

Maximum Total Strainer Flowrate = 645 gpm + 3450 gpm + 800 = 4895 gpm
This flow is still less than the Strainer design flow of 5000 gpm.

The maximum post-RAS sump temperature is less than 212°F. The following post-RAS sump temperature values are from the current containment response calculation:

= 205.0°F for cold leg break LBLOCA with two safety trains operating
= 193.2°F for cold leg break LBLOCA with one safety train operating
= 198.3°F for hot leg break LBLOCA with two safety train operating
= 201.2°F for hot leg break LBLOCA with one safety train operating

Should the post-RAS sump water temperature exceed 212°F, the containment pressure would be assumed to be the saturation pressure at that the sump pool temperature. This is a reasonable approach which does not credit containment accident pressure in the NPSH available computation. This approach is similar to that found in Reference (16), Section 1.3.1.1.
The minimum sump pool water levels for the various break sizes are provided under Item 3g8.

Response to Issue 3g2:

The assumptions used for the above analysis are:

- HPSI flow rate is throttled as directed by procedure to ensure decay heat removal and NPSH requirements are met.
- CS flow rate is that predicted by a hydraulic flow model where the containment spray flow rate is upgraded 10% above the vendor pump curve which bounds the tested performance of the pumps to ensure the assumed containment spray performance bounds actual performance as determined by surveillance testing.
- The diesel generator is assumed to be at 2% over-frequency which bounds the performance of the emergency diesel generator to increase NPSH requirements.

Response to Issue 3g3:

The NPSH required values are provided on the vendor pump curve as a function of flow rate.

The original test data for the CS pumps was used to determine the NPSH required. The CS pump was tested at decreasing NPSH available values at a given flow rate. The last data point taken during testing was that NPSH available value where a decrease in total developed head was observed. The NPSH required value was then established as the second to last tested NPSH available value (i.e., the lowest one for which no decrease in total developed head was detected).

Similar data for Calvert Cliffs HPSI pumps could not be recovered from plant history records. However, correspondence with the HPSI pump vendor (Sulzer) regarding testing they did for another client having an identical pump indicates that the NPSH required values on the pump curve are based on a 3% degradation in the pump total developed head. The 3% degradation point is a pump industry standard for reporting NPSH required.

Response to Issue 3g4:

As described in the response to Issue 3f4, hydraulic friction losses across the strainer debris bed are determined by head loss testing. As described in the response to Issue 3f9, hydraulic friction losses in the strainer flow channels are computed analytically. Hydraulic friction flow losses in the ECCS recirculation pump suction piping are computed using a hydraulic model of the ECCS piping. The NPSH available to the HPSI and Containment Spray pumps is obtained by subtracting these hydraulic friction losses from the static head differential between the containment water height and the pump suction elevation.

Response to Issue 3g5:

The ECCS consists of three HPSI pumps, two LPSI pumps, and four safety injection tanks (SITs). After a Safety Injection Actuation Signal (SIAS) is received (generated by either a low pressurizer pressure (≤1725 psia) or a high containment pressure signal (≥4.75 psig)) a start signal is given to two HPSI pumps and both LPSI pumps. Each HPSI pump has its own injection header (Main and Auxiliary) which branches into four separate lines. The four branch lines from each header join prior to injecting into each of the four Cold legs. The LPSI pumps inject into a low-pressure injection header that joins the HPSI combined HPSI header prior to injecting into each of the four cold legs. Each SIT injects into a single cold leg. The SITs automatically discharge when the RCS pressure decreases below the SIT pressure.

LBLOCA

Two HPSI and both LPSI pumps are automatically given a start signal when the pressurizer pressure is ≤1725 psia, or containment pressure is ≥4.75 psig. The third HPSI pump could be manually started if one of the other two HPSI pumps did not start. Actual HPSI pump flow to the core will not begin until the pressurizer pressure is approximately 1280 psia, and actual LPSI pump flow to the core will not begin until the pressurizer pressure is approximately 185 psia.

The Containment Spray pumps automatically start on safety injection actuation signal setpoint, low pressurizer pressure. Afterward, flow to the containment environment is delayed only by the time required to fill the empty Containment Spray headers as soon as the spray control valve begins to open at a containment pressure of 4.75 psig. Containment Air Coolers will also start at a containment pressure of 4.75 psig with their associated delay for heat removal from Containment.

The SITs automatically discharge to the RCS when the RCS pressure drops to about 200 – 250 psig.

Initially, the Safety Injection Containment Spray pumps take suction from the RWT. When the RWT level reaches the low-low level signal setpoint level, a RAS is generated, and HPSI and Containment Spray pumps suction switches from the RWT to the containment emergency sump. The LPSI pumps are automatically stopped when the RAS is generated.

The HPSI flow is throttled post-RAS to a constant value. Additional throttling of the HPSI flow rate may be implemented to match the decreasing rate of heat addition to the RCS by the decay heat. Containment Spray flow continues until the containment pressure decreases to 4.0 psig or less at which point one Containment Spray pump is turned off.

SBLOCA

The same automatic actuations exist for a SBLOCA. However, for a SBLOCA where the pressurizer pressure remains high for an extended period of time, the Operators may take actions to secure the LPSI pumps to avoid running on mini-flow recirculation for an extended period of time. Also, for SBLOCAs the SITs may be isolated prior to these tanks injecting into the RCS.

Response to Issue 3g6:

The following table describes the operational status of the ECCS and CS pumps before and after the start of recirculation.

Pump	Injection Phase	Recirculation Phase
HPSI (maximum 2 of 3)	On	On/Throttled
LPSI	On	Off
CS	On	On

Response to Issue 3g7:

Three design basis cases are used to establish the design limits for pump operation and sump performance. Both a hot leg break and a cold leg break are analyzed assuming the failure of a diesel generator (and therefore, the failure of a safety train) as the limiting single failure and also assuming the failure of a train of the Service Water System which removes a train of Containment Air Coolers from service resulting in reduced containment cooling .

One additional single failure case was evaluated (failure of one LPSI pump to turn off upon initiation of recirculation). This single failure would cause additional flow through the strainer, the accumulating debris bed, and the suction piping from the strainer to the pumps. As described in response to Issue 3g1, procedure changes are being implemented to assure the LPSI pumps are either secured prior to RAS, or LPSI flow is throttled to 600 gpm indicated, which could be as high as 800 gpm, and a HPSI pump secured (if two operating).

Response to Issue 3g8:

The water level above the containment floor is defined as a function of pool volume. To determine the pool volume, the mass of water in the sump pool is divided by the density of water at the sump pool temperature. The mass of water in the sump pool is determined by summing all the sources that contribute to the pool inventory, and subtracting the mass of water in the hold-up volumes.
There are three sources of water that contribute to the containment sump pool inventory: RWT, SITs, and RCS.

1) The total quantity of water delivered from the RWT is the difference between the initial and final tank levels. The initial level is based on the minimum Tech Spec required RWT level, and the final level is based on the maximum RWT level at which a Recirculation Actuation Signal (RAS) occurs.
2) There are four SITs that provide rapid cooling, and the mass contributed is the sum of all four SIT's. SIT inventory is not credited for break sizes ≤ 0.08 ft^2.
3) The contribution of RCS inventory into the sump pool depends on break size and elevation. To conservatively implement the RCS contribution to the sump pool inventory, only for Hot or Cold leg breaks (Break Size ≥ 30") at or above an elevation of 38'-3" was the sump pool inventory credited with receiving a portion of the RCS inventory.

   Sump pool inventory is reduced to account for water used to fill the containment spray and other piping, water used to fill containment sump trench, water beading on surfaces, condensation, and moisture in the containment atmosphere.

Note: No chemical control fluid storage volumes are credited because the charging pumps are not safety-related.
The sump pool inventory is reduced by considering the following hold-up volumes:

1) RCS Inventory held up as steam
2) Water volume lost by spray flow that beads on horizontal surfaces
3) Water condensing on surfaces inside containment
4) Water sequestered in the refueling pool transfer tube and upper guide structure compartments
5) Water sequestered in the Reactor Cavity Compartment.
6) Water in the Cavity Cooling Ventilation System
7) Piping and sump trench volumes
8) Water required to fill the sloped section of the containment floor between elevation 9'-9" and elevation 10'-0"

Water level values based on break size and elevation are presented in Table 13 below. The modeled water level is from a rule-based lookup table based on pool volume. Since there are only a few discreet values in the lookup table, relatively large changes in pool volume are needed to change water level.

Table 13: NARWHAL Water Level Heights

Case	Break Size (inches)	Break Elevation (ft)	Water Volume (gal)	Water Height
1 – RWT Inventory Only	<3	>37.4	333,425	4′-4.35″
2 – RWT Inventory Only	<3	≤37.4	343,091	4′ -4.35″
3 – RWT and SIT Inventory	≥3 to <30	>37.4	365,198	4′ -4.35″
4 – RWT and SIT Inventory	≥3 to <30	≤37.4	376,419	4′ -9.32″
5 – RWT, SIT, RCS Inventory	≥30	>37.4	391,057	4′-9.32″
6 – RWT, SIT, RCS Inventory	≥30	≤37.4	402,278	5′ -1.15″

Response to Issue 3g9:

The conservatism of the minimum containment water level is maintained by minimizing the sources of water and by maximizing the volume of water entrapment. Some of the specific examples of water sources that are minimized are given below:

- Minimum RWT inventory
    - minimum initial RWT volume allowed by Technical Specifications
    - RAS occurs at earliest point in setpoint band
    - no water transfer from RWT post-RAS even though it is the preferred source for an additional minute due to valve operation times
- RCS inventory assumed to remain in RCS except for double-ended guillotine breaks of Hot Leg or Cold Leg and Equivalent Size Longitudinal Breaks in the RCS.
- The sump piping assumed empty up to sump valves.

Response to Issue 3g10:

Assumptions are made to conservatively maximize the amount of water in the atmosphere (i.e., minimize the containment sump water level). These are:

- The maximum containment free volume is used.
- The initial humidity in containment is 0%.
- Post accident, the containment atmosphere is assumed to be fully saturated (i.e., 100% humidity).
- Bounding temperatures are used.
    - Warmer air can “hold” more moisture.
    - Maximum post-RAS temperature (approximately 200°F) used for all temperatures

The containment spray pipe and other selected pipes are assumed to be empty for the water level calculation.

The hold up of water on horizontal surfaces was investigated and it was found that a 1/16" film would account for approximately 450 gallons. This value was doubled to account for the fact that water might bead on a horizontal surface below the initial surface it beaded on for a total held-up volume of approximately 900 gallons.

The outer wall of Containment is not close enough to the spray nozzles for the containment spray to effectively reach them. The surface areas of the other vertical surfaces that could be sprayed are not sufficient to affect the water level calculation.

Condensation of water vapor released from the RCS and subsequently condensed onto surfaces is estimated to hold-up approximately 1,370 gallons.

The water volume equivalent to the mass of water in the atmosphere is calculated by multiplying the containment free volume by the ratio of the specific volume of saturated liquid to the specific volume of saturated vapor at the temperature of interest. Spray droplets in motion from the spray nozzles to any intersecting surface were not specifically considered in the minimum pool depth analysis. Moisture contained in the containment atmosphere is estimated to be approximately 7,500 gallons.

Calvert Cliffs implemented a modification to increase the size of the line from each refueling cavity drain line to general area of containment from 1" to 8". Increasing this line to 8" eliminates potential water sequestration in the refueling cavities, raises the post-LOCA sump water level, and provides additional margin for ECCS and CSS pump net positive suction head (NPSH) and strainer deaeration. A trash rack strainer is installed over the drain entrance to prevent large debris from clogging the drain. This trash rack is approximately 3½ ft long, 1½ ft wide, and 2½ ft high. The trash rack has approximately 420 equally spaced square openings measuring 2-1/8" on each side.

Response to Issue 3g11:

In the sump water level calculation, the volume occupied by concrete pillars is considered in the displacement of water. Additionally, some miscellaneous structures and components in the sump pool are assumed to displace water.

Response to Issue 3g12:

The following water sources are considered as contributors to the containment post-accident pool volume:

- RCS - An RCS inventory of 3,456.77 ft^3 is credited for Double-Ended Guillotine Breaks of RCS Hot Legs and Cold Legs and equivalent size longitudinal breaks. No RCS inventory is credited for any other RCS break.
- RWT – It is assumed that the RWT provides 49,945.16 ft^3 of water that empties to the lower level of Containment. This assumes the RWT is at the minimum water level allowed by the low-level alarm setpoint (including uncertainty) at the start of the accident. It also assumes that RAS occurs at the highest value in the setpoint band, and furthermore that no water transfers from the RWT after a RAS is reached even though the RWT will be discharging inventory to the RCS for over a minute after that time.
- Safety Injection Tanks – For LOCAs greater than 0.08 ft^2 in size it is assumed that the inventory from four SITs inject into the RCS. The minimum volume of 1113 ft^3 per SIT (Technical Specification 3.5.1) is assumed to inject into the core. Since only passive components separate the SITs from the RCS at the start of an accident the inventory from all four SITs is assumed to empty to the RCS.

Response to Issue 3g13:

Credit is not taken for containment accident pressure in determining the available NPSH.

Response to Issue 3g14:

Containment pressurization is not credited in our pump NPSH calculations. All LOCA cases have sump water temperature above 212°F at some point but none of them have sump water temperature above 212°F at the start of or after recirculation.

The sump pool temperature calculation assumes a single failure of one emergency diesel generator resulting in a loss of one ECCS train (including HPSI and CS pumps and containment air cooler), or the loss of one containment air cooler train and loss of one decay heat removal heat exchanger. There is no sump cooling since heat transfer to the containment basemat is not credited in the analysis. The sump pool temperature analysis also neglects any cooling from the sump pool by means of evaporation. Finally, a containment pressure of 14.7 psia (as compared to 16.5 psia) is assumed along with 100% humidity. All of these factors result in a conservatively high prediction of sump pool temperature.

Response to Issue 3g15:

The containment accident pressure is set at the vapor pressure corresponding to the sump liquid temperature for sump liquid temperatures greater than 212°F. For the NPSH calculation atmospheric pressure is used as the containment pressure during a LOCA.

Response to Issue 3g16:

The maximum sump fluid temperature at which the NPSH margin analysis is performed is 212°F. At this temperature there is no sub-cooled margin, and NPSH available comes only from the static head of water. The NPSH margin is also considered at 140°F because this is the temperature at which chemical precipitates are assumed to form. However, a sub-cooled margin of 27.235 feet also exists at 140°F. The increased NPSH margin at 140°F due to the 27.235 feet of sub-cooled margin is much greater than the increased head loss due to the effect of chemical precipitates as presented in Table 10 under Issue 3f4 (maximum head loss for valid test is 3.20 ft). Therefore, for NPSH margin the limiting condition is at maximum sump pool temperatures as shown in Table 14 below.

Table 14: NPSH Margin at Limiting Sump Temperature of 212°F

Pump	Sump Temp	$NPSH_R$	$NPSH_A$	NPSH Margin
HPSI	212°F	19.5’	22.6’	3.1’
LPSI	212°F	12.5’	23.2’	10.7’
CS	212°F	24.0’	25.2’	1.2’

NRC Issue 3h:

Evaluation

The objective of the coatings evaluation section is to determine the plant-specific zone of influence and debris characteristics for coatings for use in determining the eventual contribution of coatings to overall head loss at the sump screen.

1. *Provide a summary of type(s) of coating systems used in Containment, e.g., Carboline CZ 11 Inorganic Zinc primer, Ameron 90 epoxy finish coat.*

2. *Describe and provide bases for assumptions made in post-LOCA paint debris transport analysis.*
3. *Discuss suction strainer head loss testing performed as it relates to both qualified and unqualified coatings and what surrogate material was used to simulate coatings debris.*
4. *Provide bases for the choice of surrogates.*
5. *Describe and provide bases for coatings debris generation assumptions. For example, describe how the quantity of paint debris was determined based on zone of influence size for qualified and unqualified coatings.*
6. *Describe what debris characteristics were assumed, i.e., chips, particulate, size distribution and provide bases for the assumptions.*
7. *Describe any ongoing containment coating condition assessment program.*

Response to Issue 3h1:

A Bechtel construction specification was used to specify the coatings used during plant construction. It identifies the original primers used in Containment as Dimetcote No. 6 (also known as D6) and Mobilzinc 7. The original topcoats were Amercoat 66 and Mobil 89 Series.

Coatings that have been used at Calvert Cliffs since construction are identified in internal plant documents. These documents identify the primer, topcoat, and application standard to be used on the various surfaces inside Containment. A primer of Ameron D6 and a topcoat of Ameron 66 are the primary coatings referenced; however, Valspar 13F12 is used as a primer on some surfaces and Valspar 89 is used as the corresponding topcoat. Valspar 13F12 is the same as Mobilzinc 7 and Valspar 89 is the same as Mobil 89 Series.

The current service level 1 coatings allowed to be used in containment at Calvert Cliffs are Carboline Carboguard 890 metal primer, Carboline Starglaze 2011S concrete primer, and Carboline Carboguard 890 topcoat.

Also in containment are multiple coatings of unknown pedigree. Most of these coatings were applied to equipment and small components by the original equipment vendor. These unqualified coatings are tracked in a calculation.

Response to Issue 3h2:

All coatings in the zone of influence, and all coatings of unknown pedigree (i.e., no proof it was ever qualified) are assumed to fail as 10 µm particles and transport to the strainer. Degraded qualified inorganic zinc (IOZ) coatings are also assumed to fail as 10 µm particles and transport to the strainer.

As discussed in Response to Issue 3c4 , for epoxy coatings that were installed as qualified, but subsequently found to be degraded per site inspection procedures, fail as chips (Note: NARWHAL analysis conservatively assumes these epoxy coatings also fail as particulate). During head loss testing these chips were shown not to be drawn to the debris bed even when dropped in front of the strainer, and normal test loop agitation was in process. This confirmed the Reference (17) study which demonstrated that paint chips will not transport in sump pool velocities less than 0.2 ft/sec.

Degraded qualified coatings systems used at Calvert Cliffs are of a comparable nuclear grade to those tested by Keeler and Long. Calvert Cliffs verified that the coatings applied were of a nuclear grade

comparable to those in the K&L report [Reference (7)]. However, the inorganic zinc primers will fail as particulates and the epoxy top coats will fail as chips (greater than 1/32").

Additional testing was performed to investigate the transportability of coatings chips. The test of transportability of coatings chips used coating chips size distribution of 1-4 mm. Results of transport test for these coating chips are provided in Figure 17 below. These results show that at high flow rates, 8 times nominal, average transport is well under 1 meter (40 inches) from the introduction point for settlement equal to the entire depth of the containment pool. The test flow rates were much greater than expected in the plant post-LOCA. Transport distances are negligible for the size of the Containment at Calvert Cliffs.

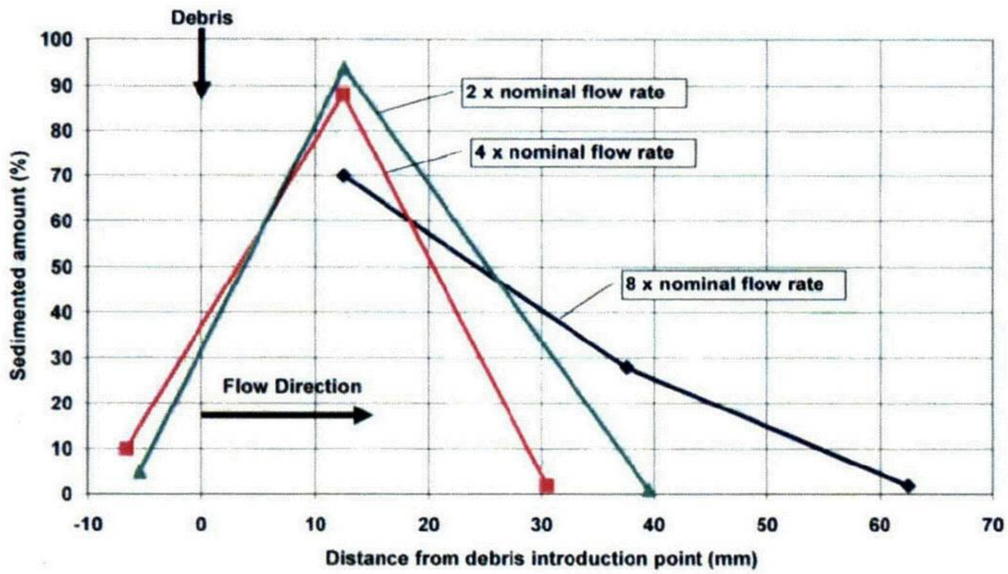


Figure 17: Coating Transport Test Results

Response to Issue 3h3:

The head loss testing used scaled quantities of coatings as part of the strainer debris load. Silicon carbide was used as a surrogate material for coatings that were assumed to fail as 10 µm particles.

Response to Issue 3h4:

For head loss testing silicon carbide was used as a surrogate material for failed coating particulate. Coatings that fail as particulate are assumed to fail as 10 µm particles. [IZ3]The silicon carbide surrogate particles have a median diameter of 9.3 ± 1 µm. [IZ4]An equivalent volume of silicon carbide surrogate was used in head loss testing. Since the silicon carbide surrogate has a smaller particle size in order to obtain an equivalent volume a larger number of particles were used. Since it is the effect of individual particulate filling interstitial voids in the fiber bed that increases flow resistance and head loss the use of a larger number of particles is conservative.

Response to Issue 3h5:

Calvert Cliffs has followed the guidance from Reference (1) for determining the quantity of coating debris. Per Reference (1), Section 3.4.2.1:

- All coating (qualified and unqualified) in the zone of influence will fail,
- All qualified (design basis accident-qualified or acceptable) coating outside the zone of influence will remain intact,
- 100% of the unqualified coatings outside the zone of influence will fail. Degraded-qualified inorganic zinc coatings will fail as particulate, Degraded-qualified epoxy coatings will fail as chips (Note: NARWHAL analysis conservatively assumed epoxy coatings also failed as particulate). Never-qualified coatings will fail as particulate.

A zone of influence of 4.0 L/D was used for epoxy-based coatings, and a zone of influence of 10.0 L/D was used for un-topcoated inorganic zinc primer. All unqualified coatings (including degraded qualified coatings) were assumed to fail, as noted above.

The volume of coatings debris was determined by multiplying the surface area of affected coating by a measured or conservatively assumed dry film thickness (DFT). The DFT of degraded-qualified coatings was assumed to be 12 mils. This is the maximum thickness permitted for Service Level 1 coatings on steel substrate [Reference (7)]. All degraded-qualified coatings are conservatively assumed to consist of an epoxy topcoat and IOZ primer. The IOZ primer is assumed to be 4 mils while the epoxy topcoat is assumed to be 8 mils. 4 mils was the maximum thickness of qualified IOZ coatings inside containment.

The DFT of never-qualified coatings is variable and from the containment assessments done during the 2003 and 2004 refueling outages. The purposes of these surveys was to locate, identify, and determine the extent of never-qualified coatings within containment. The coating thicknesses were obtained using a digital coating thickness gauge. The majority of these items have a DFT of 1 to 3 mils. All coated surfaces that were unable to be surveyed or marked as “no rdg” in the containment assessment are conservatively assumed to have a DFT of 12 mils, which bounds all DFTs identified during the assessments. It is further noted that a 15% margin was applied to Unit 1 never-qualified coating quantities and 20% margin was applied to Unit 2 never-qualified coating quantities for additional margin.

Response to Issue 3h6:

See the Response to Issue 3h2 above.

Response to Issue 3h7:

Calvert Cliffs conducts condition assessments of Service Level I coatings inside the Containment once each refueling cycle at a minimum. Generally, all of the accessible areas within the Containment are visually inspected. As localized areas of degraded coatings are identified, those areas are evaluated and scheduled for repair or replacement, as necessary. The periodic condition assessments, and the resulting repair/replacement activities, assure that the amount of Service Level I coatings that may be susceptible to detachment from the substrate during a LOCA event is minimized and is identified and tracked by the plant coatings condition assessment program.

***NRC Issue 3i*:**

Debris Source Term

The objective of the debris source term section is to identify any significant design and operational measures taken to control or reduce the plant debris source term to prevent potential adverse effects on the ECCS and CSS recirculation functions.

1. *Provide the information requested in GL 04-02 Requested Information Item 2(f) regarding programmatic controls taken to limit debris sources in Containment.*

GL 2004-02 Requested Information Item 2(f)

A description of the existing or planned programmatic controls that will ensure that potential sources of debris introduced into Containment (e.g., insulations, signs, coatings, and foreign materials) will be assessed for potential adverse effects on the ECCS and CSS recirculation functions. Addressees may reference their responses to GL 98-04, "A Potential for Degradation of the Emergency Core Cooling System and the Containment Spray System after a Loss-of- Coolant Accident Because of Construction and Protective Coating Deficiencies and Foreign Material in Containment," to the extent that their responses address these specific foreign material control issues. In responding to GL 2004 Requested Information Item 2(f), provide the following:

2. *A summary of the containment housekeeping programmatic controls in place to control or reduce the latent debris burden. Specifically for RMI/low-fiber plants, provide a description of programmatic controls to maintain the latent debris fiber source term into the future to ensure assumptions and conclusions regarding inability to form a thin bed of fibrous debris remain valid.*
3. *A summary of the foreign material exclusion programmatic controls in place to control the introduction of foreign material into the Containment.*
4. *A description of how permanent plant changes inside Containment are programmatically controlled so as to not change the analytical assumptions and numerical inputs of the licensee analyses supporting the conclusion that the reactor plant remains in compliance with 10 CFR 50.46 and related regulatory requirements.*
5. *A description of how maintenance activities including associated temporary changes are assessed and managed in accordance with the Maintenance Rule, 10 CFR 50.65.*

If any of the following suggested design and operational refinements given in the guidance report (guidance report, Section 5) and SE (SE, Section 5.1) were used, summarize the application of the refinements.

6. *Recent or planned insulation change-outs in the Containment which will reduce the debris burden at the sump strainers*
7. *Any actions taken to modify existing insulation (e.g., jacketing or banding) to reduce the debris burden at the sump strainers*
8. *Modifications to equipment or systems conducted to reduce the debris burden at the sump strainers*
9. *Actions taken to modify or improve the containment coatings program*

Response to Issues 3i1:

Coatings installed inside containment are controlled per procedure which requires involvement of the coatings engineer who maintains the GSI-191 coatings calculations. This ensures only qualified coatings are installed by Maintenance. Maintenance refers to an Engineering Standard on acceptable insulation for use inside containment. Operations procedures ensure tags and signage to be installed in containment is non-floatable.

Several Calvert Cliffs' procedures and practices are in place to ensure containment cleanliness is maintained and that debris inside Containment is identified and minimized prior to power operations. Site procedures require that specific inspections be performed and documented for loose debris prior to containment closeout and an "intense" search be made of Containment prior to entering Mode 4 for sources of loose debris and corrective actions taken. Another procedure assigns specific ownership responsibilities for plant areas including Containment when accessible, and requires weekly cleanliness inspections and prompt actions to remediate.

Response to Issues 3i2:

As discussed in Item 3i1 Calvert Cliffs has implemented several containment housekeeping actions. Calvert Cliffs is not a low fiber plant, nor is the Calvert Cliffs strainer susceptible to the thin bed effect; therefore, no specific controls exist to maintain latent debris within analyzed limits. However, latent debris is maintained at a more or less constant value due to normal containment cleanliness initiatives.

Response to Issue 3i3:

An Exelon fleet procedure contains guidance specifically addressing foreign material exclusion (FME) concerns in areas like the Containment and the containment emergency sumps. It classifies the containment emergency sumps as a Special Foreign Materials Exclusion Area (FME Zone-1), and requires an FME project plan for any entry into the sumps. Foreign material exclusion project plans are prepared, reviewed, and approved. The requirements of this procedure are stringent with regard to standards but allow flexibility for adapting an FME project plan for any kind of maintenance evolution. This procedure also requires FME training for all personnel working in Containment.

An Engineering Standard is being prepared that will include guidance and restrictions on materials installed or left in containment. An Exelon fleet procedure contains requirements for verifying containment cleanliness through closeout inspections after containment entries.

Response to Issue 3i4:

The Design Attribute Review for the Common Design Process contains a list of topics for which plant changes must be screened against to ensure all potential impacts of the change are properly assessed. The list of topics specifically identifies the introduction of materials into containment that could affect sump performance. In addition, the introduction of aluminum into containment as well as coated systems in containment are other specific topics to be evaluated. This ensures that future plant changes are properly evaluated for impact on GSI-191 analyses.
Another site procedure controls the requirements for research on the part of maintenance planners for maintenance which could introduce new debris sources into Containment. The procedure has been revised to require that for any maintenance activity that will install any materials in either Unit 1 or Unit 2 Containments expected to remain there during Mode 4 or higher operations, engineering reviews the

installation details for impact on the containment emergency sump strainer analyses and must approve the usage of these new materials.

Response to Issue 3i5:

A Calvert Cliffs site procedure establishes requirements for effective implementation of the Maintenance Rule program at the site. It describes approved methods to monitor, trend, establish and modify goals for system, structures and components. Additional site procedures for integrated work management and integrated risk management provide specific guidance on risk assessment and scheduling of maintenance and temporary changes.

Response to Issue 3i6

Calvert Cliffs has undertaken a significant effort to reduce the fibrous insulation debris source term in the design basis LOCA break ZOI. Reducing the amount of fiber decreases strainer head loss and reduces the chemical effects source term. Starting during the 2012 RFO, multiple sections of insulated piping were re-insulated with RMI. The RMI used at Calvert Cliffs is constructed of stainless steel, and does not fail in a manner that contributes to strainer head loss.

Response to Issue 3i7:

For Units 1 and 2, calcium-silicate pipe insulation within 17 L/D of the RCS piping was banded on 2 3/4" centers. Calcium-silicate pipe insulation outside of 17 L/D was banded at 6" centers. Any calcium-silicate insulation within 3 L/D of the RCS piping was replaced on Units 1 and 2 with fiberglass insulation.

For margin improvement, two pipes in Unit 1 had insulation removed during the 2010 RFO. The pipes are the shutdown cooling line which was insulated with mineral wool insulation and the pressurizer relief valve line outside of the pressurizer compartment which was insulated with generic fiberglass insulation. The corresponding pipes in Unit 2 are uninsulated.

During the Unit 1 2012 RFO and the Unit 2 2013 RFO the telescoping aluminum ladder from the polar crane was removed to reduce the aluminum content in containment, significant amounts of mineral wool and fibrous insulation were replaced with stainless steel RMI to reduce the debris burden on the strainers.

Response to Issue 3i8:

Valve equipment tags are now made of materials that would sink in water and not transport to the containment emergency sump. In addition, the tags will not delaminate in a post-accident environment. Calvert Cliffs investigated re-coating the reactor coolant pump motors with qualified coatings to reduce the unqualified coating debris load (approximate surface area is 2000 ft^2 per Unit). The reactor coolant pump motor coating was verified to be qualified and no further action is required.

Response to Issue 3i9:

Calvert Cliffs has an existing coatings program that monitors and controls the quantities and types of coatings installed inside Containment. As noted in Reference (18), Calvert Cliffs has implemented controls for procurement, application, and maintenance of qualified coatings used inside Containment that are consistent with the licensing basis and regulatory requirements. This program conducts periodic condition assessments, typically each outage, to verify the adequacy of existing coatings and

direct repair/replacement, as necessary. The quantity of unqualified coatings that are added inside Containment is tracked. This program is adequate in its current form to ensure coatings are properly controlled, and that future installations of unqualified coatings are quantified.

***NRC Issue 3j*:**

Screen Modification Package

The objective of the screen modification package section is to provide a basic description of the sump screen modification.

1. *Provide a description of the major features of the sump screen design modification.*
2. *Provide a list of any modifications, such as reroute of piping and other components, relocation of supports, addition of whip restraints and missile shields, etc., necessitated by the sump strainer modifications.*

Response to Issue 3j1:

In Calvert Cliffs Units 1 and 2, a strainer of 6,060 ft^2 filtration surface area (nominal) has been installed. The strainer is CCI's cassette pocket strainer design. The hole size through the filtration surface is 1.6 mm (1/16") with no more than 3% larger holes and no holes larger than 2 mm (0.08"). There are 33 strainer modules divided among three strainer rows. These modules are approximately 3' high. There are 324 pockets in 29 of the strainer modules, and 252 pockets in four of the strainer modules. The pocket dimensions are 84 mm x 90 mm in cross-section, and 200 mm deep. The strainer rows tie into a common duct which directs the flow to the existing containment emergency sump, sometimes referred to as the sump pit. The containment emergency sump is a concrete curb with a steel roof, and contains the inlets to both recirculation headers. See Figure 18.

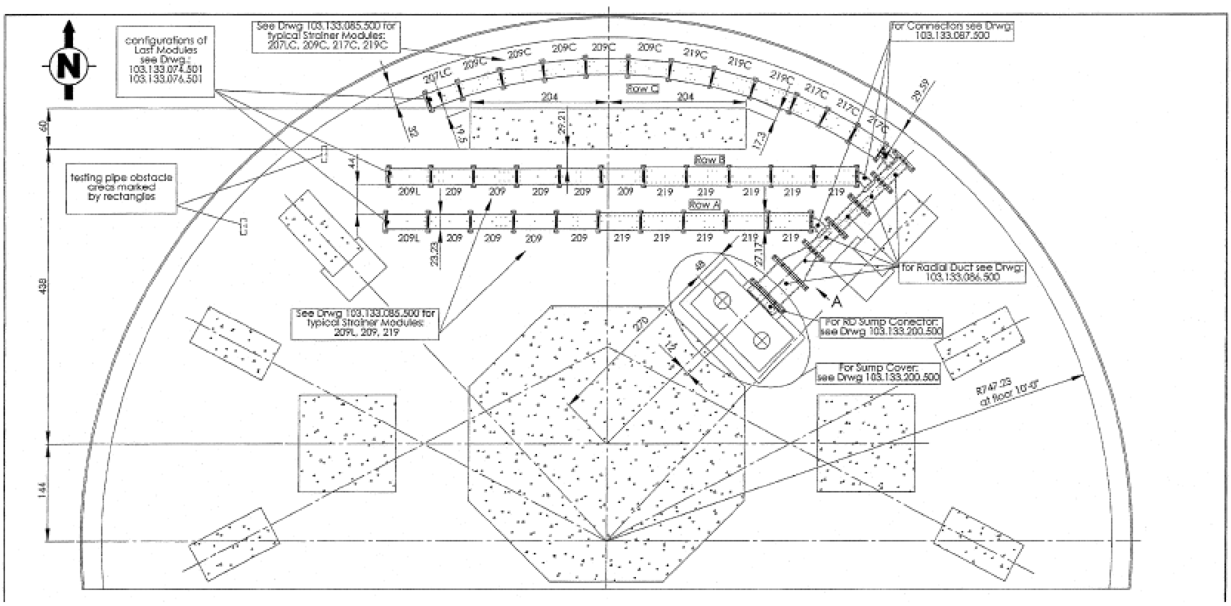


Figure 18: Strainer Arrangement

Response to Issue 3j2:

A 16" feedwater pipe support was modified on Unit 2 to allow clearance for one of the strainer rows. A cable tray support was also modified on Unit 2 to allow clearance for the radial duct. These modifications were not required on Unit 1. In addition, the 6" curb around the emergency recirculation sump was notched to allow for installation of the common duct to the sump.

***NRC Issue 3k*:**

Sump Structural Analysis

The objective of the sump structural analysis section is to verify the structural adequacy of the sump strainer including seismic loads and loads due to differential pressure, missiles, and jet forces. Provide the information requested in GL 2004-02, "Requested Information," Item 2(d)(vii), that is, provide verification that the strength of the trash racks is adequate to protect the debris screens from missiles and other large debris. The submittal should also provide verification that the trash racks and sump screens are capable of withstanding the loads imposed by expanding jets, missiles, the accumulation of debris, and pressure differentials caused by post-LOCA blockage under flow conditions.

1. *Summarize the design inputs, design codes, loads, and load combinations utilized for the sump strainer structural analysis.*
2. *Summarize the structural qualification results and design margins for the various components of the sump strainer structural assembly.*
3. *Summarize the evaluations performed for dynamic effects such as pipe whip, jet impingement, and missile impacts associated with high-energy line breaks (as applicable).*
4. *If a backflushing strategy is credited, provide a summary statement regarding the sump strainer structural analysis considering reverse flow.*

Response to Issue 3k1:

Classical and finite-element (ANSYS or ME035) methods were used to analyze the following parts of the strainer:

- Standard cartridges (cartridge depth 200 mm)
- Support structure and duct of a standard module
- Radial Duct
- Sump Cover
- Sump Back Plate

Note that the Response to Issue 3k2 below provides descriptions of these strainer parts.

The strainers and their supports were analyzed according to the rules of ASME Section III, 2004 Edition, 2005 Addenda, Subsection NF, "Supports" for Class 2 components [Reference (21)]. These rules were chosen to provide a recognized standard for structural analyses, however, the strainer components are non-ASME code items, Seismic Category 1.

The standard module analysis assumes an 18 cartridge design which envelopes the smaller 14 cartridge design.

Design Inputs

Total weight of modules (2 support structures, duct, cover plate, and cartridges)

18 Cartridge Module 941.73 lbm (427.16 kg)
14 Cartridge Module 802.68 lbm (364.09 kg)

Total debris mass transported to sump = 10,783 lbm (4,891 kg)
(Note: this is an enveloping value used for structural analyses only)

Based on conservative head loss testing conducted in 2008 completed with sodium tetraborate decahydrate (STB) buffer, the differential pressure determined by WCAP-16530-NP based tests was 10.15 psi (700 millibar) at 70°F (21°C). As described in Issue 3o2.10, Calvert Cliffs assumes that aluminum will precipitate out as sodium aluminum silicate and affect head loss at a temperature below 140°F.

Newer head loss tests conducted in 2010 as well as new chemical effects head loss methodology discussed in the response to Issue 3f4 determine the differential pressure due to chemical effects to be much less than 700 millibar. Nevertheless, the strainer is conservatively structurally qualified to a Differential Pressure of 700 millibar.

For both Units:
Operating Basis Earthquake
Maximum Horizontal Acceleration ≈ 1.96 g at ≈ 3 Hz
Maximum Vertical Acceleration ≈ 0.59 g at ≈ 10 Hz

Safe-Shutdown Earthquake
Maximum Horizontal Acceleration ≈ 2.75 g at ≈ 3 Hz
Maximum Vertical Acceleration ≈ 1.11 g at ≈ 10 Hz

Additional load from shielding blankets = 885.91 lbf (3940.76 N)

Summary of Design Load Combinations

The load combinations are summarized in Table 15 below. It was determined in the strainer structural analysis that load combinations 1, 7, and 8 enveloped the other load combinations. Therefore, only load combinations 1, 7, and 8 were analyzed.

Table 15: Load Combinations Used in Emergency Sump Strainer Verification

#	Load Combination Type	Temperature (°F)	Temperature (°C)
1	W(pool dry)	280	137.8
2	W+OBE(pool dry)	280	137.8
3	W+SSE(pool dry)	280	137.8
4	W+OBE(pool filled)	280	137.8
5	W+SSE(pool filled)	280	137.8
6	W+WD+OBE(pool filled)+ΔPD	70(220)	21(104.4)
7	W+WD+SSE(pool filled)+ΔPD	70(220)	21(104.4)
8	W+AddL	70	21

Variables:

W	weight of strainers & supporting structures
WD	weight of debris
ΔPD	pressure differential
OBE	operating basis earthquake
SSE	safe-shutdown earthquake
AddL	additional load caused by radiation shielding blankets

For the OBE and SSE cases, a sloshing load also was computed to account for the impact of water sloshing in the sump pool.

<u>Response to Issue 3k2</u>:

The emergency recirculation sump strainer structure consists of two separate structures: the floor structures, and the sump pit structures.
The floor structures consist of the strainer modules themselves which provide the filtration surface area, and a radial duct which channels the flow from the three rows of strainer modules to the sump pit. The radial duct consists of six segments each approximately 4' long. There are 29 strainer modules that are approximately 5' long, and four strainer modules that are approximately 4' long. Each of these strainer modules/radial duct segments are anchored to the concrete floor via an anchor plate at each end. There are four anchor bolts (½" Hilti bolts at 3½" minimum embedment torqued to 40 ft-lbs) on each anchor plate. A retaining structure is mounted on top of each anchor plate. This retaining structure provides the mounting frame for the radial duct segments and the interior duct of the strainer modules. The various connections are made using M8, M12, M16, and M20 bolting hardware. The retaining structures are attached to the anchor plates using two M30 bolts. The strainer cassettes (filter surface) attach to the strainer interior duct, and are covered with a deck plate.

The sump pit structure consists of cover plates which cover the sump pit and support beams fixed on and about a concrete curb and additionally supported by short columns that bear directly on the sump floor. Two pairs of mounting brackets are anchored to the concrete curb using four anchor bolts (½" Hilti bolts at 3½" minimum embedment torqued to 40 ft-lbs) on each bracket.

Brackets are used to locate the two side beams. A pair of posts support each side beam and are anchored in a similar fashion as above. Three posts, one at each end and one in the center support the middle beam.

The beams noted above are 140 mm x 140 mm I-beam and are fastened to these mounting brackets/mounting posts.

Ratios of design stress and corresponding allowable stress for various components of the emergency recirculation sump strainer structural assembly are given below. The figures illustrate the component analyzed.

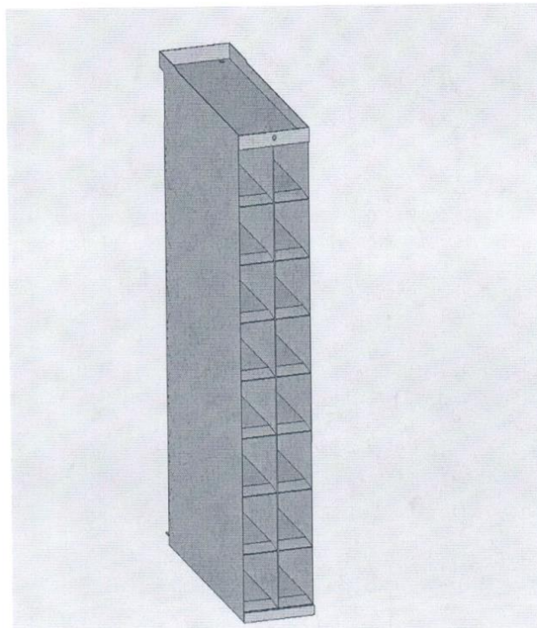


Figure 19: Cartridges

Table 16: Cartridges

Ratio	Allowable MPa (Level C)	Calculated MPa	Stress Location and Type
1.337	306.9	410.6 0.8%	Sidewall global + local bending stress Strain intensity for collapse load evaluations
0.116	122.8	14.3	Sidewall connection to coverplate shear stress
0.015	204.6	3.12	Sidewall connection to coverplate tension
0.609	252.8	154.0	Upper cover plate bearing stress
0.557	122.8	68.4	Upper cover plate shear stress
0.429	306.9	131.6	Upper cover plate bending stress
0.609	252.8	154.0	Lower cover plate bearing stress
1.56	306.9	479.7 1.6%	Cartridge pocket bending stress Strain intensity for collapse load evaluations
0.035	204.6	7.2	Cartridge pocket tension stress
0.033	122.8	4.07	Cartridge pocket support clip shear stress

Figure 20: Standard Strainer Module

Table 17

Standard Module Support Structure

Ratio	Allowable MPa	Calculated MPa	Stress Location and Type
0.556	115.1	64	Maximum principle stress intensity – Load 1 (Level A)
0.759	259	196.6	Maximum principle stress intensity – Load 7 (Level C)
0.913	172.65	157.56	Maximum principle stress intensity – Load 8 (Level A)
0.116	259	30	Welded joints (Level C)
0.023	279.77	6.56	M16 leveling screws compression stress
0.045	282.98	12.65	M20 leveling screws compression stress
0.426	239.04	101.9	M16 bolt membrane & bending stress (Level C)
0.058	89.82	5.24	M16 bolt shear stress (Level C)
0.013	92.68	1.21	M20 screws shear stress (Level C)
0.005	246.64	1.2	M12 head screws normal stress – Load 7 (Level C)
0.005	92.68	0.48	M12 head screws shear stress – Load 7 (Level C)
0.449	122.9	55.2	Pin Ø 12/M8 screws shear stress (Level C)
0.181	259.0	46.86	Closure plate of the duct bending
0.042	1515 lb_f	64.2 lb_f	Loads on anchorage – normal
0.030	3040 lb_f	92.55 lb_f	Loads on anchorage – shear

The bulk of the support structure is not loaded by the pressure differential created due to debris and chemical effects. However, the cartridge to duct cover and bottom are addressed in the cartridge section above. The module components are loaded by seismic effects including sloshing.

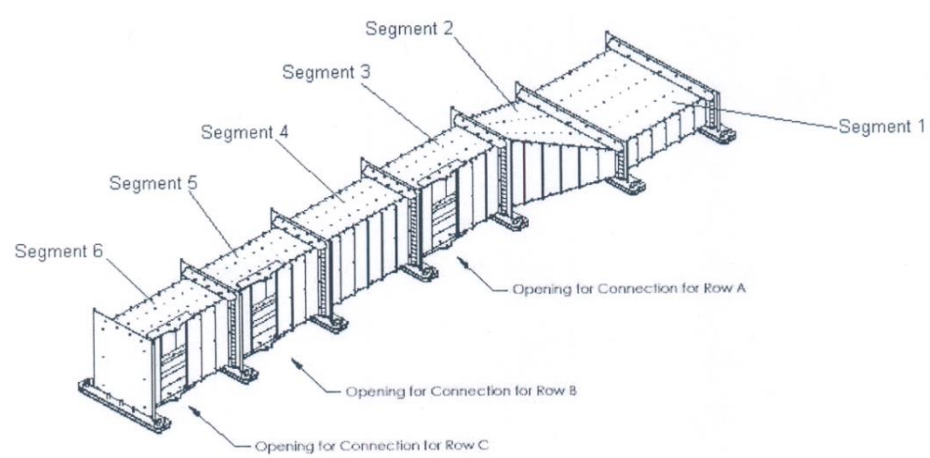


Figure 21: Radial Duct

Table 18: Radial Duct (nominal for all segments)

Ratio	Allowable MPa	Calculated MPa	Stress Location and Type
0.002	82.74	0.18	Global bending of duct shear stress – Load 8 (Level A)
0.003	206.85	0.7	Global & local bending of cover plate – Load 8 (Level A)
0.007	61.03	0.439	Sidewalls compression stress – Load 8 (Level A)
0.002	122.76	0.21	Global bending of duct shear stress – Load 7 (Level C)
0.003	124.11	0.43	Loads in horizontal directions shear stress – Load 7 (Level C)
0.002	306.9	0.67	Global bending due to Weight & Earthquakes - Load 7 (Level C)
0.109	306.9	33.3	Local & global bending of cover plate – Load 7 (Level C)
0.074	63.5	4.72	Membrane stress in compression – Load 7 (Level C)
0.053	71.9	3.81	Axial compression of the sidewalls – Load 7 (Level C)
1.11	306.9	340.3 1.2%	Global & local bending sidewalls – Load 7 (Level C) Strain intensity for collapse load evaluation
0.375	17.45	6.55	Inner duct walls – Load 7 (Level C)

The bending stress for the radial duct is above the Level C allowable stress. Plastic-elastic analysis demonstrates that the strain intensity is well below 2/3 of the collapse load and the permanent distortion of the side walls do not lead to loss of function of the duct segment.

Table 19: Analysis of Retaining Structure of Radial Duct Segment 4

Ratio	Allowable MPa	Calculated MPa	Stress Location and Type
0.002	239.04	0.7	Support plate w/anchorage M30/M16 tension (Level C)
0.185	89.82	16.6	Support plate w/anchorage M30/M16 shear stress (Level C)
0.019	92.7	1.8	Connection duct to retaining structure shear stress
0.012	246.64	3.0	Cylinder head screw M12 normal stress - Load 7
0.024	92.68	2.2	Cylinder head screw M12 shear stress – Load 7
0.360	259	93.14	Support legs membrane bending stress (Level C)
0.018	103.6	1.83	Support legs shear stress (Level C)
0.124	259	32.2	Closure plate of the duct bending stress (Level C)
0.008	1515 lb_f	12.5 lb_f	Anchor plate w/4 Hilti Kwik Bolts 111 tension
0.096	3040 lb_f	292.5 lb_f	Anchor plate w/4 Hilti Kwik Bolts 111 shear

Table 20: Analysis of the Duct Structure of Radial Duct Segment 1

Ratio	Allowable MPa	Calculated MPa	Stress Location and Type
0.002	82.74	0.18	Global bending of duct shear stress
0.002	206.85	0.35	Global & local bending of cover plate
0.006	82.3	0.51	Sidewalls compression stress
0.001	122.76	0.17	Global bending of duct shear stress (Level C)
0.001	122.76	0.13	Loads in horizontal directions shear stress (Level C)
0.001	306.9	0.4	Global bending due to Weight & Earthquakes (Level C)
0.389	306.9	119.4	Global and local bending of cover plate (Level C)
0.082	23.67	1.94	Membrane stress in compression (Level C)
0.089	100.6	9.0	Axial compression of the sidewalls (Level C)
0.187	306.9	57.5	Global & local bending sidewalls (Level C)
1.50 0.67	24.8 15.3 psi	37.3 10.2 psi	Inner duct walls (Level C) Level C Allowable Differential Pressure (NB-3228.3 of Reference (22))

The inner duct walls exhibit greater stress than that allowed for a Level C evaluation. However, an elastic-plastic analysis was performed. The actual differential pressure is below 2/3 of the collapse differential pressure. Therefore, Segment 1 of the radial duct will not collapse and the radial duct will perform its function.

Table 21: Analysis of Retaining Structure of Radial Duct Segment 1

Ratio	Allowable MPa	Calculated MPa	Stress Location and Type
0.138	89.82	12.4	Support plate w/anchorage M30/M16 shear (Level C)
0.014	92.68	1.32	Connection duct to retaining structure shear
0.012	246.64	2.95	Cylinder screw M12 normal stress – Load 7
0.023	92.68	2.16	Cylinder screw M12 shear stress – Load 7
0.116	259	30.0	Support legs membrane bending stress (Level C)
0.013	103.6	1.37	Support legs shear stress (Level C)
0.072	3040 lb_f	218.8 lb_f	Anchor plate w/4 Hilti Kwik Bolts III shear stress

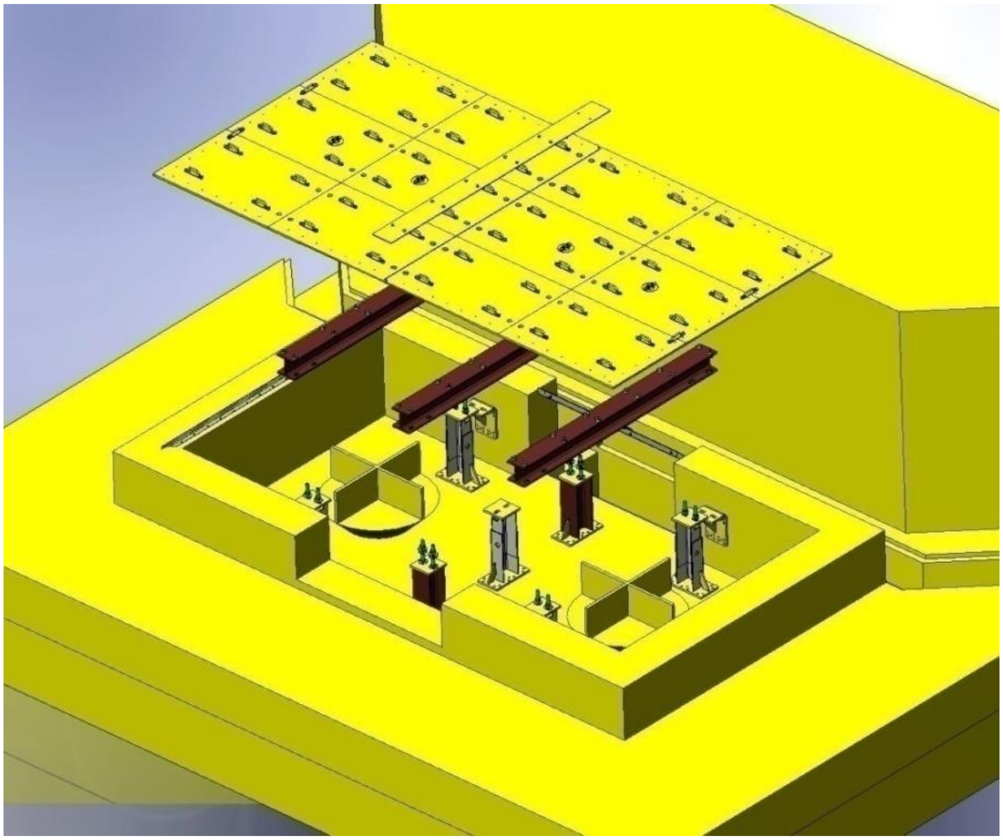


Figure 22: Sump Cover

Table 22: Sump Cover
(700 millibar differential pressure)

Ratio	Allowable	Calculated	Stress Location and Type
0.121	296.6 MPa	35.8 MPa	Cover plate bending stress (Level C)
0.166	155.8 MPa	25.8 MPa	Stresses in support beam IPB 140 (lateral beams) (Level C)
0.141	155.8 MPa	21.9 MPa	Stresses in support beam IPB 140 (middle beam) (Level C)
0.205	336.6 MPa	68.9 MPa	Adjusting Bolts (bending) (Level C)
0.33	N/A	N/A	Adjusting Bolts (combined compression, and bending stress ratios)
0.032	177.1 MPa	5.71 MPa	Support columns bending stress
0.018	177.1 MPa	3.27 MPa	Support columns compression stress
0.58	N/A	N/A	Anchor Bolts (combined compression/tension, shear, and bending stress ratios)

Response to Issue 3k3:

Calvert Cliffs has approval to use leak-before-break methodology so that the dynamic effects of a LOCA do not need to be considered in the design of structures and components. Emergency Core Cooling System sump recirculation is not required for breaks in other piping systems.

<u>*Response to Issue 3k4*</u>:

The Calvert Cliffs emergency recirculation sump strainer design does not incorporate a backflushing strategy.

<u>***NRC Issue 3l***</u>**:**

Upstream Effects

The objective of the upstream effects assessment is to evaluate the flowpaths upstream of the containment sump for holdup of inventory which could reduce flow to and possibly starve the sump. Therefore, provide a summary of the upstream effects evaluation including the information requested in GL 2004-02, "Requested Information," Item 2(d)(iv) including the basis for concluding that the water inventory required to ensure adequate ECCS or CSS recirculation would not be held up or diverted by debris blockage at choke-points in containment recirculation sump return flowpaths.

1. *Summarize the evaluation of the flow paths from the postulated break locations and containment spray washdown to identify potential choke points in the flow field upstream of the sump.*
2. *Summarize measures taken to mitigate potential choke points.*
3. *Summarize the evaluation of water holdup at installed curbs and/or debris interceptors.*
4. *Describe how potential blockage of reactor cavity and refueling cavity drains has been evaluated, including likelihood of blockage and amount of expected holdup.*

<u>*Response to Issue 3l1*</u>:

The lower level of Containment is open and contains no compartment or choke point which could prevent water from flowing to the sump.

The flow path of water from the Containment Spray System is from the containment dome area and falls into the refueling pool cavities and directly into lower containment. The refueling pool cavities drain to the sump through the enlarged drain lines with trash racks to prevent blockage by large pieces of debris.

<u>*Response to Issue 3l2*</u>:

The drain flow path from the refueling pool cavities to the lower level of containment was modified to increase the diameter of the line to 8" for the entire distance. A trash rack was installed over the drain opening in the refueling pool cavities to eliminate potential water sequestration in the refueling pool cavities.

<u>*Response to Issue 3l3*</u>:

There are no curbs of sufficient dimension to impact water flow to the sump.

<u>*Response to Issue 3l4*</u>:

Potential blockage of the refueling pool cavity drains was discussed in Issue 3I1 and 3I2 above. The reactor cavity drains were inspected via camera and found to be functional. For breaks that originate in the cavity it must be assumed that debris blocks the drain. The door to the reactor cavity is not water-tight; therefore, it is assumed that the cavity water-level is the same as that in the rest of the lower-level of containment.

***<u>NRC Issue 3m</u>*:**

Downstream effects - Components and Systems

The objective of the downstream effects, components and systems section is to evaluate the effects of debris carried downstream of the containment sump screen on the function of the ECCS and CSS in terms of potential wear of components and blockage of flow streams. Provide the information requested in GL 04-02, "Requested Information," Item 2(d)(v) and 2(d)(vi) regarding blockage, plugging, and wear at restrictions and close tolerance locations in the ECCS and CSS downstream of the sump. If approved methods were used (e.g., WCAP-16406-P), briefly summarize the application of the methods. The objective of the downstream effects, components and systems section is to evaluate the effects of debris carried downstream of the ECCS Sump screen on the function of the ECCS and CSS in terms of potential wear of components and blockage of flow streams. Provide the information requested in GL 04-02 Requested Information Item 2(d)(v) and 2(d)(vi) regarding blockage, plugging, and wear at restrictions and close tolerance locations in the ECCS and CSS downstream of the ECCS Sump.

<u>GL 2004-02 Requested Information Item 2(d)(v)</u>

The basis for concluding that inadequate core or containment cooling would not result due to debris blockage at flow restrictions in the ECCS and CSS flowpaths downstream of the ECCS Sump screen, (e.g., a HPSI throttle valve, pump bearings and seals, fuel assembly inlet debris screen, or containment spray nozzles). The discussion should consider the adequacy of the ECCS Sump screen's mesh spacing and state the basis for concluding that adverse gaps or breaches are not present on the screen surface.

<u>GL 2004-02 Requested Information Item 2(d)(vi)</u>

Verification that the close-tolerance subcomponents in pumps, valves and other ECCS and CSS components are not susceptible to plugging or excessive wear due to extended post-accident operation with debris-laden fluids.

3m1. If NRC-approved methods were used (e.g., WCAP-16406-P with accompanying NRC SE) briefly summarize the application of the methods. Indicate where the approved methods were not used or exceptions were taken, and summarize the evaluation of those areas.

3m2. Provide a summary and conclusions of downstream evaluations.

3m3. Provide a summary of design or operational changes made as a result of downstream evaluations.

<u>Response to Issue 3m1</u>:

Reference (8) is used to evaluate the downstream components for the effects of plugging/wear with no exceptions. A bounding debris source term was used in this evaluation addressing all potential LOCA scenarios. All particulate debris is assumed to transport through the system, and not deplete over 30 days. A conservative wear equation which does not use any debris size distribution was used in the wear analysis of downstream components excluding pumps.

In the evaluation of pump wear, the size distribution from Table I-1 of WCAP-16406 was used for unqualified coatings to determine the amount that passes through the strainer. The pump wear evaluation also does not model any depletion over time for unqualified coatings.
The use of Table I-1 of WCAP-16406 for unqualified coatings is conservative when compared to using a uniform 10 µm distribution. Based on Section F8 of WCAP-16406-P-A, 10 µm debris particles cause

erosive wear of pump clearances. Per Equation F6-1 of WCAP-16406-P-A, the erosive wear rate caused by particles less than 100 μm is reduced by multiplying the mass of the particles by the square of the ratio of the debris size to 100 μm. Therefore, the mass of debris with a size equal to 10 μm is reduced to $(10\ \mu m / 100\ \mu m)^2 = 0.01$ = 1% of the original quantity. Thus, if the unqualified coating at Calvert Cliffs were modeled using 100% 10 μm particles, effectively 1% of the total amount of unqualified coatings would contribute to wear in the pumps. The pump wear evaluation size distribution based on Table I-1 of WCAP-16406 resulted in 26.9% of the total amount of the unqualified coatings going downstream of the sump screen and never getting depleted. It did not credit size distribution for reducing the effective concentration of unqualified coatings. Thus, 26.9% of the total amount of unqualified coating conservatively contributes to wear in the pumps as compared to 1% that would result from using a 10 μm uniform distribution.

As described in Attachment 1-3, and Attachment 1-4 a margin on fiber fines has been included in the strainer head loss analysis. However, the downstream effects calculations used fine fiber debris load masses from 2,930 lb_m to 4,400 lb_m which is two to three times greater than the maximum fine fibrous debris load predicted on the strainer for a double-ended guillotine break of the RCS Hot Legs and Cold Legs.

Response to Issue 3m2:

Testing of a replacement HPSI pump cyclone separator was performed by Wyle Labs in May and June 2008. The testing demonstrated that the selected replacement cyclone separator would not plug and would not erode sufficiently to defeat its function. Replacement of all HPSI pump cyclone separators with the tested unit was completed by June 30, 2008.

Evaluation of the HPSI and Containment Spray pump mechanical seals determined that testing was not needed.

Debris loads for the downstream analytical evaluations are based on bypass testing of the CCI strainer. The sump strainer opening consists of 1.6 mm (1/16") diameter holes. A post-installation examination inspects for gaps at all strainer interfaces/joints. The acceptance criterion is no gap greater than 1/32" can remain. These small openings will ensure no large particles enter the downstream recirculation piping.

Impeller / casing wear of the HPSI, LPSI, and Containment Spray pumps was performed using bounding debris bypass quantities. All static piping components and valves were evaluated according to methods of Reference (8) as noted in Response to Issue 3m1 above. Most piping components pass the evaluation criteria for plugging and wear. Those that did not pass the evaluation criteria were shown to have no adverse effect on component function.

Response to Issue 3m3:

Replacement of the HPSI pump cyclone separators was the only design modification change required as a result of Calvert Cliffs downstream effects evaluations. The only operational change was to revise the Emergency Operating procedures to ensure that when the HPSI MOVs are throttled they are still at least 30% open to avoid excessive wear.

***NRC Issue 3n*:**

Downstream Effects - Fuel and Vessel

The objective of the downstream effects, fuel and vessel section is to evaluate the effects that debris carried downstream of the containment sump screen and into the reactor vessel has on core cooling.

1. *Show that the in-vessel effects evaluation is consistent with, or bounded by, the industry generic guidance (WCAP-16793), as modified by NRC staff comments on that document. Briefly summarize the application of the methods. Indicate where the WCAP methods were not used or exceptions were taken, and summarize the evaluation of those areas.*

Response to Issue 3n1:

The methods described in WCAP-16793-NP-A [Reference (19)] as modified and approved by the NRC (refer to ADAMS accession No. ML 15096A012) were used to evaluate downstream effects on the fuel and in the reactor vessel. A bounding debris source term was used in this evaluation addressing all potential LOCA scenarios. The 14 limitations and conditions presented in the Safety Evaluation on WCAP-16793 were addressed in the evaluation.

The fuel used at Calvert Cliffs is Framatome (formerly AREVA) Advanced CE-14 HTP/HMP Fuel with FUELGUARD lower end fitting. For this hardware, WCAP-16793 establishes a 15 g/FA fiber limit to assure long-term core cooling provided the flow per fuel assembly (FA) does not exceed 44 gpm. The maximum flowrate per fuel assembly at Calvert Cliffs is 6.9 gpm which assumes a LPSI pump failed to trip and is operating at 800 gpm, and a HPSI pump is at a conservatively high flow of 700 gpm. Calvert Cliffs has demonstrated an in-vessel fiber loading ranging from 7.6 to 14.4 grams of fiber per fuel assembly (7.6 g/FA to 14.4 g/FA) depending upon whether containment spray flow split is credited for debris diversion from the core region. Both fiber bypass quantities (7.6 g/FA and 14.4 g/FA) are based on a hot leg break with cold leg recirculation. The grams of fiber per fuel assembly would be less for a cold leg break since some fiber will spill out the break before reaching the core.

WCAP-16793 also presents a method for evaluating debris deposition on the fuel rods (LOCADM). The Calvert Cliffs LOCADM evaluation demonstrated acceptable deposition thickness and acceptable long-term core cooling. The maximum cladding temperature was 365.2°F resulting in a margin of 434.8°F based on the allowable maximum cladding temperature of 800°F. The maximum total LOCA generated debris deposition thickness was 872.2 microns or 34.3 mils as compared to the allowable of 50 mils. The amount of fiber that transports to the reactor core was determined by the strainer vendor performing scaled fiber bypass testing using a prototypical fiber debris mix and a nominal strainer flow rate. Two bypass tests were performed, and the results from the test having the higher amount of fiber bypass were used in subsequent calculations.

A similar bypass test was performed by the same vendor for the Salem Nuclear Generating Station. Following an extensive review of the Salem test work, the NRC accepted the Salem response to fiber bypass to the core, which included an adjustment factor to be applied to the original fiber bypass test results.

Calvert Cliffs used the same evaluation approach as approved by the NRC for the Salem Station, and following discussions on July 2, 2014, Calvert Cliffs submitted their fiber bypass calculation for NRC review (ADAMS Accession No. ML 15096A012).

In 2018 the Calvert Cliffs fiber bypass calculation was updated to reflect the latest input data from the risk informed approach. The calculation methodology itself is nearly the same as that used in the original version. The only notable difference is that during the computation of the fiber quantity predicted to bypass the test loop fiber bypass capture screen, it is assumed that all fibers shorter than or equal to the largest capture screen dimension (0.44 mm) penetrate through the capture screen. This is different from the original version, which assumed all fibers shorter than or equal to 0.50 mm penetrate through the capture screen. While it is possible that some fibers longer than 0.44 mm may have passed through the fiber bypass capture screen this is offset by the fact that some fibers less than 0.44 mm will be filtered out on the fiber bypass capture screen.

After the strainer bypass test results are adjusted using the Salem methodology the resultant fiber bypass quantity is 14.4 grams per fuel assembly. The adjustment factor was also updated to be correlated to the total captured mass in the fiber bypass test.

This result conservatively assumes that all fiber which passes through the sump strainer transports to the reactor fuel assemblies; i.e., no credit is taken for containment spray flow split reduction.

***NRC Issue 3o*:**

Chemical Effects

The objective of the chemical effects section is to evaluate the effect that chemical precipitates have on head loss and core cooling.

1. *Provide a summary of evaluation results that show that chemical precipitates formed in the post-LOCA containment environment, either by themselves or combined with debris, do not deposit at the sump screen to the extent that an unacceptable head loss results, or deposit downstream of the sump screen to the extent that long-term core cooling is unacceptably impeded.*
2. *Content guidance for chemical effects is provided in Enclosure 3 to a letter from the NRC to NEI dated September 27, 2007 (ADAMS Accession No. ML072600372).*
   - 2.1 *Sufficient 'Clean' Strainer Area: Those licensees performing a simplified chemical effects analysis should justify the use of this simplified approach by providing the amount of debris determined to reach the strainer, the amount of bare strainer area and how it was determined, and any additional information that is needed to show why a more detailed chemical effects analysis is not needed.*
   - 2.2 *Debris Bed Formation: Licensees should discuss why the debris from the break location selected for plant-specific head loss testing with chemical precipitate yields the maximum head loss. For example, plant X has break location 1 that would produce maximum head loss without consideration of chemical effects. However, break location 2, with chemical effects considered, produces greater head loss than break location 1. Therefore, the debris for head loss testing with chemical effects was based on break location 2.*
   - 2.3 *Plant Specific Materials and Buffers: Licensees should provide their assumptions (and basis for the assumptions) used to determine chemical effects loading: pH range, temperature profile, duration of containment spray, and materials expected to contribute to chemical effects.*
   - 2.4 *Approach to Determine Chemical Source Term (Decision Point): Licensees should identify the vendor who performed plant-specific chemical effects testing.*

2.5 Separate Effects Decision (Decision Point): State which method of addressing plant-specific chemical effects is used.

2.6 AECL Model: Since the NRC USNRC is not currently aware of the testing approach, the NRC USNRC expects licensees using it to provide a detailed discussion of the chemical effects evaluation process along with head loss test results.

2.7 AECL Model: Licensees should provide the chemical identities and amounts of predicted plant-specific precipitates.

2.8 WCAP Base Model: For licensees proceeding from block 7 to diamond 10 in the Figure 1 flow chart [in Enclosure 3 to a letter from the NRC to NEI dated September 27, 2007 (ADAMS Accession No. ML0726007425)], justify any deviations from the WCAP base model spreadsheet (i.e., any plant specific refinements) and describe how any exceptions to the base model spreadsheet affected the amount of chemical precipitate predicted.

2.9 WCAP Base Model: List the type (e.g., AlOOH) and amount of predicted plant-specific precipitates.

2.10 WCAP Refinements: State whether refinements to WCAP-16530-NP were utilized in the chemical effects analysis.

2.11 Solubility of Phosphates, Silicates and Al Alloys: Licensees should clearly identify any refinements (plant-specific inputs) to the base WCAP-16530 model and justify why the plant-specific refinement is valid.

2.12 Solubility of Phosphates, Silicates and Al Alloys: For crediting inhibition of aluminum that is not submerged, licensees should provide the substantiation for the following: (1) the threshold concentration of silica or phosphate needed to passivate aluminum, (2) the time needed to reach a phosphate or silicate level in the pool that would result in aluminum passivation, and (3) the amount of containment spray time (following the achieved threshold of chemicals) before aluminum that is sprayed is assumed to be passivated.

2.13 Solubility of Phosphates, Silicates and Al Alloys: For any attempts to credit solubility (including performing integrated testing), licensees should provide the technical basis that supports extrapolating solubility test data to plant-specific conditions. In addition, licensees should indicate why the overall chemical effects evaluation remains conservative when crediting solubility given that small amount of chemical precipitate can produce significant increases in head loss.

2.14 Solubility of Phosphates, Silicates and Al Alloys: Licensees should list the type (e.g., AlOOH) and amount of predicted plant specific precipitates.

2.15 Precipitate Generation (Decision Point): State whether precipitates are formed by chemical injection into a flowing test loop or whether the precipitates are formed in a separate mixing tank.

2.16 Chemical Injection into the Loop: Licensees should provide the one-hour settled volume (e.g., 80 ml of 100 ml solution remained cloudy) for precipitate prepared with the same sequence as with the plant-specific, in-situ chemical injection.

2.17 Chemical Injection into the Loop: For plant-specific testing, the licensee should provide the amount of injected chemicals (e.g., aluminum), the percentage that precipitates, and the percentage that remains dissolved during testing.

2.18 Chemical Injection into the Loop: Licensees should indicate the amount of precipitate that was added to the test for the head loss of record (i.e., 100%, 140%).

2.19 Pre-Mix in Tank: Licensees should discuss any exceptions taken to the procedure recommended for surrogate precipitate formation in WCAP-16530.

2.20 Technical Approach to Debris Transport (Decision Point): State whether near field settlement is credited or not.

2.21 Integrated Head Loss Test with Near-Field Settlement Credit: Licensees should provide the one-hour or two-hour precipitate settlement values measured within 24 hours of head loss testing.

2.22 Integrated Head Loss Test with Near-Field Settlement Credit: Licensees should provide a best estimate of the amount of surrogate chemical debris that settles away from the strainer during the test.

2.23 Head Loss Testing Without Near Field Settlement Credit: Licensees should provide an estimate of the amount of debris and precipitate that remains on the tank/flume floor at the conclusion of the test and justify why the settlement is acceptable.

2.24 Head Loss Testing Without Near Field Settlement Credit: Licensees should provide the one-hour or two-hour precipitate settlement values measured and the timing of the measurement relative to the start of head loss testing (e.g., within 24 hours).

2.25 Test Termination Criteria: Provide the test termination criteria.

2.26 Data Analysis: Licensees should provide a copy of the pressure drop curve(s) as a function of time for the testing of record.

2.27 Data Analysis: Licensees should explain any extrapolation methods used for data analysis.

2.28 Integral Generation (Alion):

2.29 Tank Scaling / Bed Formation: Explain how scaling factors for the test facilities are representative or conservative relative to plant-specific values.

2.30 Tank Scaling / Bed Formation: Explain how bed formation is representative of that expected for the size of materials and debris that is formed in the plant specific evaluation.

2.31 Tank Transport: Explain how the transport of chemicals and debris in the testing facility is representative or conservative with regard to the expected flow and transport in the plant-specific conditions.

2.32 30-Day Integrated Head Loss Test: Licensees should provide the plant-specific test conditions and the basis for why these test conditions and test results provide for a conservative chemical effects evaluation.

2.33 30-Day Integrated Head Loss Test: Licensees should provide a copy of the pressure drop curve(s) as a function of time for the testing of record.

2.34 Data Analysis Bump Up Factor: Licensees should provide the details and the technical basis that show why the bump-up factor from the particular debris bed in the test is appropriate for application to other debris beds.

Response to Issue 3o1:

Debris and other containment sources which could contribute to the formation of chemical precipitates in the sump pool were evaluated using the methodology of Reference (12). The results of these analyses showed the elemental amounts silicon (Si) and aluminum (Al) expected to be released into the sump pool as well as the predicted quantity of $NaAlSi_3O_8$ precipitate.

Strainer chemical effects head loss testing was conducted in 2010 as discussed in the response to Issue 3f4 using $NaAlSi_3O_8$ surrogate chemical precipitate prepared in accordance with Reference (12). This head loss testing showed acceptable head loss for most breaks in accordance with the Calvert Cliffs simplified risk-informed approach as described in Attachment 1-3 of this submittal.

Response to Issue 3o2.1:

Calvert Cliffs is not crediting a simplified chemical effects analysis.

Response to Issue 3o2.2:

As discussed in response to issue 3f4, the chemical effects head loss test program performed in 2010 was a test for success test campaign in which multiple plant insulation configurations were tested seeking the optimum insulation replacement option. An insulation configuration specific chemical precipitate calculation was prepared for each option.

As discussed in response to issue 3f6, thin bed effects were investigated by using low quantities of the postulated fibrous debris and the entire particulate loading to verify that the CCI strainer does not produce a thin bed effect for the debris from Calvert Cliffs. This also ensures that a break that produces little debris does not produce an unexpectedly high head loss.

The simplified risk-informed evaluated debris loads for breaks at all ASME Class I welds in primary RCS within the first closed valve that could lead to emergency recirculation strainer operation. The debris loads included fibrous, particulate, and chemical precipitate debris source terms. The quantities of fine fiber, particulate, and chemical precipitate were each used to determine strainer head loss based on plant-specific testing which was the performance acceptance criteria for the strainer as discussed in Attachment 1-3.

Response to Issue 3o2.3:

Calvert Cliffs considered time-dependent production of chemical precipitates predicted in containment following a LBLOCA. The following assumptions or results of calculations were used to determine the chemical effects loading for each break analyzed:

- 100% of the debris dislodged from targets was assumed to transport to the post-LOCA containment pool.
- The aluminum release rate for the initial 15 days of the analysis duration was doubled as described in the NRC Limitations and Conditions in Reference (12).
- The containment pool pH was initially set to 7.34 and the spray pH was set to 4.3 until recirculation actuation signal (RAS). At RAS the spray pH was set to 7.34 and then both the pool and spray pH gradually reduced to 7.29 to account for the production of strong acids in the pool from radiologic decomposition of cable insulation.
- Temperature of containment sprays, sump water, and containment gas volume are based on a containment accident analysis with margin added which results in a maximum sump water temperature of about 283°F and a maximum sump water temperature at the start of recirculation of about 209°F.
- Continuous containment spray.
- The NARWHAL software (see Enclosure 1-3) analysis accounts for the change in water volume with respect to time and uses assumptions that minimize the water volume in containment. The

water volume is dependent on break size and break location. The RCS holdup volume is dependent on the break location/elevation. It is acknowledged that water volume has competing effects with respect to chemical release versus solubility; therefore, water volume was included in the sensitivities evaluated in Enclosure 1-3.).

- Materials in Containment considered in the calculation of chemical effects precipitate with quantity of each as determined in calculations.
  - Aluminum metal exposed to sprays and submerged – 150 ft^2.
  - Fibrous debris, Nukon, Thermal Wrap, generic fiberglass, and mineral wool, except for intact blankets of Nukon and Thermal Wrap. These intact blankets are encased in a tightly woven mesh that does not allow for fluid in the sump to readily pass through the blanket.
  - Submerged concrete – 5005 ft^2.
  - Calcium silicate from Marinite boards.
  - The fiberglass jacketing on permanent lead shielding was assumed to not contribute to chemical effects. This material is specifically designed for high temperature (500°F) and is resistant to attack by acidic and alkaline solutions. This material was included in Calvert Cliffs specific autoclave chemical dissolution testing where no dissolution was observed in test of 10-day duration.
- No head loss due to aluminum-based precipitates until a temperature below 140°F.

Response to Issue 3o2.4:

CCI performed plant-specific chemical effects strainer head loss testing for Calvert Cliffs.

Response to Issue 3o2.5:

The methods of Reference (12) were used to assess the plant specific chemical effects precipitate loading and testing. Chemical precipitates were produced using the methods of Reference (12). Aluminum solubility was credited for sump fluid temperatures >140°F.

Response to Issue 3o2.6:

Calvert Cliffs did not use an AECL model.

Response to Issue 3o2.7:

Calvert Cliffs did not use an AECL model.

Response to Issue 3o2.8:

Calvert Cliffs considered time-dependent production of chemical precipitates for the chemical effects head loss testing. The aluminum release rate for the initial 15 days of the analysis duration was doubled as described in the NRC Limitations and Conditions in Reference (12).

Also, aluminum solubility was credited for sump fluid temperatures >140°F.

Response to Issue 3o2.9:

The simplified risk-informed analysis performed break-specific WCAP-16530 precipitate quantity calculations for each break analyzed. This is discussed in detail in Attachment 1-3 of this submittal.

Calvert Cliffs considered three potential precipitates: calcium phosphate, sodium aluminum silicate, and aluminum oxy-hydroxide. Because Calvert Cliffs is a now a STB buffered plant, the lack of Tri-Sodium Phosphate eliminated consideration of calcium phosphate and limits consideration to the potential aluminum precipitates. The debris source term for each break that produced enough debris to threaten strainer performance contained sufficient silicon from the dissolution of fiberglass that $NaAlSi_3O_8$ (sodium aluminum silicate) precipitate was formed preferentially over AlOOH (aluminum oxy-hydroxides). This is an acceptable simplification since both $NaAlSi_3O_8$ and AlOOH are acceptable surrogates for aluminum precipitates.

The largest quantity of $NaAlSi_3O_8$ predicted from all the breaks analyzed was 115.9 lbm.

Response to Issue 3o2.10:

Calvert Cliffs utilizes one refinement to the methods of WCAP-16530-NP-A [Reference (12)], where chemical precipitant effects are not considered until the sump pool temperature drops to 140°F and below. This is based on the temperature at which the aluminum based precipitates would be expected to begin forming.

Argonne National Laboratory (ANL) presented aluminum solubility data as a function of pH and temperature in NUREG/CR-7172. This report provides the following equation for aluminum solubility as a function of pH and temperature for temperatures equal to or below 175°F:

$$[Al(ppm)] = 26980 \times 10^{pH-14.4+0.0243T}$$

The break that produces the largest quantity of chemical precipitate (117.21 lbm of sodium aluminum silicate) is a longitudinal break at Weld 30-RC-12B-7. The aluminum mass concentration for this break is calculated using the minimum mass of water at 31,680 minutes (3,317,574 lbm), which is when the sump pool temperature has been reduced to 140°F (the temperature at which chemical precipitate formation is assumed to occur). The aluminum concentration for this break is 3.64 ppm. The minimum sump pool pH predicted at 140°F is 7.29. Using the aluminum concentration and sump pH in the ANL equation yields a precipitation temperature of 133.3°F. Therefore, assuming aluminum precipitation at 140°F is conservative. When determining the total strainer head loss, the chemical debris head loss was included for sump pool temperatures up to 140°F.

Response to Issue 3o2.11:

There were no plant-specific refinements used other than those discussed above.

Response to Issue 3o2.12:

Inhibition or passivation of aluminum was not used in determining aluminum corrosion and the resultant chemical precipitates.

Response to Issue 3o2.13:

No reduction of chemical precipitates was achieved by crediting solubility. The timing of the effect of chemical precipitates is based on solubility, especially for sodium aluminum silicate. Although testing by Alion (using Calvert Cliffs-specific data) showed no aluminum based precipitate effects down to 60°F, Calvert Cliffs conservatively assumes aluminum based precipitates form as sodium aluminum silicate and affect head loss at temperatures below 140°F.

Response to Issue 3o2.14:

As discussed in Response to Issue 3o2.9, the simplified risk-informed analysis performed break-specific WCAP-16530 precipitate quantity calculations for each break analyzed. This is discussed in detail in Attachment 1-3 of this submittal.

Response to Issue 3o2.15:

Precipitates are formed in a separate mixing tank.

Response to Issue 3o2.16:

Precipitates were not formed by injection into the test loop.

Response to Issue 3o2.17:

Precipitates were not formed by injection into the test loop.

Response to Issue 3o2.18:

Precipitates were not formed by injection into the test loop.

Response to Issue 3o2.19:

No exceptions to the procedures of Reference (12) were taken.

Response to Issue 3o2.20:

Credit for near-field settlement in the plant is not taken. Debris and chemical precipitates in the tests were transported to the strainer and lodged in the strainer pockets, on the face of the strainer, or at the base of the strainer. The debris found at the base of the strainer could not be made to enter the strainer pockets even with mechanical agitation. This debris behavior was observed and could not be eliminated. All credited tests demonstrated repeatability. Similar quantities of debris at the base of the strainer under test were observed in all tests.

Near-field settlement of chemical precipitates was not credited in the tests. Chemical precipitates accumulated on the fibrous debris in all locations similar to the accumulation on the debris bed captured by the strainer.

Response to Issue 3o2.21:

Calvert Cliffs chemical effects head loss testing did not credit near field settlement. See the Response to Issue 3o2.24 below for the one-hour settlement values of the chemical precipitates.

Response to Issue 3o2.22:

Calvert Cliffs chemical effects head loss testing did not credit near field settlement. No chemical precipitate settled away from the strainer.

Response to Issue 3o2.23:

The strainer pockets were full of fibrous and particulate debris and a six inch plus debris bed had formed on the outside of the strainer immediately prior to chemical precipitate addition. Agitation was unable to move more debris into the strainer pockets because of the low flow rates at and into the strainer. The strainer face flow speed is about 0.002 feet per second and the approach speed for the strainer as it transitions to a more simple shape once it is full is about 0.02 feet per second. Neither flow speed is adequate to maintain debris in suspension for long. Debris that does not get into the pockets during initial loading and subsequent agitation cannot move into pockets later. A typical debris bed from the 2010 testing at CCI prior to the introduction of chemical precipitates is shown in Figure 23. This shows that the majority of the debris is on the strainer.

Figure 23: Typical Debris Bed Before Chemical Precipitate Addition

The strainer pockets generally were full of fibrous debris and chemical precipitates at the end of the tests. Increased head loss due to the chemical precipitates created boreholes during testing as evidenced by sudden head loss decreases. (Calvert Cliffs takes no credit for viscosity or temperature corrections in determining head loss as noted in Response to Issue 3f13.)

Response to Issue 3o2.24:

One hour precipitate settling for the 2010 tests is provided in Table 23 below. The settling tests were performed within 24 hours of precipitate addition to the test flume.

Table 23: One-Hour Chemical Precipitate Settlement Volume Percentages

Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
95%	97%	99%	98%	90%	90%	96%

These results all satisfy the 60% of the total volume or greater within 24 hours acceptance criterion.

Response to Issue 3o2.25:

Test termination criteria were as follows:

1) At the discretion of the Test Director and after consultation with the Calvert Cliffs Representative and with the Test Monitor.
2) Once the final chemical addition has occurred and either of the following conditions is achieved:
   a) The test strainer head loss has stabilized to less than a 1% increase per hour for head loss values >60 mbar or ≤0.6 mbar for head loss values ≤60 mbar. If 48 hours has elapsed since the final chemical addition was completed and the head loss trend is extrapolated to be increasing greater than the allowable stabilization criteria then Calvert Cliffs shall be contacted to decide on test continuation.
   b) The strainer head loss is clearly and significantly greater than 50 mbar and 12 hours have elapsed since the final chemical addition was completed.
3) At the discretion of the Test Director for safety of personnel or equipment only.

Response to Issue 3o2.26:

Calvert Cliffs performed seven strainer head loss tests during the summer of 2010 on a test-for-success basis where the amount of debris for each test was based on different postulated plant insulation configurations. Five of these tests are being used as tests of record for strainer performance assessment. The following head loss plots were created from data from these five tests.

Test 2

The second test in this series was a thin-bed test. The test alternated the addition of fiber fines and particulate to the loop, starting with particulate. This sequence was chosen due to previous CCI experience which showed this methodology resulted in higher head loss than initially adding all particulate to the loop followed by batching in fiber. This test resulted in debris bed head losses less than 0.6 inch of water. It is concluded that the Calvert Cliffs strainer is not susceptible to the thin bed effect due to the complex geometry of the CCI pocket strainer resulting in non-uniform deposition of debris and the low approach velocity. The head loss test data from Test 2 is shown in Figure 24.

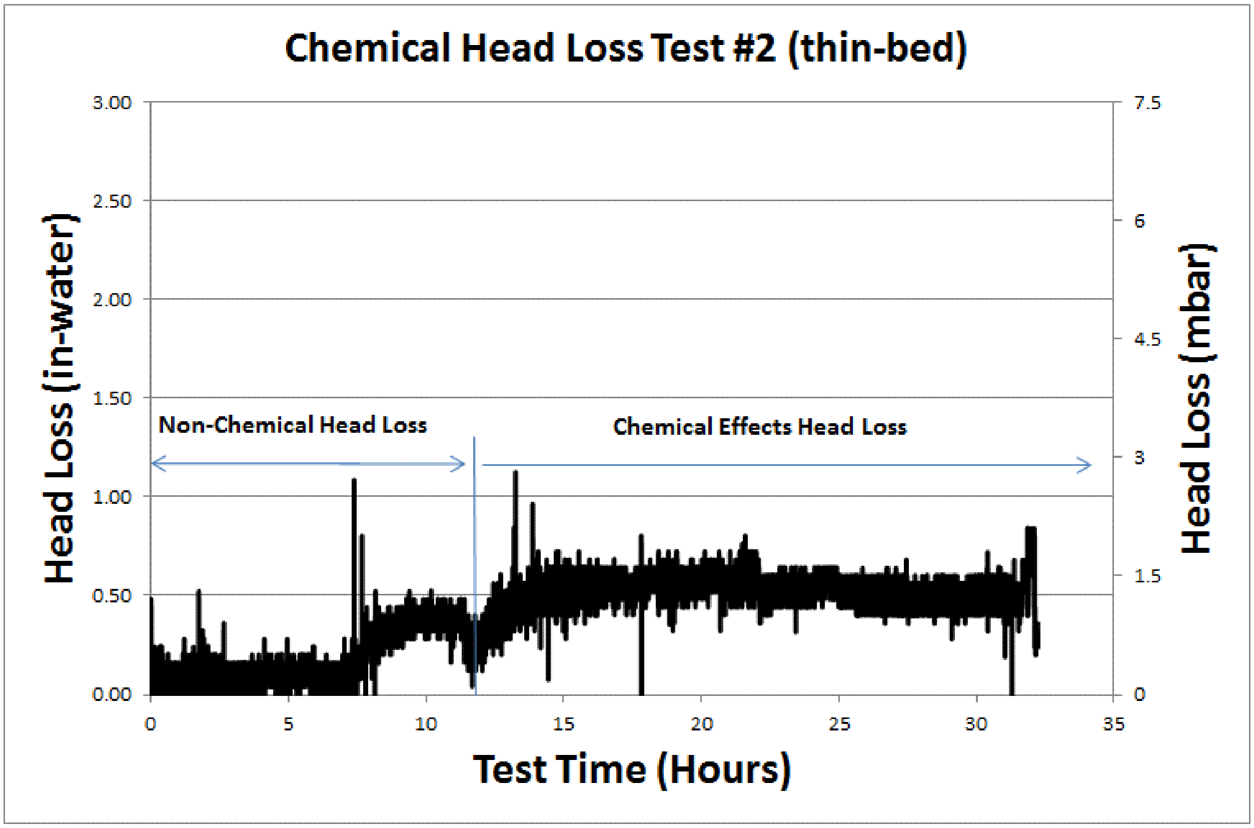


Figure 24: Test 2 Head Loss Data

Test 3

The third test in the series was a test with the equivalent of 369 ft^3 of fine fibrous debris. The maximum debris bed head loss prior to introduction of chemical precipitates was 1 inch of water. After introduction of the chemical precipitates, the debris bed head loss climbed to 38.4 inches of water at which time a bore hole formed in the debris bed and the head loss dropped to approximately 10.8 inches of water before leveling off at 14.4 inches of water. The head loss test data from Test 3 is shown in Figure 25.

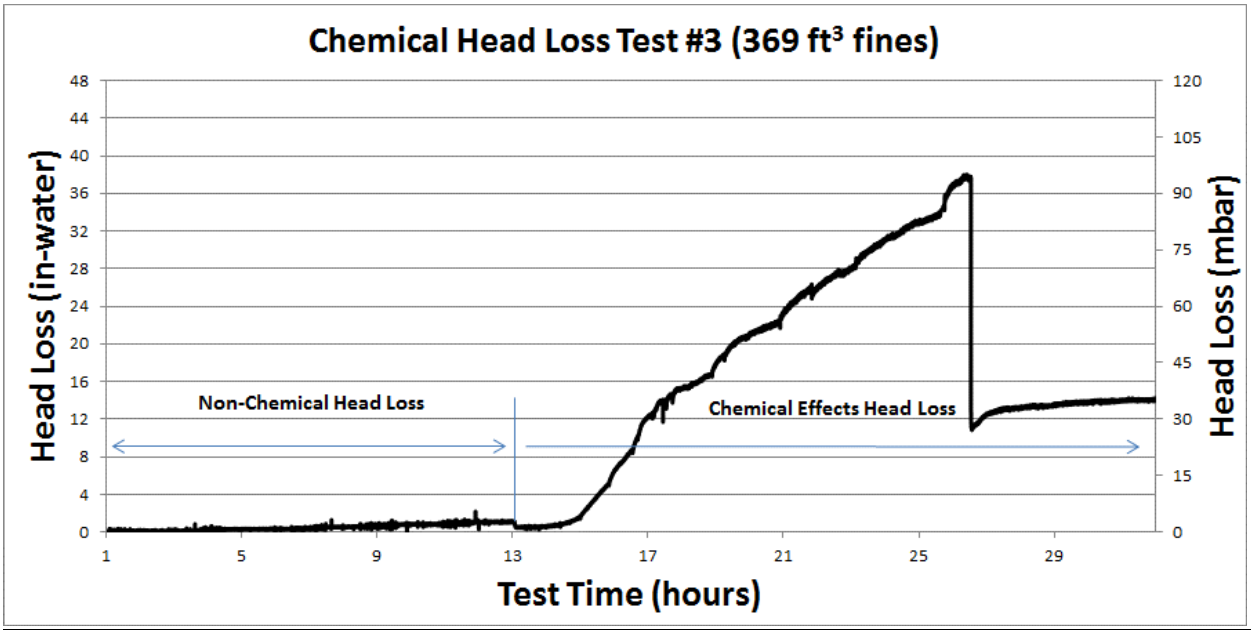


Figure 25: Test 3 Head Loss Data

Test 4

The fourth test in the series was a test with the equivalent of 270 ft^3 of fine fibrous debris. The maximum debris bed head loss prior to introduction of chemical precipitates was 0.6 inch of water. After introduction of the chemical precipitates, the debris bed head loss climbed to 6.1 inches of water at which time a bore hole formed in the debris bed. The last of the precipitate was added to the loop and the head loss slowly returned to 7.2 inches of water at which time another bore hole formed in the debris bed. The head loss leveled off to 4.1 inches of water at the end of the test. The head loss data from Test 4 are shown in Figure 26.

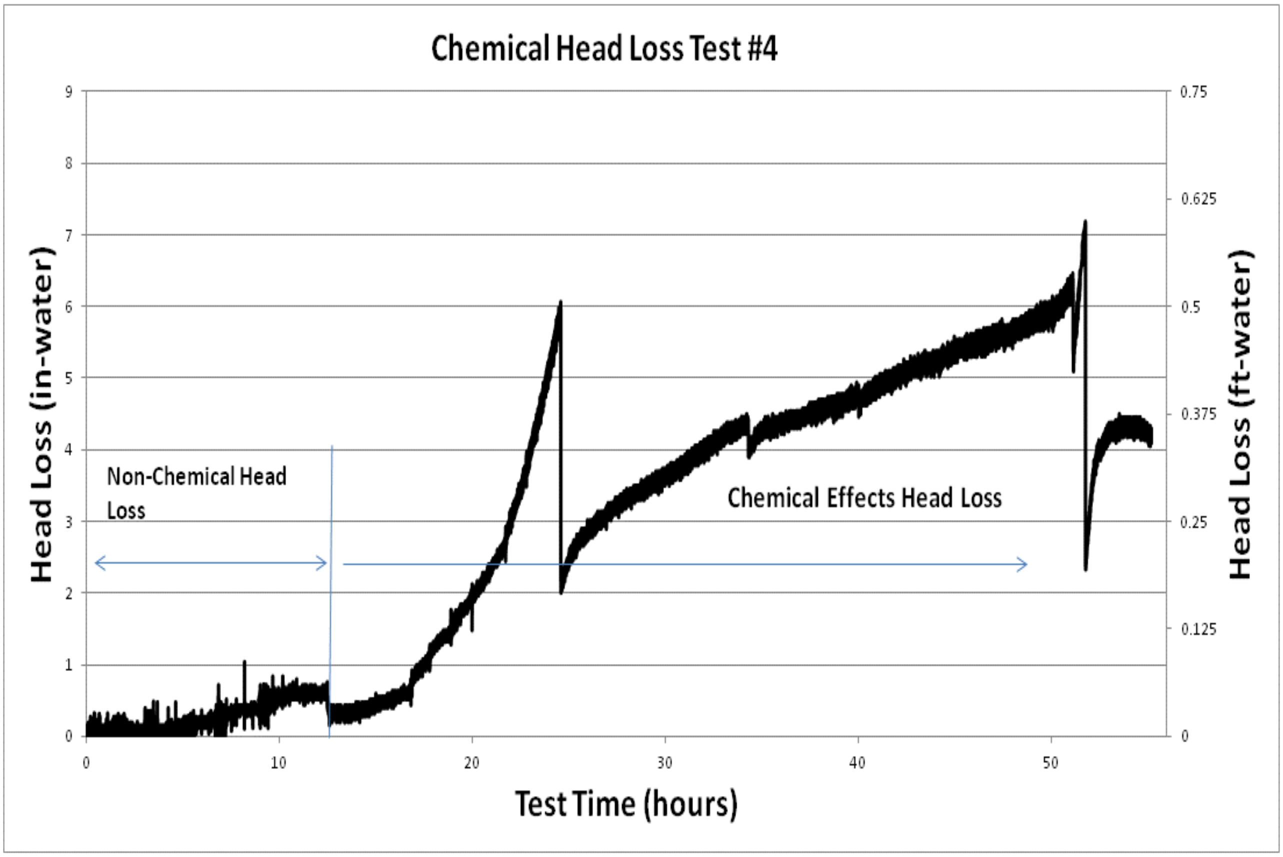


Figure 26. Test 4 Head Loss Data

Test 5

The fifth test in the series was a test with the equivalent of 323 ft^3 of fine fibrous debris. The maximum debris bed head loss prior to introduction of chemical precipitates was 0.7 inch of water. After introduction of the chemical precipitates, the debris bed head loss climbed to 1.2 feet of water at which time a bore hole formed in the debris bed and the head loss dropped to 3.5 inches of water. The head loss leveled off at test end to 7.8 inches of water. The head loss data from Test 5 are shown in Figure 27.

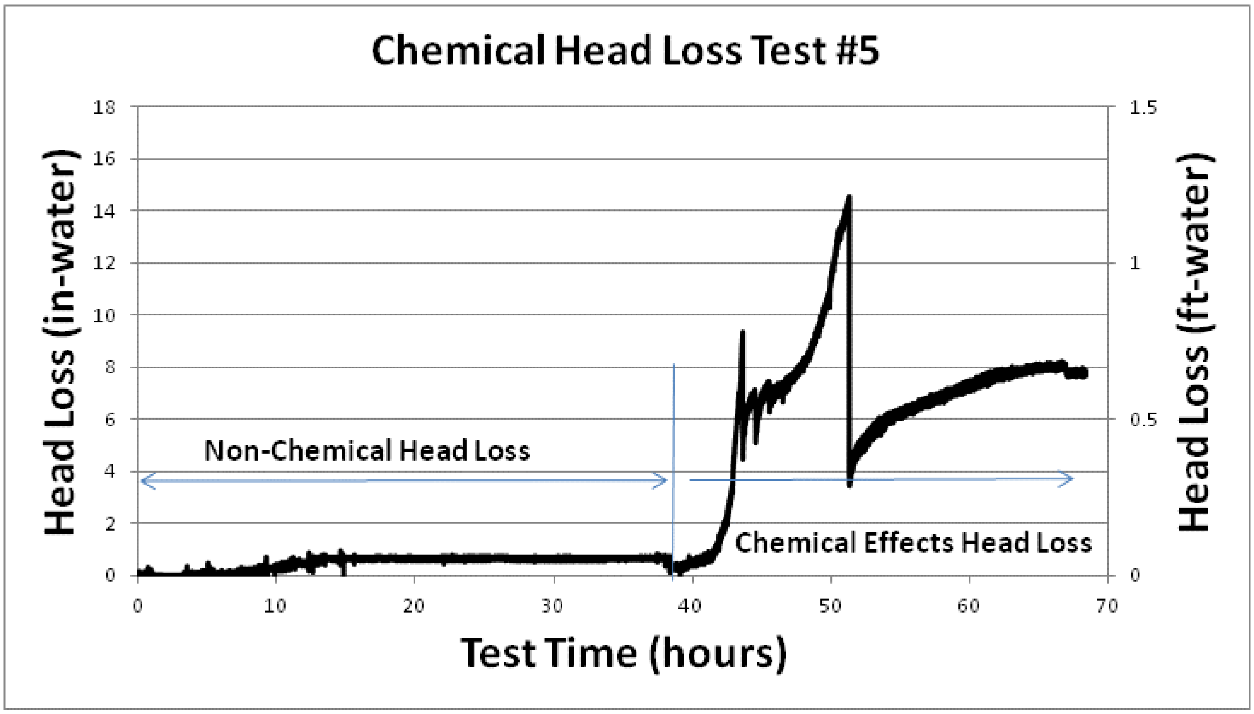


Figure 27. Test 5 Head Loss Data

Test 7

The final test in the series was a test with the equivalent of 292 ft^3 of fine fibrous debris. The maximum debris bed head loss prior to introduction of chemical precipitates was 0.56 inch of water. After introduction of the chemical precipitates, the highest debris bed head loss was 7.9 inches of water before an interruption formed in the debris bed. The head loss leveled off at test end around 7.5 inches of water after multiple debris bed interruptions. The head loss data from Test 7 are shown in Figure 28

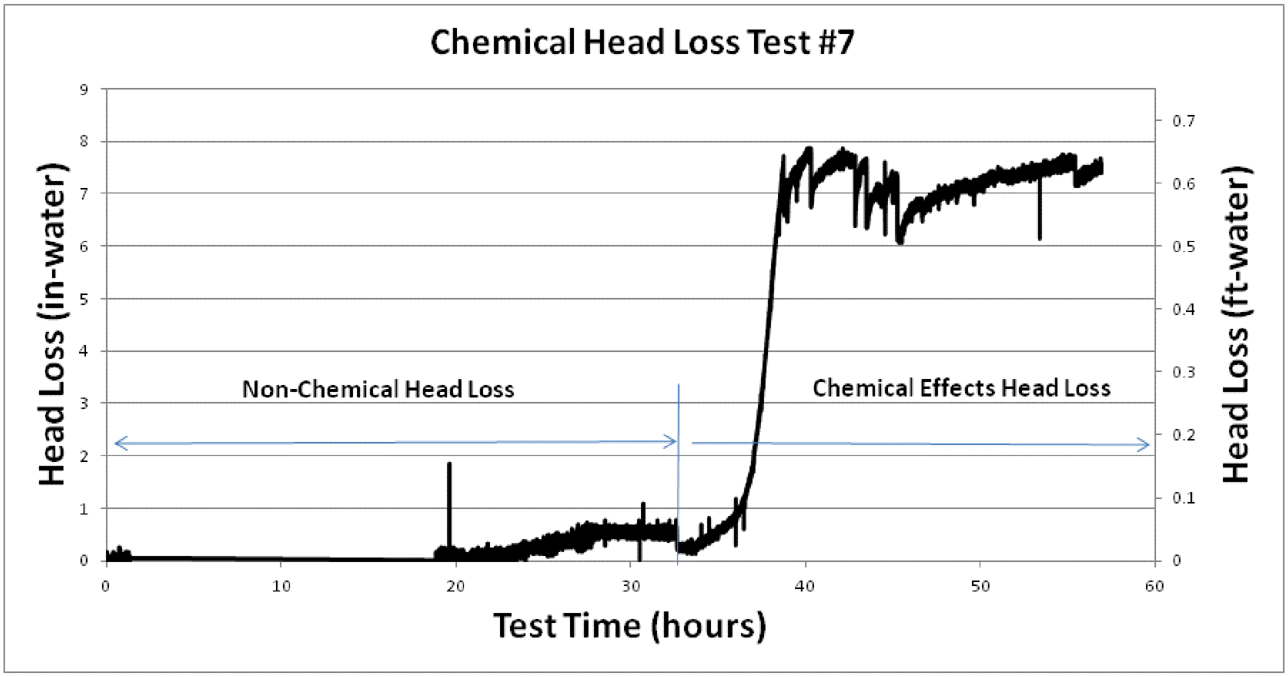


Figure 28. Test 7 Head Loss Data

Response to Issue 3o2.27:

Calvert Cliffs uses no data extrapolation methods. Calvert Cliffs uses area-based scaling between the test and the plant design for debris quantities, chemical precipitate quantities, and flow rate through the strainer. Calculations dependent on head loss testing use the head loss test results without modification. The scaled test parameters were bounding on the containment emergency sump strainer especially for debris loading and flow.

Response to Issue 3o2.28:

Calvert Cliffs did not perform Alion style Integral Generation testing.

Response to Issue 3o2.29:

Calvert Cliffs did not perform Alion style Integral Generation testing.

Response to Issue 3o2.30:

Calvert Cliffs did not perform Alion style Integral Generation testing.

Response to Issue 3o2.31:

Calvert Cliffs did not perform Alion style Integral Generation testing.

Response to Issue 3o2.32:

Calvert Cliffs did not perform Alion style Integral Generation testing.

Response to Issue 3o2.33:

Calvert Cliffs did not perform Alion style Integral Generation testing.

Response to Issue 3o2.34:

Calvert Cliffs did not perform Alion style Integral Generation testing.

***NRC Issue 3p*:**

Licensing Basis

The objective of the licensing basis section is to provide information regarding any changes to the plant licensing basis due to the sump evaluation or plant modifications. Provide the information requested in GL 04-02, "Requested Information," Item 2(e) regarding changes to the plant licensing basis. That is, provide a general description of and planned schedule for any changes to the plant licensing bases resulting from any analysis or plant modifications made to ensure compliance with the regulatory requirements listed in the Applicable Regulatory Requirements section of this generic letter. Any licensing actions or exemption requests needed to support changes to the plant licensing basis should be included. The effective date for changes to the licensing basis should be specified. This date should correspond to that specified in the 10 CFR 50.59 evaluation for the change to the licensing basis.

Response to Issue 3p:

This supplemental response is part of an exemption request and license amendment request to use a risk-informed approach the resolution of GSI-191 and response to GL 2004-02. See Attachment 2 for the exemption request and Attachment 3 for the license amendment request.

REFERENCES:

(1) Safety Evaluation on NEI 04-07, Revision 0, December 2004, "Pressurized Water Reactor Sump Performance Evaluation Methodology," ADAMS Accession Number ML043280007.

(2) C.D.I. Report No. 96-06, Revision A, "Air Jet Impact Testing of Fibrous and Reflective Metallic Insulation," included in Volume 3 of GE Nuclear Energy Document No. NEDO-32686-A, DRF A74-00004, "Utility Resolution Guide for ECCS Suction Strainer Blockage," dated October 1998.

(3) WCAP-16727-P, Revision 0, "Evaluation of Jet Impingement and High Temperature Soak Tests of Lead Blankets for Use Inside Containment of Westinghouse Pressurized Water Reactors."

(4) NRC Audit Report, "Indian Point Energy Center Corrective Actions for Generic Letter 2004-02", ADAMS Accession Number ML082050433.

(5) Wyle Laboratories Report No. 54497R07, Revision B, dated August 31, 2007, Jet Impingement Test of Electromark Labels and Thermal and Fire Barrier Insulation.

(6) SL-009195, Revision 0, dated November 9, 2007, "Wyle Jet Impingement Testing Data Evaluation".

(7) SP-0898, Revision 2, dated April 18, 2004, "Specification for the Safety-Related Level 1 coating Applications inside reactor Containment Building"..

(8) WCAP-16406-P-A, Revision 1, dated March 2008, Evaluation of Downstream Debris Effects in Support of GSI-191 with associated NRC SER dated December 20, 2007.

(9) NUREG/CR-6772, "GSI-191: Separate Effects Characterization of Debris Transport in Water", 2002.

(10) NUREG/CR-6808, "Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance", February 2003.

(11) CA10216, Rev. 0000, Technical Report ALION-REP-CCNPP-7636-01, "Calvert Cliffs Low Density Fiberglass Debris Erosion Testing Report", Revision 0, July 30, 2010.

(12) WCAP-16530-NP-A, Revision 0, dated March 2008, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191.

(13) NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing, dated March 2008.

(14) I. E. Idelchik, "Flow Resistance, a Design Guide for Engineers".

(15) EPRI Report No. 1011753, "Design Basis Accident Testing of Pressurized Water Reactor Unqualified Original Equipment Manufacturer Coatings," September 2005.

(16) Regulatory Guide 1.82, Revision 4, Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident, March 2012.

(17) NUREG/CR-6916, dated December 2006, "Hydraulic Transport of Coating Debris".

(18) Letter from Mr. C. H. Cruse (CCNPP) to Document Control Desk (NRC), dated November 13, 1998, Response to Generic Letter 98-04, "Potential for Degradation of the Emergency Core Cooling System and the Containment Spray System after a Loss-of-Coolant Accident Because of Deficiencies and Foreign Material in Containment".

(19) WCAP-16793-NP-A, Revision 2, dated July 2013, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid".

(20) Letter from Mr. G. H. Gellrich (CCNPP) to Document Control Desk (NRC), dated July 23, 2010, Request for Additional Information Regarding Generic Letter 2004-02.

(21) ASME B&PVC Section III, Division I, Subsection NF, "Supports," 2004 Edition including 2005 Addenda.

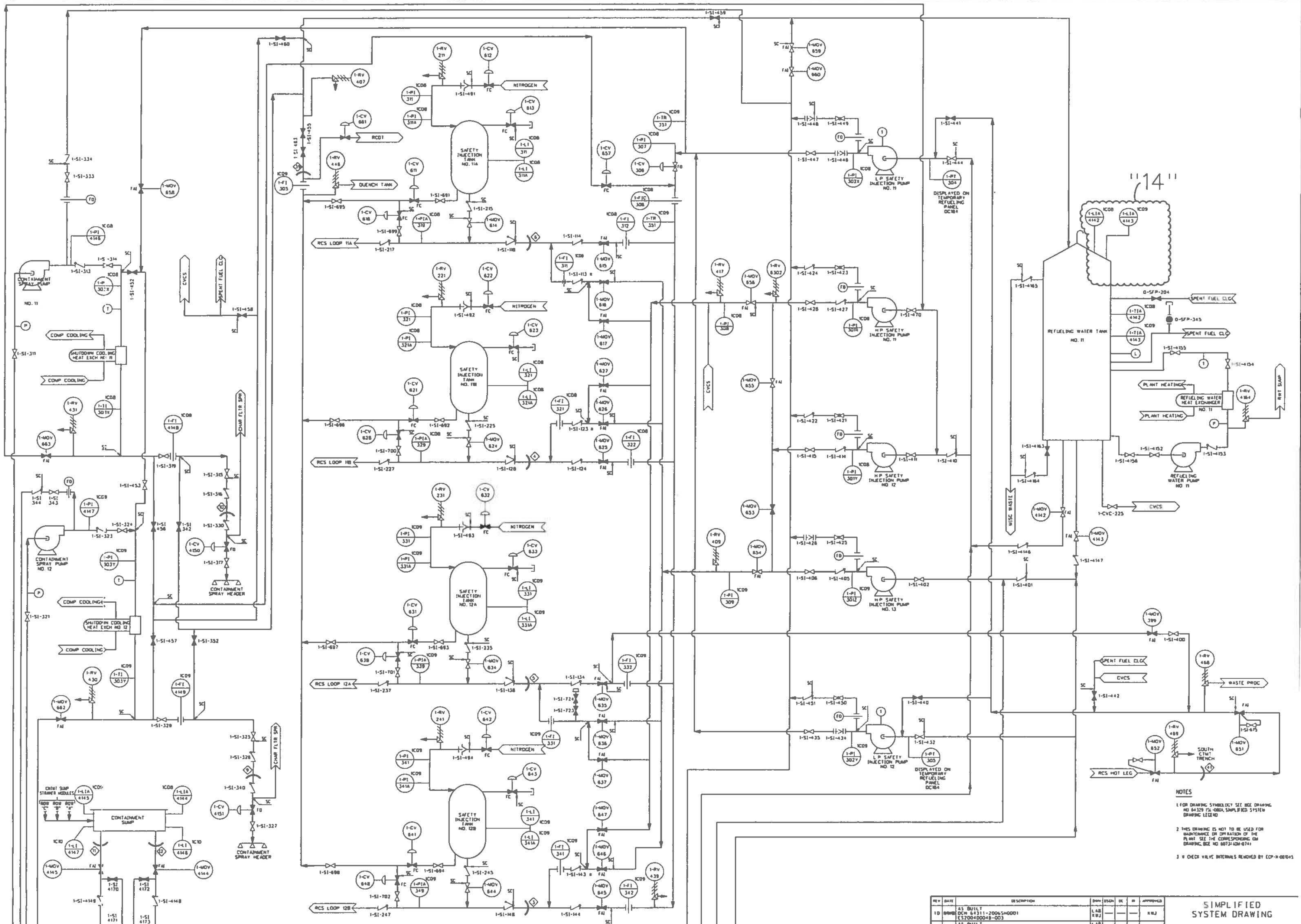
(22) ASME B&PVC Section III, Division I, Subsection NB, Class 1 Components," 2004 Edition including 2005 Addenda.

(23) Keeler & Long PPG Report No. 06-0413, "Design Basis Accident Testing of Coating Samples from Unit 1 Containment TXU Comanche Peak SES," April 13, 2006.

ENCLOSURE (1-2.1)

ECCS and CSS SYSTEM FIGURES

DELETED



NOTES

1. FOR DRAWING SYMBOLOGY SEE BGE DRAWING NO 64329 [illegible] SIMPLIFIED SYSTEM DRAWING LEGEND
2. THIS DRAWING IS NOT TO BE USED FOR MAINTENANCE OR OPERATION OF THE PLANT. SEE THE CORRESPONDING OM DRAWING, BGE NO 60731 (OM-074)
3. # CHECK VALVE INTERNALS REMOVED BY ECP-[illegible]

REV	DATE	DESCRIPTION	DWN	DSGN	CK	[illegible]	APPROVED
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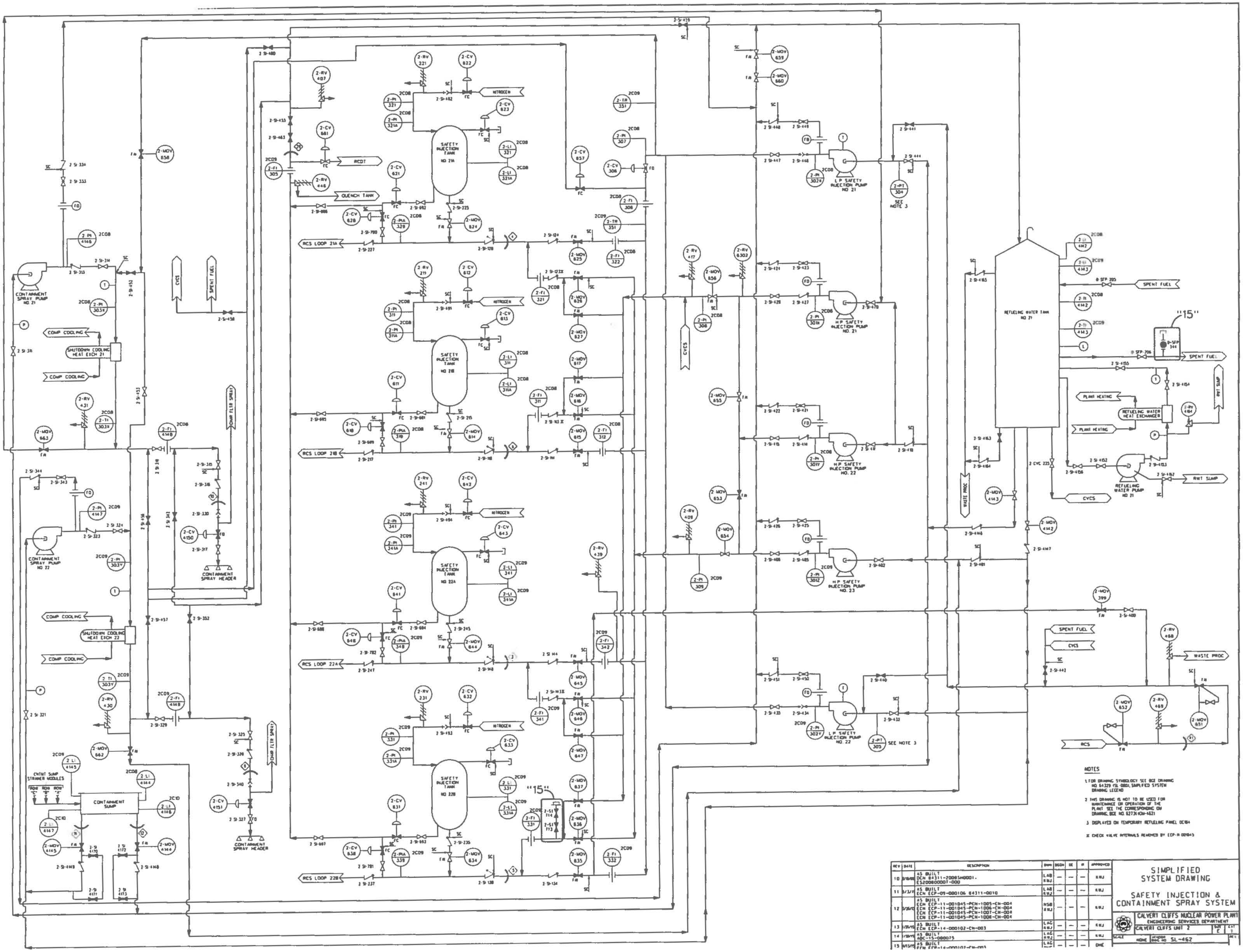
11	[illegible]	AS BUILT ECN ECP-09-000105 64311-0010	LAB RWJ	—	—	—	RWJ
12	[illegible]	AS BUILT ECN ECP-11-001045-PCN-1001-CN-003-64311-0011 ECN ECP-11-001045-PCN-1002-CN-003-64311-0011 ECN ECP-11-001045-PCN-1003-CN-003-64311-0011 ECN ECP-11-001045-PCN-1004-CN-003-64311-0011	RAM CPM	—	—	—	CPM
13	[illegible]	AS BUILT ECN ECP-15-000400-CN-004 AND ECN ECP-14-000100-CN-006	DME RAM	—	—	—	RAM
14	[illegible]	AS BUILT ECN ECP-16-000076-PCN-1001-CN-008	RAM CPM	—	—	—	CPM

SIMPLIFIED SYSTEM DRAWING

SAFETY INJECTION & CONTAINMENT SPRAY

CALVERT CLIFFS NUCLEAR POWER PLANT
ENGINEERING SERVICES DEPARTMENT
CALVERT CLIFFS UNIT 1 | SIZE E | SHT 1
SCALE NONE | DRAWING NO. SL-074 | REV


SIMPLIFIED SYSTEM DRAWING
SAFETY INJECTION & CONTAINMENT SPRAY SYSTEM
CALVERT CLIFFS NUCLEAR POWER PLANT
ENGINEERING SERVICES DEPARTMENT
CALVERT CLIFFS UNIT 2
SL-462
NOTES
1 FOR DRAWING SYMBOLOGY SEE BGE DRAWING NO 64329 (SL-000) SIMPLIFIED SYSTEM DRAWING LEGEND
2 THIS DRAWING IS NOT TO BE USED FOR MAINTENANCE OR OPERATION OF THE PLANT. SEE THE CORRESPONDING OM DRAWING, BGE NO. 62731 (OM-462)
3 DISPLAYED ON TEMPORARY REFUELING PANEL 0C184
CHECK VALVE INTERNALS REMOVED BY ECP-11-001045
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13 AS BUILT ECN ECP-14-000102-CN-003
14 AS BUILT ADC-15-000075
15 AS BUILT
REFUELING WATER TANK NO 21
SAFETY INJECTION TANK NO 21A
SAFETY INJECTION TANK NO 21B
SAFETY INJECTION TANK NO 22A
SAFETY INJECTION TANK NO 22B
L P SAFETY INJECTION PUMP NO 21
L P SAFETY INJECTION PUMP NO 22
H P SAFETY INJECTION PUMP NO. 21
H P SAFETY INJECTION PUMP NO. 22
H P SAFETY INJECTION PUMP NO. 23
CONTAINMENT SPRAY PUMP NO 21
CONTAINMENT SPRAY PUMP NO 22
SHUTDOWN COOLING HEAT EXCH 21
SHUTDOWN COOLING HEAT EXCH 22
CONTAINMENT SUMP
CONTAINMENT SPRAY HEADER
REFUELING WATER PUMP NO 21
REFUELING WATER HEAT EXCHANGER
RCS LOOP 21A
RCS LOOP 21B
RCS LOOP 22A
RCS LOOP 22B
QUENCH TANK
RCDT
NITROGEN
COMP COOLING
SPENT FUEL
CVCS
WASTE PROC
RWT SUMP
PLANT HEATING
CHMP FLTR SPRAY
RCS

ENCLOSURE (1-2.2)

Aluminum Precipitate Head Loss Considerations

DELETED

1-3 Risk Informed Basis

The general approach for the Calvert Cliffs simplified risk-informed approach is:

1. For all breaks that result in less than or equal to the strainer head loss that was observed in a strainer head loss test that was performed in accordance with Nuclear Regulatory Commission (NRC) guidance [Reference (1)], then evaluation of those breaks is complete with the conclusion that these breaks do not contribute to an increase in Core Damage Frequency (CDF) or Large Early Release Frequency (LERF), and
2. For those breaks that result in greater than the tested head loss, then the risk significance of those breaks are evaluated via Regulatory Guide (RG) 1.174 [Reference (2)].

The Calvert Cliffs simplified risk informed approach does not address ex-vessel or in-vessel downstream effects. These downstream effects associated with GSI-191 were addressed through deterministic analyses in accordance with NRC-accepted methodologies [References (3) & (4)] and have been shown to not contribute to an increase in CDF or LERF.

Summary of Calvert Cliffs Simplified Risk- Informed Approach

The Calvert Cliffs simplified risk informed approach involves the following steps:

1) Determine the maximum allowable head loss for the strainer.
   This must consider Net Positive Suction Head (NPSH), deaeration, flashing, and structural requirements.

2) Identify acceptable strainer head loss tests.
   The quantity of fine fiber, particulate, and WCAP-16530 [Reference (5)] surrogate precipitate used in the tests and the clean screen head loss, conventional (non-chemical) head loss, and chemical head loss become the criteria for identifying Loss of Coolant Accident (LOCA) breaks that satisfy deterministic qualification methods and those breaks that must be addressed through risk analysis.

3) Perform a debris generation calculation using the BADGER software (Break Accident Debris Generation EvaluatoR). This calculation determines the quantity of various types of debris impacting the containment sump strainer. Pipe breaks at all in-service inspection (ISI) weld locations in the Reactor Coolant System (RCS) and systems connected to the RCS upstream of normally closed valves are evaluated.

4) Assume 100% of the debris dislodged from targets is transported to the containment post-LOCA pool to maximize contribution to chemical effects.

5) Perform a Nuclear Accident Risk-WeigHted AnaLysis (NARWHAL) analysis to determine the particulate, calculate chemical precipitate debris quantities and time-dependent accumulation of debris on the strainer and compare against the strainer acceptance criteria to determine which breaks pass and fail.

6) Assume 100% of the particulate debris, chemical precipitate, and fine fiber debris, including those fine fibers produced through erosion of small and large pieces of fibrous debris, is transported to the strainer to contribute to strainer head loss.

7) Identify breaks at welds that produce strainer head loss that exceeds the allowable head loss for each break. This defines the *Critical Break Size*. The head loss for each break scenario is compared to the allowable head loss criteria established in Step 1.

   a. Break scenarios producing a strainer head loss less than or equal to the allowable head loss satisfy strainer performance criteria using NRC-accepted analysis methods and do not contribute to an increase in CDF or LERF.
   b. Critical Breaks producing strainer head losses greater than allowable are assumed to threaten strainer performance and must be evaluated for impact on CDF and LERF.

8) Evaluate the risk contribution of Critical Breaks against the RG 1.174 criteria for CDF, ΔCDF, LERF, and ΔLERF.
   a. CDF and LERF are taken from the Calvert Cliffs Probabilistic Risk Assessment (PRA) Model of Record.
   b. ΔCDF is determined from the LOCA exceedance frequency for the Critical Break size from NUREG-1829 [Reference (6)] and the strainer conditional failure probability (CFP) calculated using NARWHAL.
      i. The NUREG-1829 LOCA frequency is apportioned across all welds equal to or greater than the smallest Critical Break size within the NUREG-1829 LOCA Category using the top-down LOCA frequency methodology.
         1. Plant-wide LOCA frequencies are based on the break frequencies in NUREG-1829 with log-linear interpolation for intermediate break sizes.
         2. The frequency for a given break size is allocated to individual welds (that can experience a break of that size).
      ii. PRA model LOCA categories (e.g., very large breaks) are broken up into size ranges to more accurately calculate the overall CFP for the LOCA category. Smaller breaks within the size range are assumed to have the same probability as larger breaks within the size range.
      iii. The CFP for a PRA LOCA category can be approximated by dividing the number of welds in the LOCA category that threaten strainer performance by the total number of welds analyzed in the LOCA category. NARWHAL performs a much more comprehensive calculation for CFP.
      iv. ΔCDF is defined as the product of the CFP and the LOCA exceedance frequency for the Critical Break size.
   c. ΔLERF is determined by obtaining a CDF multiplier from the Calvert Cliffs LERF model that is bounded by a worst-case accident sequence for the Critical Break scenarios.
   d. Compare CDF, ΔCDF, LERF, and ΔLERF results against RG 1.174 criteria for Region III.
   e. Verify other requirements (for example, safety margin, defense in depth) of RG 1.174 are met.

9) If all requirements are met, the simplified risk informed approach is complete and the results are acceptable.

The remainder of this enclosure is organized with the same layout as draft RG 1.229 Appendix B [Reference (7)].

1.0 SCOPE, FAILURE MODES, SCENARIOS, AND DEBRIS

1.1 Scope

As described in RG 1.174, the systematic risk assessment should consider all hazards, initiating events, and plant operating modes. However, a screening process can be used to eliminate scenarios that are not relevant, not affected by debris, or have an insignificant contribution.

Calvert Cliffs performed a systematic risk assessment considering all accident sequences leading to a demand for recirculation. This includes the entire spectrum of LOCAs, Reactor Coolant Pump (RCP) seal LOCA, secondary system high energy line breaks, and accident sequences leading to once-through-core-cooling (feed & bleed). As presented in Section 2.5 of this attachment, only large weld failures in the main reactor coolant piping generate sufficient debris to threaten strainer performance.

1.1.1 Screened Plant Operating Modes

The systematic risk assessment of debris at Calvert Cliffs screened out operating MODE 3 with pressurizer pressure < 1750 psia and MODE 4 LOCA events. As presented in Section 2.5 of this attachment, only the largest weld failures in the main reactor coolant piping generate sufficient debris to threaten strainer performance.

MODE 3 with pressurizer pressure < 1750 psia and MODE 4 LOCAs have been screened because these lower pressure plant conditions do not support generation or transport of large quantities of debris. Also, due to the stable conditions associated with operation in MODE 3 with RCS pressure ≤1750 psia and MODE 4, and the reduced probability of a LOCA, the Emergency Core Cooling System (ECCS) operational requirements are reduced to a single High Pressure Safety Injection (HPSI) pump. Included in these reductions is that certain automatic safety injection actuation signals (SIASs) are not available. In these modes, sufficient time exists for manual actuation of the required ECCS to mitigate the consequences of a LOCA. Protection against single failures is not relied on for these modes of operation. Containment spray is not required to be operational in these modes so the recirculation flow rate through the strainer would be that of a single HPSI pump which is insufficient to cause high strainer head loss.

MODE 5 and MODE 6 were also screened because LOCAs capable of generating debris are not considered in these low-pressure modes.

1.1.2 Breaks Downstream of Normally Closed Valves

The piping attached to the Reactor Coolant System (RCS) at Calvert Cliffs includes welds in ASME Class 1 piping downstream of normally closed valves. These welds can become pressurized to RCS pressure due to valve leakage and could potentially fail as a high energy line break. However, for the failure of one of these welds to produce a high energy blowdown capable of forming a jet that will generate debris and lead to recirculation would also require the upstream valve to fail to remain closed.

Failure of these valves to close or to remain closed was not modeled in the Calvert Cliffs PRA. However, failure to close was modeled for similar valves in the PRA. The failure rate for similar valves to close is 2.38×10^{-4} per demand, therefore the probability for welds downstream of normally closed valves to rupture and result in a debris generating jet resulting in recirculation is at least 1000 times less than

welds upstream of the valves to do so. Therefore, welds downstream of normally closed valves were excluded from the analysis.

1.1.3 Secondary System Breaks

In the Chapter 14 safety analysis of the Calvert Cliffs UFSAR [Reference (8)], main steam and feedwater line break accidents do not lead to recirculation mode of operation. However, there are accident sequences in the Calvert Cliffs PRA involving feedwater and main steam line breaks that do eventually lead to recirculation.

The risk-informed approach performed a conservative and bounding evaluation of feedwater line and main steam line break sequences that lead to recirculation in the Calvert Cliffs PRA. The typical accident sequences for secondary system breaks that lead to recirculation additionally involve either 1) a complete loss of feedwater that requires once-through-core cooling, or 2) failure of the reactor coolant pump seals.

One possible accident sequence starts with a secondary system line break in the containment. Main feedwater fails directly because of the break or subsequent automatic events. Events then occur that cause the failure of Auxiliary Feedwater (AFW). These events could be a hardware failure, operator error, or combination of the two. Once-through-core cooling is initiated, but cannot be sustained because the recirculation function is lost with the postulated failure of the emergency recirculation sump strainer. Core damage occurs due to loss of the RCS heat removal function.

Another possible accident sequence starts with a secondary system line break in the containment. The energy added to the containment environment causes containment pressure to rise, and a Containment Isolation Signal (CIS) is generated. The CIS causes the Component Cooling Water (CCW) valve to the containment to close. A RCP Seal LOCA will occur if the operators fail to trip the RCPs on loss of CCW cooling. There is also an increased probability of seal failure on loss of cooling, even if the pumps are tripped. Safety injection is initiated due to the LOCA, but cannot be sustained when recirculation mode is started, due to the postulated failed emergency recirculation sump strainer. Core damage occurs due to loss of inventory control.

Neither of these scenarios are likely to result in sufficient debris to threaten strainer performance. However, using the PRA model, a bounding sensitivity analysis was performed to measure the potential increases in CDF and LERF for secondary system breaks. The increases in CDF and LERF sensitivity analysis show the following upper bound risk increases:

$\Delta CDF = 5.97 \times 10^{-8}$ $\Delta LERF = 5.04 \times 10^{-9}$

These results are conservatively developed, are bounding, and are well within Region III of RG 1.174. For these reasons, secondary breaks have been screened from the risk-informed analysis.

The analysis very conservatively assumes that a break greater than or equal to 1" diameter produces a sufficient quantity of debris to fail the strainer. As discussed later in this attachment, only large breaks in the RCS primary loops threaten strainer performance. Crediting strainer successful performance for secondary breaks smaller than very large breaks would significantly reduce these ΔCDF and ΔLERF values.
Neither seismic, internal fire, nor internal flood induced were included in the sensitivity analysis for main steam and main feedwater pipe breaks in the containment.

1.1.3.1 Seismic

Seismically induced Main Steam or Main Feedwater pipe breaks in the containment are excluded from the sensitivity analysis based on the following.

There are no internal fire PRA scenarios that induce Main Steam or Main Feedwater pipe breaks in the containment.

Section 2.7.1 of Attachment (1-1) describes that during a seismic event, the support systems for core and containment cooling are expected to fail before the RCS piping would fail. Like the RCS piping, the Main Feedwater and Main Steam piping in the containment are safety-related and high-pressure piping. The Main Feedwater and Main Steam piping in the containment are at least equally robust with the support systems described. Similarly, then, during a seismic event, the support systems for core and containment cooling would be expected to fail with, or before the Main Feedwater or Main Steam piping in the containment. With the support systems unavailable ECCS will be unable to prevent core damage whether debris is generated and transported to the strainer or not.

1.1.3.2 Internal Fire

There are no internal fire PRA scenarios that induce Reactor Coolant , Main Steam, or Main Feedwater pipe breaks inside containment. This is consistent with the guidance in NUREG/CR-6850 [Reference (10)], internal fire hazards were not assumed to result in pipe breaks.

Consistent with the guidance in NUREG/CR-6850 [Reference (10)], internal fire hazards were not assumed to result in pipe breaks. However, fire-induced LOCAs can occur. These include spurious opening of a pressurizer PORV or safety valve, spurious reactor head vent, continuous letdown, spurious interfacing system LOCA, or reactor coolant pump (RCP) seal LOCA due to loss of seal cooling. Of these, only an RCP seal LOCA has the potential to generate debris inside containment. A spurious opening of a pressurizer PORV or safety valve, or spurious reactor head vent discharge to the Reactor Coolant Quench Tank, located in the lowest level of containment. The rupture disc on the Reactor Coolant Quench tank directs steam vertically upward to structural concrete forming the bottom of the refueling pool. There are no significant debris sources in this area. Continuous letdown and spurious interfacing system LOCAs discharge outside containment. Therefore, these scenarios may be screened from the analysis. The quantity of debris generated by an RCP seal LOCA is not significant. Leakage from an RCP seal LOCA is directed vertically upward around the pump shaft and against the bottom of the RCP motor. From there, it will be deflected horizontally, mostly contained within the driver mount (cylinder shaped steel motor mount between the pump and motor), and then it will flow out of access holes in the driver mount onto the steel casing covering the insulated RCP pump. Based on these considerations and the limited flow rate, RCP Seal LOCAs may also be screened from the analysis.

1.1.3.3 Internal Flood

The Calvert full-power internal events model is a combined internal events/internal flood model. In the Calvert PRA model, Main Steam and Main Feedwater pipe breaks are considered separately from other flood scenarios, as these breaks may impact nearby equipment due to the high energy and high temperature potential of the breaks. These additional impacts are considered in the PRA model accident sequences. The Calvert PRA model has no other internal flood events in the containment. Internal flood events from support systems inside of the containment, are screened from the PRA internal flood analysis. Fire Water and Demineralized Water system containment isolation valves are

closed while the plant is operating and therefore need not be considered for flood. The Component Cooling and Service Water systems are in-service, but these closed systems do not have adequate inventory to challenge equipment inside containment. Containment components are designed to operate in a LOCA environment and the containment floor and sump would accommodate support system flooding without submerging any important equipment. Further, the Component Cooling and Service Water Systems are relatively low-pressure systems and do not have sufficient energy to damage Reactor Coolant System piping. Based on the above, internal floods may be screened from the analysis.

1.1.4 Non-Piping LOCA Initiators

Non-piping failures have also been screened. Component failures including manway covers, valves, control element drive assemblies, and instrument lines are much smaller than the main coolant piping. As presented in Section 2.5 of this attachment, only large weld failures in the main reactor coolant piping generate sufficient debris to threaten strainer performance. The diameters of these other components are much smaller and will not generate sufficient debris to threaten strainer performance as discussed below.

1.1.4.1 Steam Generator Primary Manway Covers

The steam generator primary manways are in the lower head of the steam generators near the hot leg and cold leg nozzles. The diameter of the manways is less than 22" compared to the 42" and 30" diameters of the hot and cold legs. The hemispherical zone of influence of a manway cover failure will be directed away from the steam generator which is the largest source of potential insulation debris in the area. The debris generated from the spherical zone of influence of a double-ended guillotine break in the hot leg and cold legs will bound the debris generated from a failure of a manway cover.

1.1.4.2 Valves

The largest valves in the primary reactor coolant system that are normally pressurized such that failure of the valve body, bonnet, or cover could result in an un-isolable blowdown are the 12" safety injection system injection check valves; SI-217, SI-227, SI-237 & SI-247, and the 12" shutdown cooling isolation valve, MOV-652. The blowdown flow rate from the failure of the bonnet or cover from these valves is limited by the inside diameter of the 12" piping. The hemispherical zone of influence of a bonnet or cover failure will be directed away from the piping which is the largest source of potential insulation debris in the area. The debris generated from the spherical zone of influence of a double-ended guillotine break in the safety injection or shutdown cooling piping at these valves will bound the debris generated from a failure of a valve bonnet or cover.

1.1.4.3 Reactor Head Penetrations

The reactor head has penetrations for 61 control element drive assemblies, 8 in-core instrumentation nozzles, and one vent pipe. These penetrations are much less than 12" in diameter. The hemispherical zone of influence of a penetration failure will be directed away from the reactor head which is the largest source of potential insulation debris in the area. The debris generated from the spherical zone of influences of a double-ended guillotine break in the primary loop piping will bound the debris generated from a failure of a head penetration.

1.2 Scenario Development

1.2.1 Plant Operating Modes

Calvert Cliffs is a two-train plant with a single emergency recirculation suction strainer. The risk assessment considered plant operating modes 1, 2; and mode 3 with pressurizer pressure ≥ 1750 psia.

With a single strainer, two train operation is the limiting operating scenario as it maximizes the recirculation flow rate, debris transport to the strainer, and strainer head loss.

Key operating components influencing strainer performance during recirculation phase include two HPSI pumps and two containment spray (CS) pumps. The two HPSI pumps remain in operation throughout the mission time and one CS pump is secured when containment pressure reduces to below 4.0 psig.

1.2.2 Long-Term Period of Performance

A 30-day mission time was considered for all breaks evaluated. The long-term period of performance is until after the containment atmospheric temperature reduces to 120°F, which is the temperature at which containment spray is terminated and recirculation flow rate is significantly reduced. A safe and stable end state is one in which strainer head loss remains within allowable head loss and long-term core and containment cooling is maintained.

1.2.3 Human Actions Credited

The following operator actions that have an influence on strainer performance are credited in the analysis:

1. Throttling HPSI pump flow to achieve balanced flow of 250 gpm per header with 2 HPSI pumps operating or 150 gpm per header with 1 HPSI pump running.
2. Securing both low pressure safety injection (LPSI) pumps prior to recirculation actuation signal (RAS).
3. Throttling a LPSI pump that has failed to trip and securing one HPSI pump to assure recirculation flow <2900 gpm prior to RAS.
4. Securing one CS pump when containment pressure reduces to 4.0 psig after RAS.

Operator action #1 is currently specified and actions #2, #3, and #4 are being incorporated in the Calvert Cliffs Emergency Operating Procedure (EOP) for Loss of Coolant Accident [Reference (9)]. Plant operators are and will be trained on these actions.

1.2.4 Assumptions and Considerations

As discussed in Sections 1.2.1, 1.2.2, and 1.2.3.

1.3 Failure Mode Identification

The Calvert Cliffs simplified risk informed approach considered the following debris-related failure modes:

a. Excessive head loss at the strainer leads to loss of NPSH margin for adequate operation of the pumps;
b. Excessive head loss at the strainer causes mechanical collapse of the strainer;
c. Excessive head loss at the strainer lowers the fluid pressure, causing release of dissolved gases (i.e., deaeration or flashing); and
d. Debris prevents adequate flow to the strainer or prevents the strainer from attaining adequate submergence.

The Calvert Cliffs risk informed approach did not consider the following debris-related failure modes:

a. Debris in the system downstream of the strainer exceeds ex-vessel limits (e.g., blocks small passages in downstream components or causes excessive wear);
b. Debris results in core blockage and decay heat is not adequately removed from the fuel; and
c. Debris buildup on cladding results in inadequate decay heat removal.

These failure modes are addressed in Attachment 1-2 using existing NRC-accepted methodologies.

1.4 Debris Source Term

Calvert Cliffs prepared multiple calculations to determine the debris source term. The accidents postulated to generate debris were high energy line pipe breaks at welds in ASME Class 1 piping in the primary reactor coolant system and attached piping. The types of debris include the following:

- Fibrous Debris: Nukon, Thermal Wrap, Mineral Wool, Temp-Mat, lead wool shielding blanket cover, and latent fiber.
- Particulate Debris: Marinite Board, calcium silicate, failed coatings, latent dirt and dust.
- Chemical Debris: Sodium Aluminum Silicate precipitate.
- Tags and labels.

The debris quantities and characteristics were determined using NRC-accepted methodologies as described in Attachment 1-2 under NRC Issues 3a, 3b, 3c, 3d, 3h, and 3o.

Marinite and Cal-Sil were combined with coatings and latent particulate debris in the Particulate Debris type. This is acceptable in this analysis for the following reasons:

1. As shown in Section 2.2, the strainer head loss is a function of mass of fiber fines on the strainer,
2. The quantities of Marinite and Cal-Sil are much smaller than fibrous and other particulate debris in the analysis, and
3. The Marinite that was included in the strainer test program did not have a noticeable impact on strainer head loss.

1.5 Debris Transport

Calvert Cliffs assumed 100% of the debris that was dislodged from a target transported to the containment pool. This maximized the production of chemical precipitates. Calvert Cliffs also assumed 100% of the fine fibers, particulate, and precipitate debris was transported to the strainer. This maximized debris loading on the strainer and strainer head loss, which was the performance acceptance criteria for the analysis.

2.0 IMPACT OF DEBRIS

2.1 Maximum Allowable Head Loss

The maximum allowable strainer head loss was determined using existing NRC-accepted methodologies as discussed in Attachment 1-2 under NRC Issue 3f.7 where deaeration is identified as the limiting failure mode for the Calvert Cliffs strainer. Incipient deaeration occurs at the downstream face of the strainer when debris bed head loss exceeds strainer submergence.

Strainer submergence is dependent on LOCA size and break location. Smaller LOCAs have less water injected because the Safety Injection Tanks do not inject. Also, the break location for less than complete

double-ended guillotine breaks (DEGBs) and equivalent size breaks in longitudinal welds in the primary RCS loops can retain more water inside the reactor coolant system. The maximum allowable head loss for three LOCA sizes is presented in Table 1.

A minimum sump water temperature of 120°F is appropriate for the deaeration failure mode. Lower sump water temperatures result in lower water level due to the increased fluid density. However, the Calvert Cliffs containment response analyses demonstrate that the containment vapor temperature remains lower than the sump temperature at sump temperatures at and below 120°F. Containment spray is terminated at a vapor temperature of 120°F and the strainer head loss due to only HPSI pump flow is negligible.

The 140°F temperature division is to account for chemical effects induced head loss increase. The chemical precipitants at Calvert Cliffs remains in solution until the containment pool temperature reduces to 140°F at which time the sodium aluminum silicate precipitates.

Table 1: Maximum Allowable Head Loss

Break Size	Sump Water Temperature (°F)	Maximum Allowable Head Loss (feet)
1) DEGB of Hot Leg/Cold Leg or Equivalent Size Longitudinal Breaks	$120 < T_{sump} \leq 140$	2.21
	$140 < T_{sump} \leq 220$	2.09
2) Other Break Sizes > 0.08 ft^2	$120 < T_{sump} \leq 140$	1.89
	$140 < T_{sump} < 220$	1.77
3) Break Sizes ≤ 0.08 ft^2	$120 < T_{sump} \leq 140$	1.47
	$140 < T_{sump} \leq 220$	1.35

2.2 Acceptable Strainer Head Loss Test

The Calvert Cliffs strainer head loss testing is discussed in Attachment 1-2 under NRC Issue 3f.4 where a test for success program is described. This program resulted in five valid head loss tests. These tests were performed with fiber fines, particulate, and chemical surrogate debris materials. The results of these tests are presented in Table along with the clean screen head loss for the entire strainer assembly and total calculated head loss for the strainer assembly.

Table 2: Head Loss Test Results

Test #	Mass of Fiber Fines (lbm)	Debris Bed Head Loss (ft-water)	
		Clean	Maximum
2	1.429	0.288	0.34
3	3.750	0.288	3.49
4	2.460	0.288	0.90
5	2.926	0.288	1.51
7	2.599	0.288	0.95

The total head loss is plotted as a function of mass of fine fiber debris in Figure 1. An exponential trend line was fit to the results and shows a good empirical correlation between mass of fine fiber and head loss. The correlation is based on Calvert Cliffs prototypical strainer chemical effects head loss testing and a calculation of clean screen head loss for the strainer assembly. This demonstrates that strainer head loss is directly proportional to the mass of fine fibrous debris deposited on the strainer.

This strainer head loss correlation was not used to determine strainer head loss in this analysis. The correlation is only used to demonstrate that strainer head loss at Calvert Cliffs is a function of the mass of fine fibrous debris.

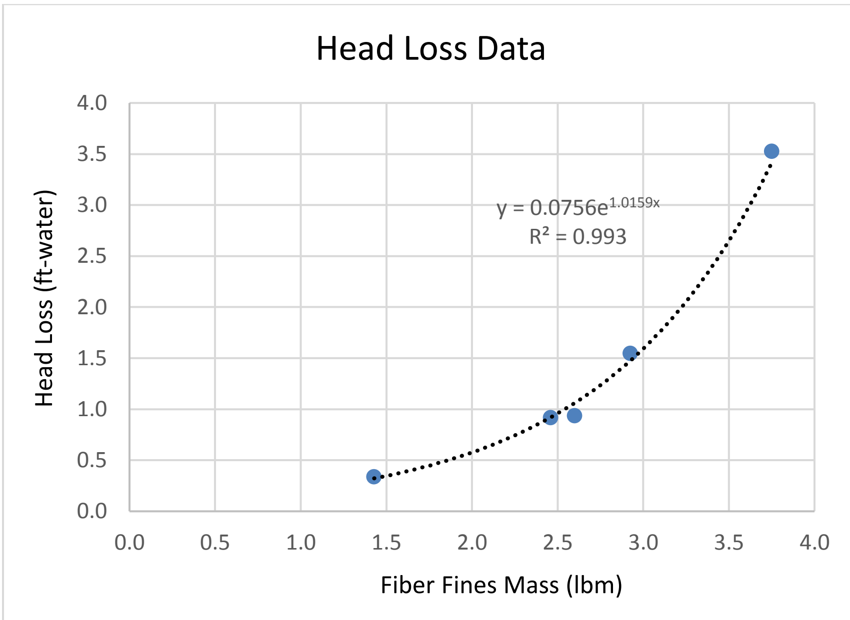

Figure 1: Head Loss Data

During a LOCA, after the RAS is received, EOP-5, Loss of Coolant Accident requires that HPSI flow be throttled to either an indicated flow of 600 gpm (one pump operation) or 1000 gpm (two pump operation). If instrument uncertainty is included, the maximum HPSI flow is 1055 gpm. The maximum post-RAS CS pump flow rate is 1821.4 gpm. EOP-5 also requires that one CS pump be secured at a containment pressure of 4 psig. Containment response analyses demonstrate that a containment pressure of 4 psig is reached before the containment sump fluid temperature drops to 140°F, which is the temperature at which chemical effects head loss impacts the strainer. Therefore, the total emergency recirculation flow rate at the onset of chemical effects head loss is:

1055 gpm + 1821.4 gpm = 2876.4 gpm.

For additional margin, a flow rate of 2900 gpm is assumed.

The 2010 strainer head loss test program used a flow rate corresponding to a plant strainer flow rate of 5000 gpm prior to the addition of chemical precipitates and 2400 gpm after the addition of chemical precipitates. Since the maximum post-RAS strainer flow rate is 2900 gpm, the chemical head loss results reported above must be adjusted to account for the higher flow rate.

To account for the higher strainer flow rate, the chemical head loss recorded in each of the acceptable tests is scaled by the square of the ratio of the expected flow rate (2900 gpm) to the tested flow rate (2400 gpm). Relating the head loss by flow rate squared is consistent with traditional fluid flow relationships (e.g., conservation of energy for incompressible flows, pump affinity laws). Additionally, scaling the chemical head loss by the square of the ratio of the expected flow rate to the tested flow rate is supported by the flow sweep data obtained at the conclusion of each test. The acceptable maximum test head losses scaled to a plant flow rate of 2900 gpm are presented in Table:

Table 3: Scaled Head Loss Test Results

Test #	Head Loss (ft-water)				
	Conventional	Chemical	Scaled Chemical	Clean Screen	Total
2	0.03	0.03	0.05	0.288	0.38
3	0.08	3.16	4.61	0.288	4.98
4	0.05	0.58	0.842	0.288	1.18
5	0.06	1.19	1.742	0.288	2.08
7	0.05	0.64	0.942	0.288	1.28

The plant-equivalent debris quantities for these five tests are presented in Table .

Table 4: Plant Debris Quantities

Test	Total Fiber Fines (lb_m)	Total Particulate (ft^3)	Total Precipitate (lb_m)
2	403	11.18	59.7
3	1058.6	11.18	59.7
4	695	9.076	47.9
5	826	11.38	54.1
7	734	8.877	56.6

2.3 BADGER Debris Generation Calculation

The simplified risk-informed approach determined the quantity of insulation, fire barrier, and radiation shielding debris produced by high energy line breaks at each weld in ASME Class 1 piping As described in Attachment 1-2 under NRC Issues 3a1, 3a3, and 3b4these debris quantities are predicted using the BADGER calculation produced debris source terms for more than 17,500 breaks.

2.4 NARWHAL Risk Quantification Calculation

The NARWHAL software uses the debris results from the BADGER database developed in the BADGER debris generation calculation, and adds on qualified and unqualified coating debris loads, latent debris loads, and miscellaneous (tags, labels,) debris loads to determine a total debris load for each location. NARWHAL then uses 100% debris transport fractions for debris dislodged from targets and calculates break-specific WCAP-16530 chemical precipitate quantities as discussed in Attachment 1-2 under NRC Issue 3o.

The break-specific quantities of fine fiber, particulate, and chemical precipitate debris are compared to the tested head loss values in Table and debris quantities in Table to determine a strainer head loss value for each break. Welds with break locations that produced higher head loss than presented in Table 1 are classified as potential threats to strainer performance. Head loss acceptance criteria include strainer structural margin, pump NPSH margin, and strainer gas void fraction.

The process used in NARWHAL to calculate strainer head loss is described below:

- Clean strainer head loss was input in NARWHAL as a constant value (0.288 ft as discussed in the Response to Issue 3f9 in Attachment 1-2). This head loss is applied as soon as there is flow through the strainer.
- Conventional debris head loss is also input in NARWHAL as a constant value (0.08 ft) based on the maximum tested conventional debris head loss observed in any of the valid Calvert Cliffs head loss tests (see Attachment 1-3 Table 3). This head loss is applied as soon as any conventional debris accumulates on the strainer.
- Chemical debris head loss is computed in NARWHAL using a head loss lookup table that was directly developed from Calvert Cliffs strainer head loss test results. The chemical head losses range from 0.05 ft to 4.61 ft as a function of varying fiber, particulate, and precipitate debris quantities based on five different Calvert Cliffs head loss tests (see Attachment 1-3 Tables 3 and 4). This head loss is applied as soon as any chemical debris accumulates on the strainer and can increase over time as more debris accumulates.
  The following chemical head loss lookup table was used in NARWHAL:

Table 5: NARWHAL Look-Up Table for Chemical Head Loss as a Function of Debris Load

Precipitate (lbm)	Fiber Fines (lbm)	Particulate (ft^3)	Chemical Head Loss (ft)
0	2,500	15.0	0
47.9 (59.7 in test)*	403	11.18	0.05
47.9	695	9.076	0.842
54.1 (56.6 in test)*	734	8.877	0.942
54.1	826	11.38	1.74
59.7	1,058.6	11.18	4.61

*Precipitate quantity conservatively adjusted to ensure that column is in ascending order (work-around for software error documented in NARWHAL-SAR-2018-0002)

- The total strainer head loss is the sum of the clean strainer head loss, conventional debris head loss, and chemical debris head loss.

The NARWHAL analysis evaluated 13,984 break cases and identified that 735 of these breaks generated sufficient debris to produce a head loss higher than allowable. Table 6 identifies these break locations along with the acceptance criteria that was exceeded for each break.

Table 6: Welds Generating Head Loss Greater than Allowable

Weld Identification	Debris Exceedance Criteria			Deaeration Failure
	Fiber Fines	Particulate	Precipitate	
ISI 30-RC-11A-10				X
ISI 30-RC-11A-10LD				X
ISI 30-RC-11A-2				X
ISI 30-RC-11A-3				X
ISI 30-RC-11A-3LU	X		X	X
ISI 30-RC-11A-4				X
ISI 30-RC-11A-4LU	X		X	X
ISI 30-RC-11A-5				X
ISI 30-RC-11A-5LU	X			X
ISI 30-RC-11A-6			X	X
ISI 30-RC-11A-6LU			X	X
ISI 30-RC-11A-7				X
ISI 30-RC-11A-7LU	X	X	X	X
ISI 30-RC-11A-8				X
ISI 30-RC-11A-9				X
ISI 30-RC-11A-W6				X
ISI 30-RC-11B-10			X	X
ISI 30-RC-11B-10LD			X	X
ISI 30-RC-11B-2				X
ISI 30-RC-11B-3				X
ISI 30-RC-11B-3LU			X	X
ISI 30-RC-11B-4				X
ISI 30-RC-11B-4LU	X		X	X
ISI 30-RC-11B-5				X
ISI 30-RC-11B-5LU			X	X
ISI 30-RC-11B-6			X	X
ISI 30-RC-11B-6LU				X
ISI 30-RC-11B-7				X
ISI 30-RC-11B-7LU			X	X
ISI 30-RC-11B-8				X
ISI 30-RC-11B-9			X	X
ISI 30-RC-11B-W7				X
ISI 30-RC-12A-02				X
ISI 30-RC-12A-03				X
ISI 30-RC-12A-04			X	X
ISI 30-RC-12A-05			X	X
ISI 30-RC-12A-06			X	X
ISI 30-RC-12A-07				X

Weld Identification	Debris Exceedance Criteria			Deaeration Failure
	Fiber Fines	Particulate	Precipitate	
ISI 30-RC-12A-08				X
ISI 30-RC-12A-09				X
ISI 30-RC-12A-10				X
ISI 30-RC-12A-10LD			X	X
ISI 30-RC-12A-3LU			X	X
ISI 30-RC-12A-4LU				X
ISI 30-RC-12A-5LU				X
ISI 30-RC-12A-6LU		X	X	X
ISI 30-RC-12A-7LU		X	X	X
ISI 30-RC-12A-W6				X
ISI 30-RC-12B-02				X
ISI 30-RC-12B-03				X
ISI 30-RC-12B-04			X	X
ISI 30-RC-12B-05			X	X
ISI 30-RC-12B-06			X	X
ISI 30-RC-12B-07			X	X
ISI 30-RC-12B-08			X	X
ISI 30-RC-12B-09				X
ISI 30-RC-12B-10				X
ISI 30-RC-12B-10LD			X	X
ISI 30-RC-12B-3LU			X	X
ISI 30-RC-12B-4LU			X	X
ISI 30-RC-12B-5LU			X	X
ISI 30-RC-12B-6LU			X	X
ISI 30-RC-12B-7LU			X	X
ISI 30-RC-12B-W7				X
ISI 42-RC-11-3	X	X	X	X
ISI 42-RC-11-3LU		X	X	X
ISI 42-RC-11-4	X		X	X
ISI 42-RC-11-W5	X		X	X
ISI 42-RC-12-3			X	X
ISI 42-RC-12-3LU		X	X	X
ISI 42-RC-12-4	X		X	X
ISI 42-RC-12-W5	X		X	X

2.5 Critical Break Size

The smallest break size that results in strainer head loss greater than allowable is a 18-inch partial break in a 30 inch inside diameter reactor coolant system primary loop piping. Therefore, the Critical Break size is 18 inches.

2.6 Calvert Cliffs CDF and LERF

The annual CDF and LERF for Calvert Cliffs are presented in Table.

Table 7 : Calvert Cliffs Total Baseline CDF and LERF

Risk	Frequency per Reactor Calendar Year
Unit 1 CDF	5.3E-05
Unit 1 LERF	4.5E-06
Unit 2 CDF	5.1E-05
Unit 2 LERF	4.8E-06

In the Calvert Cliffs simplified risk-informed approach ΔCDF and ΔLERF are computed independent of CDF and LERF. It is more conservative to use the higher CDF and LERF base values. Therefore, the CDF value for Unit 1 and LERF value for Unit 2 will be used in this evaluation.

2.7 ΔCDF

ΔCDF is determined from the LOCA exceedance frequency for the Critical Break size from NUREG-1829 and the strainer CFP calculated using NARWHAL. The NUREG-1829 LOCA frequency is apportioned across all welds equal to or greater than the smallest Critical Break size within the NUREG-1829 LOCA Category using the top-down LOCA frequency methodology.

ΔCDF is calculated in NARWHAL using the following equation:

$$\Delta CDF = \sum_{i=0}^{i=N} \sum_{j=0}^{j=x} IEF_i \times CFP_{ij} \times FFP_j$$

Where:

- I = PRA LOCA size category from PRA
- N = Number of LOCA size categories in PRA
- j = Equipment configuration
- x = Number of equipment configuration in analysis
- IEF = LOCA frequency for size category
- CFP = Conditional failure probability for each size category and equipment configuration
- FFP = Functional failure probability for each equipment configuration

The Calvert Cliffs PRA includes the five (5) LOCA categories presented in Table 8:

Table 8: Calvert Cliffs PRA LOCA Categories

LOCA Category	Break Size
Very Small LOCA	0.43” to 0.96”
Small LOCA	0.96” to 1.66”
Medium LOCA	1.66” to 6.06”
Large LOCA	6.06” to 14.0”
Very Large LOCA	Greater than 14.0”

The Critical Break Size is 18”, which is greater than 14.0”, therefore, the Calvert Cliffs risk-informed GSI-191 evaluation is limited to one LOCA size category which is the Very Large LOCA (VLLOCA).
Calvert Cliffs has a single bounding equipment configuration with respect to GSI-191 which is both Engineered Safety Features trains operating.
Because Calvert Cliffs has only one bounding equipment configuration and only very large LOCAs threaten strainer performance, the ΔCDF equation reduces to:

$\Delta CDF = IEF \times CFP$

Where:

IEF = LOCA Frequency for VLLOCA from NUREG-1829
CFP = VLLOCA conditional failure probability calculated in NARWHAL

The ΔCDF for the base case is conservatively estimated to be 6.3E-08 yr^{-1}.

2.8 ΔLERF

ΔLERF is determined by obtaining a CDF multiplier from the Calvert Cliffs LERF model that is bounded by a worst-case accident sequence for the Critical Break size. A simplified Level 2 event tree, showing only the branches discussed for this analysis is shown in Figure 2. Non-applicable branches and top events are hidden.

This analysis uses the current, peer reviewed, PRA model of record and support documentation. Open updating requirement evaluation items were reviewed for applicability to this analysis.

As discussed in Section 2.7, only very large LOCA events threaten strainer performance. Therefore, ΔLERF can be reasonably estimated by summing the frequency of containment failure and containment isolation failure due to large LOCA, which is also applicable to very large LOCA.

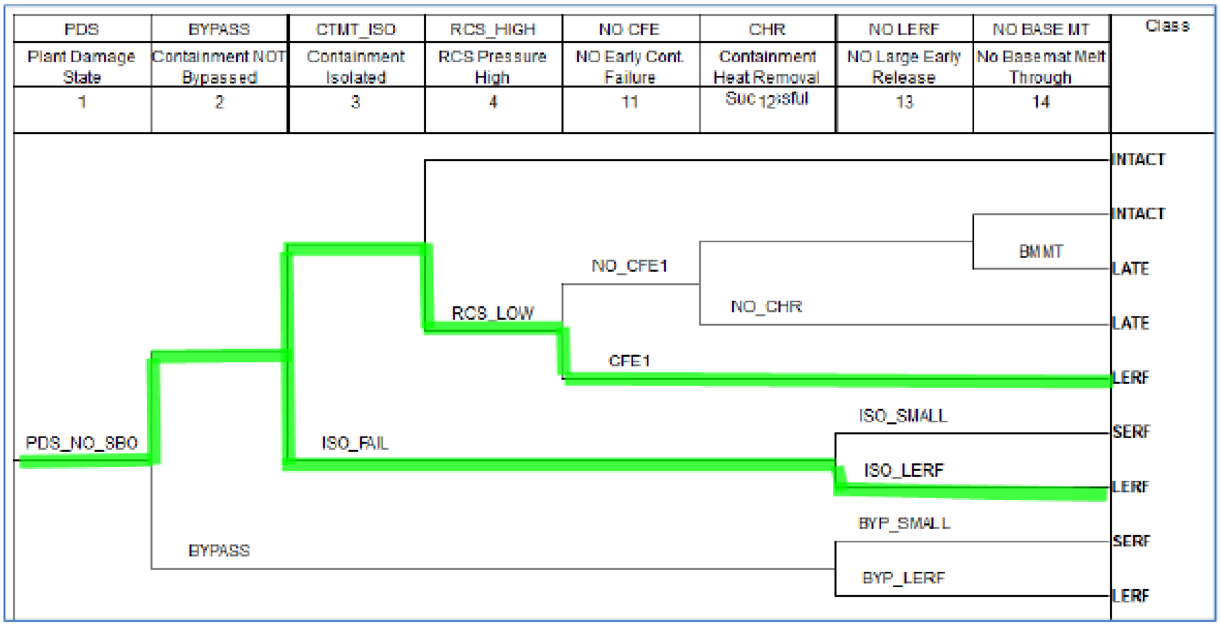

Figure 2: Simplified Level 2 Event Tree

Examination of the Station Blackout (SBO) and Non-SBO event trees shows the accident sequences are the same for these branches, so the discussion below is applicable to both the SBO and Non-SBO event trees.

1) Starting from the left, the first top event is “BYPASS” for “Containment NOT Bypassed.” When the containment is bypassed, the recirculation mode is not questioned, as the RCS inventory is assumed to exit the containment and CDF and LERF events occurs regardless of the status of the containment emergency recirculation sump strainer performance. Therefore, the upper branch (i.e. not BYPASS) is selected.

2) The next top event is “CTMT_ISO” for “Containment Isolated. This event branch is considered for the GSI-191 CDF-to-LERF multiplier. LERF sequences are identified by branch “ISO_LERF.”

3) For non-ISO_FAIL events (e.g. Containment NOT bypassed and Containment Isolation successful), the next top event is “RCS_HIGH” for “RCS Pressure High. As discussed in Section 2.7, only very large LOCA events threaten strainer performance. Large LOCAs are low RCS pressure events. In the Level 2 event trees, the branch for low RCS pressure is “RCS_LOW.” LERF sequences are identified by early containment response event “CFE1.” All other sequences are non-LERF sequences (e.g. INTACT, LATE, or SERF).

2.8.1 Containment Isolation Failure Probability for Large LOCAs

The two branches for the calculation of containment isolation failure probability are ISO_FAIL and ISO_LERF. The fault tree gates for those two events are shown in Figure 3.

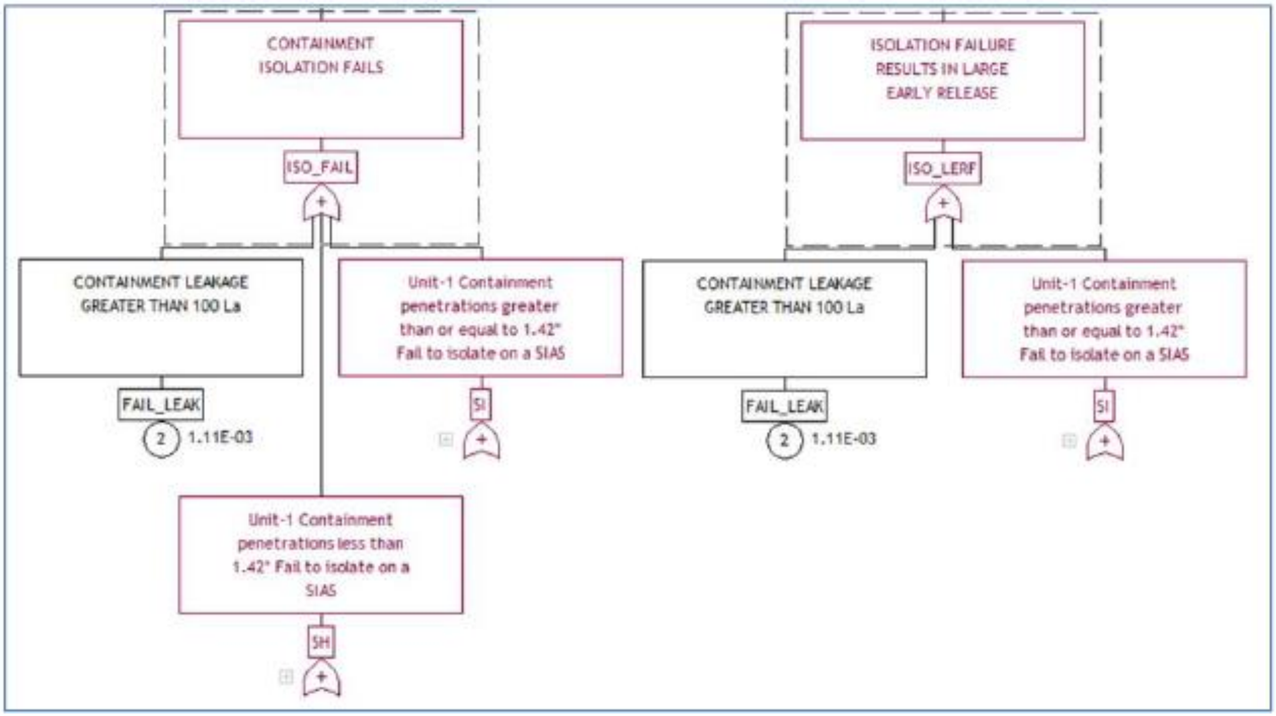

Figure 3: Containment Isolation Fault Tree

Top Event "SH", is non-minimal (that gate is applicable to "ISO_SMALL" scenarios). So, the minimal events are "FAIL_LEAK" and "SI", which is represented by Gate "ISO_LERF".

Using PRAQuant, top event "ISO_LERF" is quantified at 1E-12 for Large LOCA events (the "Normalizing Initiator" option is set to "IE0LLOCA" in the PRA sequence definition). The resulting cutset is "ISO_LERF.cut". A review of the results file shows that the results are reasonable. Some extraneous cutsets are included, but these are not significant and cause conservative results.

The containment isolation failure probability for large LOCAs is 1.11E-03.

2.8.2 Containment Response Failure Probability for Large LOCAs

The containment response CDF-to-LERF conditional multiplier is event "CFE1". CFE represents the probability that the containment fails early with low RCS pressure at vessel breach. The primary contributors to containment failure for this sequence are hydrogen combustion and ex-vessel steam explosions.

The containment failure probability for large LOCAs is 5.95E-02.

2.8.3 CDF-to-LERF Multiplier of LargeLOCAs

The CDF-to-LERF multiplier for large LOCAs is calculated by adding the conditional events calculated above.

CDF-to-LERF multiplier = 1.11E-03 + 5.95E-02 = 6.06E-02.

The ΔLERF is conservatively estimated to be 6.06E-02 x 6.3E-08 yr^{-1} = 3.8E-09 yr^{-1}.

2.8.4 Uncertainties in CDF to LERF Multiplier

The containment isolation failure contribution is not significant, but the containment failure probability analysis contains uncertainties.

1) There are many conservatisms in the containment failure probability due to hydrogen burn, including:

- It is assumed combustion of all generated hydrogen occurs in a single burn. Also, no pre-burning of hydrogen generated in the core melt progression is considered.
- No credit is taken for temperature effects of the gaseous heat capacity.
- There is a conservative uncertainty associated with the estimation of the amount of hydrogen produced for given sequences.

2) The containment failure model assumes that the containment failure contribution due to ex-vessel steam explosions is bounded by all low-pressure vessel failures.

3.0 COMPARISON TO RG 1.174 ACCEPTANCE CRITERIA

The Calvert Cliffs maximum CDF is 5.3 x 10^{-5} and the ΔCDF is 6.3 x 10^{-8} using the "End-of-Plant-License Estimate (40 year) geometric mean LOCA frequencies from NUREG-1829. As shown in Figure 4, this places the risk-significance of pipe breaks that result in higher head loss than allowable and potentially threaten strainer performance is very small and in Region III of Regulatory Guide 1.174.

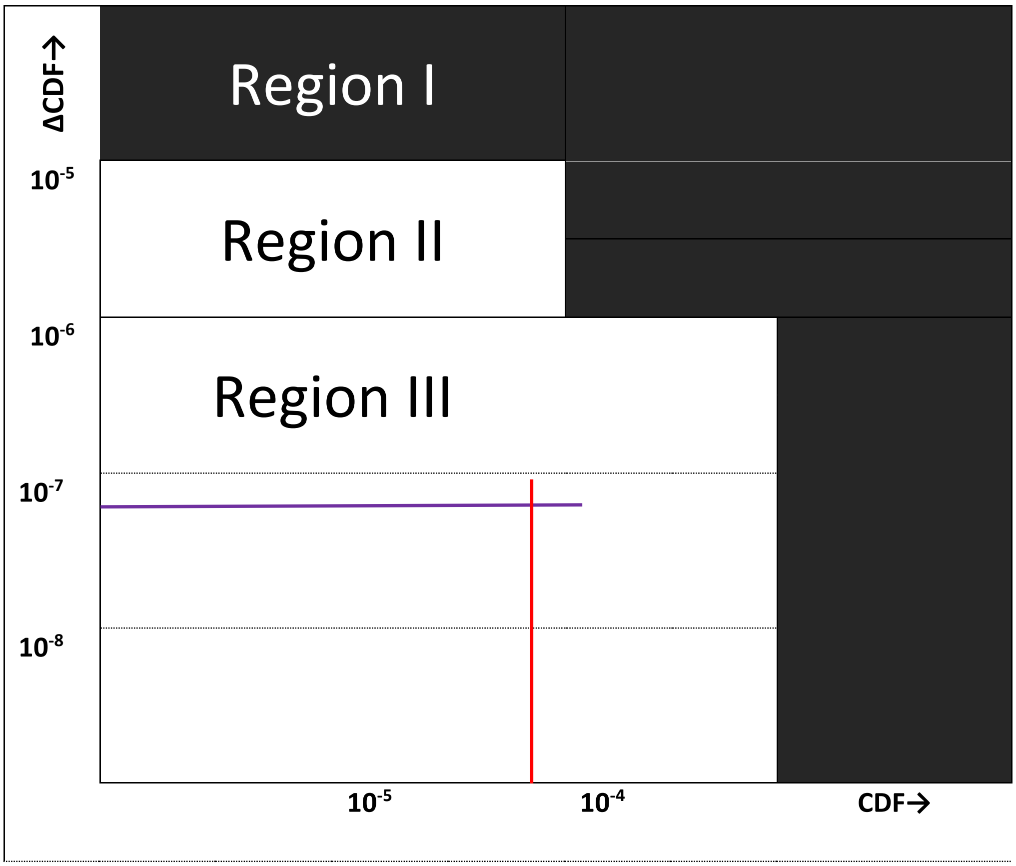

Figure 4: Regulatory Guide 1.174 Acceptance Criteria for CDF

The Calvert Cliffs maximum LERF is 4.8×10^{-6} and the ΔLERF is 3.8×10^{-9} using the "End-of-Plant-License Estimate (40 year) geometric mean LOCA frequencies from NUREG-1829. As shown in Figure 5, this places the risk-significance of pipe breaks that greater head loss than allowable and potentially threaten strainer performance is very small and in Region III of Regulatory Guide 1.174.

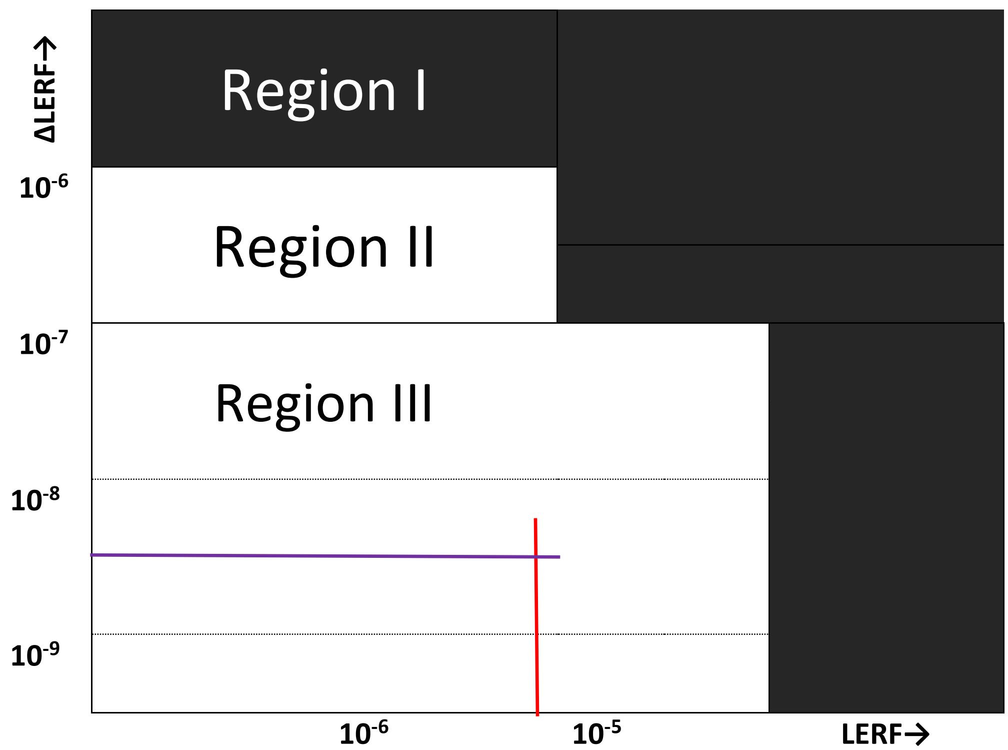

Figure 5: Regulatory Guide 1.174 Acceptance Criteria for LERF

4.0 SENSITIVITY ANALYSIS

Parametric sensitivity analysis was performed to identify which inputs have the greatest impact on the risk quantification results. The parametric sensitivity analysis includes the process of identifying input variables to evaluate, selecting minimum, nominal, and maximum values for each variable, quantifying risk in terms of ΔCDF as a common output that can be compared for each sensitivity, and using the ΔCDF results to rank the sensitivity of each input variable.

The Calvert Cliffs NARWHAL model includes numerous inputs that could have been included in the sensitivity analysis. However, some of these input parameters are directly correlated to other parameters (and therefore should not be independently analyzed), some parameters were pre-screened as having an insignificant effect on the results, and some parameters do not require an independent analysis because they would have the same type of effect as other similar parameters that are evaluated.

A consistent methodology was used to determine the minimum, nominal, and maximum values for each of the parametric sensitivity inputs. Consistency is important because using a very large range for one parameter and a very small range for another parameter may mask the true sensitivity of the second parameter and indicate that the first parameter has a much greater effect on the results. However,

selecting consistent minimum and maximum values is challenging due to practical considerations. For example, the initial RWT level may vary between the technical specification minimum limit and the high-level alarm, and debris head loss may vary from 0 ft at the low end to an unknown value at the high end. In addition, some parameters are not fixed values and may be determined as a function of time (e.g., pool temperature) or as a correlation based on other calculated parameters (e.g., gas void fraction). The following methodology provides an approach for evaluating the various input parameters in a consistent manner.

- The minimum and maximum values for each sensitivity input depend on the nominal value and the available information. If the nominal value was conservatively skewed toward the minimum direction, the minimum value used for the parametric sensitivity was 10 percent lower than the nominal value. Similarly, if the nominal value was conservatively skewed toward the maximum direction, the maximum value used for the parametric sensitivity was 10 percent higher than the nominal value.
- For all other cases, the minimum and maximum values were determined by the available information. Design limits were used preferentially if they were available. If a range of values was determined analytically, the minimum or maximum from the range was used if design limits were not available.
- If no information was available for the range of a given input, then the minimum or maximum value was assumed to be ± 25 percent of the nominal value.

The results of the parametric sensitivity analysis are used to rank each input parameter. This is done using a tornado diagram and a spider plot, which illustrate how sensitive the chosen output metric (ΔCDF) is to a change in an input variable's value from nominal to maximum (or minimum). The tornado diagram and spider plot are created by first running NARWHAL with all inputs set at nominal conditions, and recording the output metric. For both schematics, one variable is then changed to its maximum value (with all others held constant), the software is re-run, the output metric is recorded, and is then compared to the nominal case. This process is repeated with each variable being independently modified to the maximum and minimum values. For the tornado diagram, the output responses are then sorted by magnitude and shown from highest output response (most risk-sensitive parameter) to lowest output response (least risk-sensitive parameter). For the spider plot, the output responses are plotted against the minimum/maximum percent change. The slopes of the lines in the spider diagram represent the most risk-sensitive parameter (steepest slope) and the least-sensitive parameter (no slope).

The minimum and maximum values used in the sensitivity analysis are shown in Table. The ΔCDF results are shown in Table, and the difference in ΔCDF was plotted in the tornado diagram shown in Figure 6 and in the spider plot shown in Figure 7.

An additional sensitivity analysis was performed to investigate the quantity of fiber that could be added to the base case debris source term that would result in a ΔCDF value exceeding RG 1.174 Region III guidelines. The fine fiber increase values and the ΔCDF results are shown in Table and the difference in ΔCDF (compared to the NARWHAL base case value of 6.3E-08 yr-1 is plotted in the spider plot shown in Figure 7. A 500 lbm increase in fine fiber debris increases ΔCDF to a value exceeding RG 1.174 Region III guidelines.

Table 9: Maximum and Minimum Parametric Sensitivity Inputs

Input Parameter	Minimum Input	Maximum Input
Simulation Time	32,400 minutes	54,000 minutes
Initial RWT Mass	3,075,689.8 lbm	3,480,834 lbm
Pressure & Temperature Profiles	75% of Design Basis	110% of Design Basis
Sump and Spray Ph	Max Boric Acid Concentration Max Water Quantity Max LiOH Concentration	Min Boric Acid Concentration Min Water Quantity Max LiOH Concentration
ZOI Debris Quantity	75% of Base Case	110% of Base Case
Unqualified Coatings Quantity	Base Case – 15%	Base Case + 10%
Latent Debris Quantity	75% of Base Case	110% of Base Case
Miscellaneous Debris Quantity	75% of Base Case	200% of Base Case
Aluminum Surface Area	58% of Base Case	167% of Base Case
Debris Head Loss	75% of Base Case	110% of Base Case
Strainer Debris Limits	90% of Base Case	125% of Base Case
Precipitation Temperature	75% of Base Case	110% of Base Case
Geometric LOCA Frequency Values	5^{th} Percentile	95^{th} Percentile

Table 10: Results of Parametric Sensitivity Analysis

Input Parameter	ΔCDF at Minimum Input	ΔCDF at Maximum Input
Simulation Time	6.1E-08	6.7E-08
Initial RWT Mass	8.0E-08	5.9E-08
Pressure & Temperature Profiles	5.4E-08	8.8E-07
Sump and Spray pH	6.2E-08	7.2E-08
ZOI Debris Quantity	2.8E-08	8.0E-08
Unqualified Coatings Quantity	1.7E-08	7.0E-08
Latent Debris Quantity	5.9E-08	6.4E-08
Miscellaneous Debris Quantity	5.8E-08	8.6E-08
Aluminum Surface Area	5.8E-08	9.8E-08
Debris Head Loss	2.3E-08	8.0E-08
Strainer Debris Limits	7.4E-08	6.3E-08
Precipitation Temperature	2.0E-09	6.3E-08
Geometric LOCA Frequency Values	1.1E-10	1.8E-07

Table 11: Fiber Increase Sensitivity Inputs and Results

Fine Fiber Increase (lbm)	ΔCDF
0	6.3E-08
100	1.1E-07
200	1.5E-07
250	1.8E-07
500	1.1E-06

The top five most risk-sensitive parameters for Calvert Cliffs in order of risk significance are:

1. Pressure and temperature profiles
2. Geometric LOCA frequency values
3. Precipitation temperature
4. Unqualified Coatings
5. Head Loss

None of the parametric sensitivity cases showed a large increase in ΔCDF and the resulting ΔCDF for each of the parametric sensitivity cases is within RG 1.174 Region III. The exception to this is the fiber increase sensitivity but that was the intent for this sensitivity.

Two of the parametric sensitivities warrant further discussion as the results are not intuitive.

4.1 Precipitation Temperature

The minimum precipitation temperature improves ΔCDF because the sump fluid never drops to the minimum temperature and precipitates do not form which results in no chemical effects strainer head loss. The maximum precipitation temperature has no effect on ΔCDF because even though precipitates form earlier in the event, the same quantity of precipitates form so no additional strainer failures are predicted.

4.2 Strainer Debris Limits

Reducing strainer debris limits increases ΔCDF because the allowable debris on the strainer is reduced resulting in the prediction of additional strainer failures. Increasing strainer debris limits has no effect on ΔCDF because the results are dominated by chemical precipitate failures which are independent of strainer debris limits.

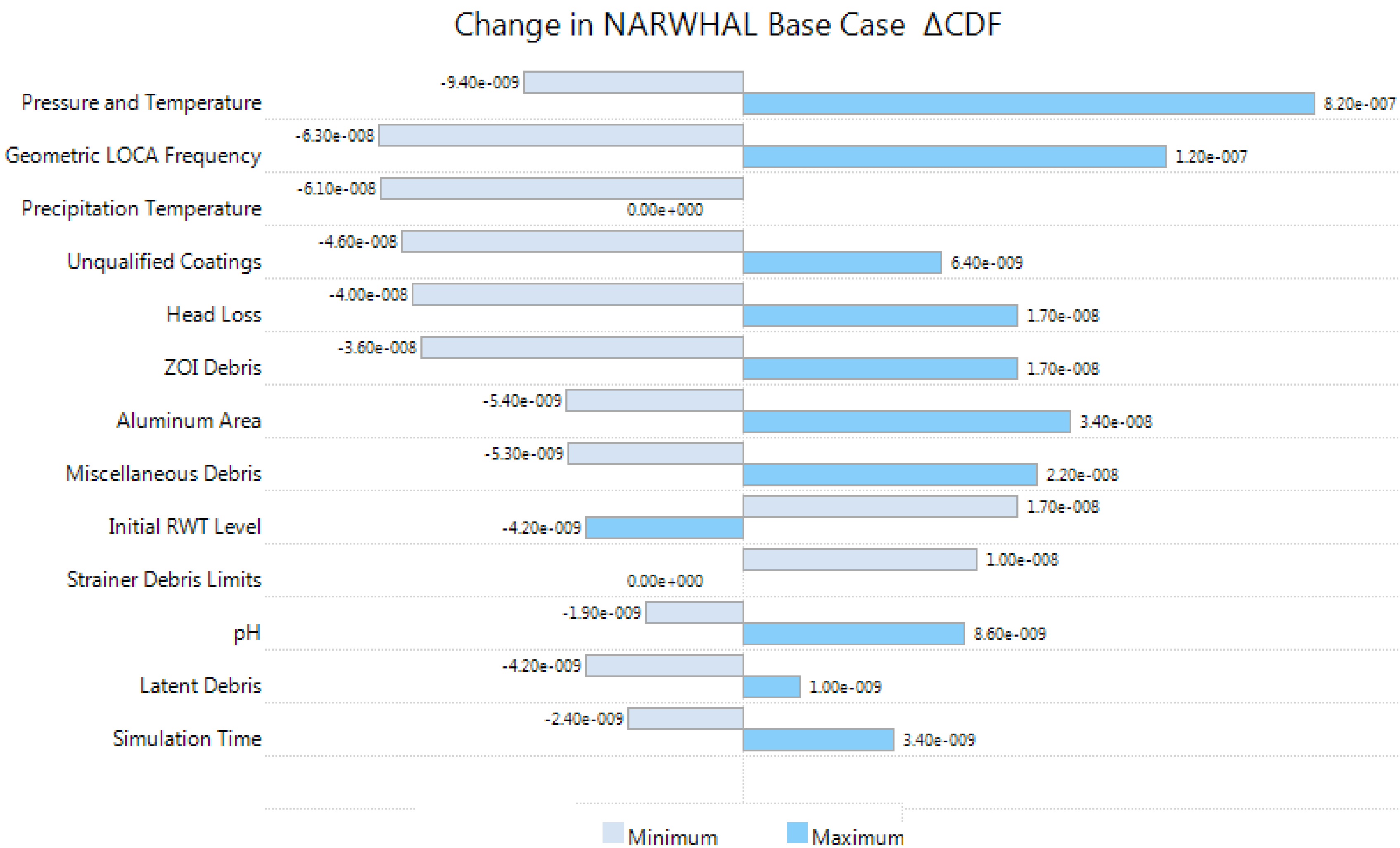

Figure 6: Tornado Diagram Showing Risk Sensitivity Ranking

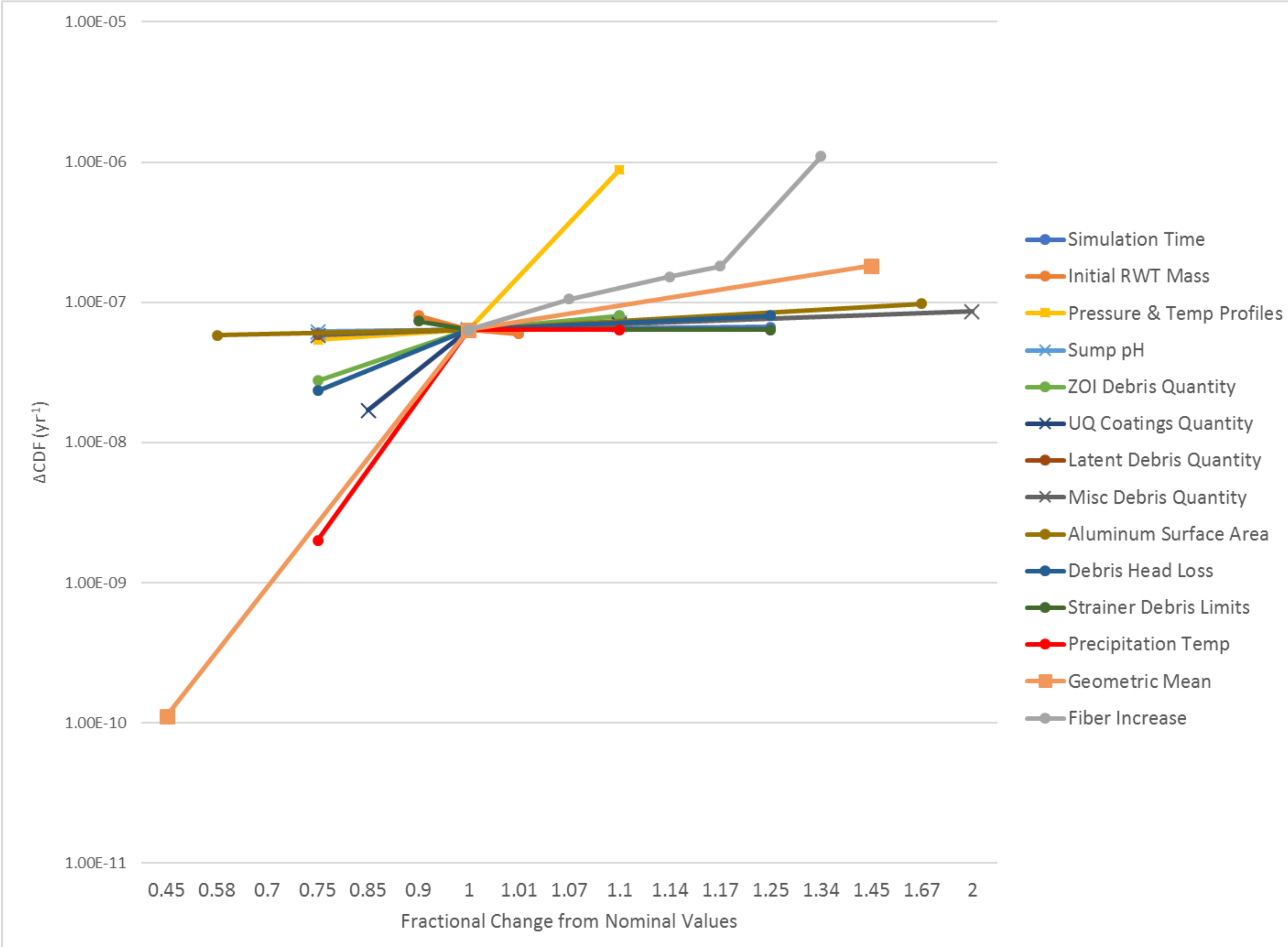

Figure 7: Spider Plot Showing ΔCDF Values vs Change in Input Parameters

5.0 REFERENCES:

(1) NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing, dated March 2008.

(2) Regulatory Guide 1.174, “An Approach for Using Probabilistic Risk Assessment In Risk-Informed Decisions On Plant-Specific Changes to the Licensing Basis”, Revision 2, Nuclear Regulatory Commission, Washington, DC.

(3) WCAP-16406-P-A, “Evaluation of Downstream Sump Debris Effects in Support of GSI-191, Rev. 1, March 2008.

(4) WCAP-16793-NP-A, “Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid”, Rev. 2, July 2013.

(5) WCAP-16530-NP-A, Revision 0, dated March 2008, “Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191.

(6) NUREG-1829, “Estimating Loss-of-Coolant Accident (LOCA) Frequencies Through the Elicitation Process”, April 2008.

(7) Regulatory Guide 1.229, “Risk-Informed Approach for Addressing the Effects of Debris on Post-Accident Long-Term Core Cooling”, Revision Preliminary Draft, Nuclear Regulatory Commission, Washington DC. [ML17025A256, ML1606A016]

(8) Calvert Cliffs Updated Final Safety Analysis Report, Revision 50.

(9) Calvert Cliffs Nuclear Power Plant Technical Procedure Unit One EOP-5, Loss of Coolant Accident, Revision 30 and Unit 2 EOP-5, Loss of Coolant Accident, Revision 29.

(10) NUREG/CR-6850, “Fire PRA Methodology for Nuclear Power Facilities”, September 2005

1-4 Defense in Depth and Safety Margin

1.0 INTRODUCTION

The defense-in-depth (DID) and safety margin (SM) evaluation applies for all debris effects addressed in the risk-informed element of the Calvert Cliffs simplified risk-informed methodology described in Attachment 1-3. That scope is generally described as ≥18-inch breaks in reactor coolant system primary loop piping where a sufficient amount of debris can be generated and transported to the sump to result in strainer head loss higher than allowable based on Calvert Cliffs plant-specific testing. 735 breaks in 72 welds were identified on the reactor coolant system (RCS) main loop piping that could generate sufficient debris to result in strainer head loss exceeding the allowable head loss from deterministic testing.

The DID evaluation shows that there is adequate system capability to provide assurance that public health and safety are protected in the event there is a loss of coolant accident (LOCA) that threatens strainer performance. It identifies operator actions that can be taken to mitigate the event and maintain the robustness of the containment emergency sump design.

The SM evaluation identifies margins and conservatisms in the design, analysis and construction of the Engineered Safety Features at Calvert Cliffs. The evaluation credits very low susceptibility of the welds to degradation mechanisms that could lead to a LOCA, expected smaller actual amounts of debris that would be generated and transported to the sump, little or no actual contribution to head loss from chemical effects, and margin in head loss evaluation.

The conclusion of the evaluation is that substantial defense in depth and safety margin exists.

2.0 DEFENSE IN DEPTH

Defense-in-depth for Calvert Cliffs Units 1 and 2 is based on the plant design, operating procedures, and administrative controls. In responses to NRC Bulletin 2003-01 [Reference (1)] and Generic Letter (GL) 2004-02 [Reference (2)], Calvert Cliffs described modifications to plant hardware (most notably new advanced design recirculation strainers), and operating procedures and administrative controls that were implemented to address Generic Safety Issue 191 (GSI–191) concerns. Calvert Cliffs operating procedures have actions that prevent and mitigate strainer blockage based on indications available to operators such as instrumentation to monitor sump water levels and containment temperatures. Actions include initiation of core flush (combined cold leg and hot leg injection), which provides an alternate flow path that bypasses core inlet blockage, and refilling the refueling water tank (RWT) which can allow temporary termination of recirculation and a return to injection mode of operation. The Calvert Cliffs Technical Specifications (TS) include surveillance requirements for visual inspections of the recirculation strainer to verify inlets are not restricted by debris and that the strainer components show no evidence of structural distress or abnormal corrosion. The Calvert Cliffs Technical Requirements Manual (TRM) includes Technical Normal Condition (TNC) 15.6.2 [Reference (3)] for cleanliness in accessible areas of the containment to verify no loose debris (rags, trash, clothing, etc.) is present which could be transported to the recirculation sump and cause restriction of the suction strainer during LOCA conditions.

The current licensing basis for the Containment Emergency Sump strainer installed to address GSI–191 consists of the current assumptions, initial conditions and conclusions of GL 2004-02 related evaluations, including the current evaluations of design basis accident debris generation and transport, recirculation

strainer performance, impact of chemical effects and downstream effects of debris. Substantial plant-specific testing that supports assumptions and corresponding conclusions contained in the GL 2004-02 evaluations for Calvert Cliffs has been performed. This information supporting the previous deterministic methodology for demonstrating compliance is documented in supplemental information provided in response to GL 2004-02 and forms the deterministic basis for the Calvert Cliffs simplified risk-informed methodology. The risk-informed element of the analyses associated with the proposed exemption and license amendment along with the design, procedure and administrative controls already incorporated demonstrate that the risk from LOCAs where the Containment Emergency Sump strainer will not perform its required functions is very small and acceptable in accordance with the criteria of Regulatory Guide (RG) 1.174 [Reference (4)]. The Calvert Cliffs simplified risk-informed approach follows RG 1.174, verifying DID and SM are maintained through design modifications, ongoing design modification controls, and maintenance procedures including the inservice inspection (ISI) program. The approach is comprehensive in nature, analyzing a full spectrum of LOCAs including double-ended guillotine breaks (DEGB) for all piping sizes up to and including the largest pipe in the RCS. By requiring that mitigative capability be maintained in a realistic and risk-informed evaluation of GSI–191 for a full spectrum of LOCAs, the approach ensures that DID is maintained.

The proposed change to the licensing basis is consistent with maintaining DID in that the following aspects of the facility design and operation are maintained:

- Functional requirements and design configurations of systems
- Existing plant barriers to the release of fission products
- Design provisions for redundancy, diversity and independence
- Plant response to transients and other initiating events
- Preventative and mitigative capability of plant design features.

Based on the results of the risk-informed method and the hardware, operating procedures and administrative controls already implemented to address GSI–191 concerns, Calvert Cliffs has high confidence that plant systems and operators would respond as required to mitigate postulated LOCAs. This confidence is bolstered by the DID features for Calvert Cliffs described below.

2.1 Effectiveness of Defense in Depth Actions

The effectiveness of the DID actions is shown to be acceptable when considering the following:

- Calvert Cliffs Emergency Operating Procedures (EOPs) are based on the approved industry standard Emergency Response Guidelines (ERGs). These symptom-based EOPs have generic or site–specific analyses that support them.
- Calvert Cliffs Severe Accident Mitigation Guidelines (SAMGs) are based on approved industry standard guidance.
- The procedures are trained upon and evaluated as part of the classroom training.
- The DID actions are trained upon using the simulator to demonstrate effectiveness.
- The procedures that make the framework for the DID actions are evaluated during the Calvert Cliffs station review and approval process.

2.2 Evaluations

Calvert Cliffs DID measures that are associated with the concerns of GSI–191 are evaluated by applying regulatory guidance and industry guidance.

2.2.1 Guidance in RG 1.174

Calvert Cliffs proposes a licensing basis change to use a risk-informed approach to address the concerns of GSI–191 with respect to maintaining long term cooling post–LOCA on the basis that the change meets the principles and acceptance guidelines of RG 1.174. The DID elements given in Section 2.1.1 of RG 1.174 discussed below have been evaluated to show that the proposed change is consistent with DID for Calvert Cliffs Units 1 and 2. The DID for Calvert Cliffs is based on the hardware, operating procedures, and administrative controls and design modifications that have been implemented or planned to address the concerns of GSI–191 and GL 2004-02. The proposed licensing basis change does not propose any additional DID measures.

A reasonable balance is preserved among prevention of core damage, prevention of containment failure, and consequence mitigation.

Calvert Cliffs Units 1 and 2 each have two trains of Safety Injection (SI) equipment for the prevention of core damage. Each train includes two SI Tanks (SITs), a High Pressure SI (HPSI) pump, and a Low Pressure SI (LPSI) pump. There are also two independent trains of equipment for containment heat removal to prevent containment failure. The heat removal equipment for each train includes a Containment Spray (CS) pump that has its discharge routed through the Shutdown Cooling heat exchanger for cooling by safety-related component cooling water (CCW) and two containment air cooler units per train that are cooled by safety–related service water. Consequence mitigation is achieved using active equipment of these Engineered Safety Features and by maintaining the containment building as an effective barrier to radioactive release.

The proposed license change does not involve any change to the design or design requirements of the current plant equipment associated with GSI–191. As discussed further below, the proposed change does not affect the containment integrity or the capability of the independent and safety–related containment air coolers (CACs) to remove post–LOCA decay heat from containment. There is no change to the strategies for the prevention of core damage, for prevention of containment failure, or for consequence mitigation. Thus, the existing balance among these is preserved.

Over–reliance on programmatic activities as compensatory measures associated with the change in the licensing basis is avoided.

Programmatic activities associated with the proposed change include the ISI program, plant personnel training, RCS leak detection program, and containment cleanliness inspection activities. The ISI program requires non-destructive examinations of the RCS components and piping. The inservice testing (IST) program requires testing of active components such as pumps and valves in the RCS, SI, and CS systems. The proposed change does not rely heavily on programmatic activities as compensatory measures nor propose any new programmatic activities that could be heavily relied upon. The risk-informed approach does consider pipe break frequencies. Calvert Cliffs has previously implemented a risk-informed ISI program that was approved by the NRC. The ISI program is an effective element of DID that performs an important role in the prevention of pipe breaks. It is important to note that the risk-informed GSI-191 program, and the risk-informed ISI program are complementary in that the risk insights from the stations plant specific probabilistic risk assessment (PRA) are used in conjunction with deterministic information to improve the safety and effectiveness of the ISI program.

The leak detection program at Calvert Cliffs is capable of early identification of RCS leakage in accordance with RG 1.45 [Reference (5)] to provide time for appropriate operator action before a flaw causing a leak would propagate to a break. This program is an important contributor to DID.

Containment cleanliness inspection activities are performed prior to reactor startup following outages, as required by the TRM. The deterministic element of the Calvert Cliffs GSI-191 program uses an input for the assumed amount of latent debris inside containment after the cleanup activity is complete that is in accordance with the Nuclear Energy Institute (NEI) 04-07 guidance [Reference (6)] for a deterministic approach. Thus, there is no over–reliance on Calvert Cliffs programmatic activities to quantify or manage latent debris as compensatory measures for the risk–informed approach.

System redundancy, independence, and diversity are preserved commensurate with the expected frequency, consequences of challenges to the system, and uncertainties (for example, no risk outliers).

Calvert Cliffs Units 1 and 2 each have two trains of SI equipment for the prevention of core damage. Each train includes two SITs, a HPSI pump, and a LPSI pump. There are also two independent trains of equipment for containment heat removal to prevent containment failure. The heat removal equipment for each train includes a CS pump that has its discharge routed through the Shutdown Cooling heat exchanger for cooling by CCW and two CACs per train that are cooled by safety–related service water. Each train draws recirculation suction through a single, large emergency recirculation sump strainer to provide suction flow during the recirculation mode to the respective train's pumps.

The proposed license change does not require any design change to these systems. Thus, system redundancy, independence, and diversity are preserved. The proposed licensing basis change also does not call for any changes to the system operating procedures. These systems have been fully analyzed relative to their contribution to nuclear safety through the Calvert Cliffs plant–specific PRA. The Calvert Cliffs PRA includes the risk contributions for the full spectrum of LOCA events and meets industry PRA standards for risk–informed applications. The treatment of uncertainties in the risk-informed model ensures results are obtained for realistic assessments. The uncertainties using the risk-informed approach methodology have been examined in the PRA and there are 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.

The proposed license change does not change any defenses against common–cause failures. A potential common cause failure would be the recirculation strainer becoming clogged so that there would not be adequate flow to any of the SI and CS pumps. The defenses that apply to potential strainer clogging (for example change in flow rate, conserving RWT inventory, refilling the RWT, use of alternate injection sources, and stopping/starting of pumps) are not changed by the use of the risk-informed methodology since there are no design changes to the equipment or changes to the EOPs.

The potential for new common–cause failure mechanisms has been assessed for the GSI–191 issues. The primary failure mechanisms of concern are recirculation strainer clogging. A new aspect of clogging is the consideration of non-condensable gas evolution from the recirculation flow and eventual gas binding of the strainer. However, the defenses against gas binding are effective, reasonable and acceptable operational measures to mitigate or ameliorate adverse strainer performance. Additionally, these defenses do not change due to the proposed licensing basis change to use the RG 1.174 risk–informed approach. Since the risk-informed approach does not involve any design changes to the equipment or changes to the operating procedures beyond those already taken in response to the concerns raised in GSI–191, it does not introduce any new common–cause failures or reduce the current plant defenses against common–cause failures.

Independence of barriers is not degraded.

The three barriers to a radioactive release are the fuel cladding, the RCS piping and components, and the containment building. For the evaluation of a LOCA, the RCS barrier is postulated to be breached. The proposed licensing basis change does not involve any change to the design and analysis requirements for the fuel. Thus, the fuel barrier independence is not degraded. Consequently, the risk–informed GSI–191 analysis approach focuses primarily on addressing the integrity of the fuel cladding by assuring the SI and CS cooling function is maintained. The Calvert Cliffs risk–informed evaluation includes both the SI and CS cooling function and the containment function.

In the recirculation mode of accident mitigation, the post–LOCA fluid that collects on the containment floor is pumped by the HPSI and CS pumps that are located in the Auxiliary Building. Thus, the recirculated fluid goes from the containment to the Auxiliary Building and back to the containment. The barrier to release from the Auxiliary Building is the SI and CS piping and components in the recirculation flow path. The Auxiliary Building heating, ventilation, and air conditioning (HVAC) system has filters to handle gaseous leakage that would come from any recirculating sump water leakage in the Auxiliary Building. The proposed licensing basis change does not involve any change to the design and operating requirements for this equipment. Thus, there is no change to the containment bypass path.

The containment is fully analyzed for not only design basis considerations but also from a Level 2 PRA perspective. Detailed analyses for severe accident phenomena, including LOCAs, have been evaluated for impact to containment building integrity; and these events do not challenge the overall capability of the containment to remain intact. Also, it should be noted that additional DID capability is available through the use of the CACs. The CACs have enough cooling capability to remove decay heat from the containment through containment atmosphere cooling during the SI and CS recirculation phase thereby further reducing containment integrity challenges.

The proposed license change does not involve any design change to these barriers (fuel, piping, building, HVAC filters). Thus, the independence of the barriers is maintained and not degraded.

Defenses against human errors are preserved.

The proposed license change does not involve any design change to the current equipment or any change to operating procedures. Operator actions during the initial accident mitigation stage are

focused on monitoring of the automatic mitigation actions including automatic SI and CS responses to the event. Prior to depletion of the RWT, there is an automatic shutdown of the LPSI pumps and switchover of the HPSI and CS pumps from taking suction from the RWT to taking suction from the emergency recirculation sump. In accordance with EOPs, the switchover from cold leg injection to core flush (combined cold leg and hot leg injection) is a manual action performed by the operator. The use of the methodology for the risk-informed approach does not change any of the EOPs that would be used or impose any additional operator actions or complexity. Thus, the defenses that are already in place with respect to human errors are not impacted by the proposed licensing basis change.

The intent of the plant's design criteria is maintained.

The proposed license change does not involve any change to the design or design requirements of the current plant equipment associated with GSI–191. Based on the results of the proposed license change showing that the risk-informed approach meets RG 1.174 acceptance criteria, the proposed license change revises the licensing basis for acceptable Containment Emergency Sump strainer design and performance in support of SI and CS operation in recirculation mode following postulated LOCAs. Therefore, the intent of the plant's design criteria is maintained.

The design and licensing basis descriptions of accidents requiring SI and CS operation, including analysis methods, assumptions, and results provided in Updated Final Safety Analysis Report (UFSAR) Chapters 6 and 14 remain unchanged. The proposed change to the licensing basis continues to meet the intent of the design criteria that apply to functions addressed by GSI–191. This conclusion is based on the results of the risk-informed approach that demonstrate that the calculated risk associated with GSI–191 concerns for Calvert Cliffs Units 1 and 2 is very small and in accordance with the Region III acceptance guidelines defined by RG 1.174.

The performance evaluations for accidents requiring SI and CS operation described in UFSAR Chapters 6 and 14 are based on the Calvert Cliffs Units 1 and 2 10CFR50 Appendix K Large–Break Loss–of–Coolant Accident analysis. These evaluations demonstrate that for breaks up to and including the double–ended guillotine break of a reactor coolant pipe, the SI will limit the clad temperature to below the limit specified in 10 CFR 50.46 [Reference (7)], thus assuring that the core will remain in place and substantially intact with its essential heat transfer geometry preserved. The proposed license change does not involve a change to the emergency core cooling system acceptance criteria specified in 10 CFR 50.46. Therefore, the intent of the plant's design criteria is maintained.

2.3 NEI Guidance for Defense in Depth Measures in Support of Response to GL 2004-02

For the purposes of GL 2004-02 resolution, the primary regulatory objective is specified in 10 CFR 50.46(b)(5) as long-term cooling. A method for ensuring adequate DID is to maintain the capability for operators to detect and mitigate inadequate flow through recirculation strainers and inadequate flow through the reactor core due to the potential impacts of debris blockage. The following evaluation of the Calvert Cliffs DID measures that support the Calvert Cliffs application for a risk-informed approach to closing GL 2004-02 is based on NEI guidance that includes additional justification for the measures discussed [Reference (8)).

2.3.1 Prevention of Inadequate Recirculation Strainer Flow

Calvert Cliffs Units 1 and 2 have within their EOP framework, specific steps for monitoring for indications of sump strainer blockage and actions to be taken if this condition occurs. These actions are described in the Calvert Cliffs response to NRC Bulletin 2003-01 and the subsequent responses to the NRC requests for additional information. The actions taken in response to NRC Bulletin 2003-01 are still in effect at Calvert Cliffs Units 1 and 2.

In summary, these actions include (1) reducing flow through the strainer by stopping pumps, (2) monitoring for proper pump operation, core exit thermocouples, and reactor water level indication, (3) refilling the RWT for injection flow, (4) using injection flow from alternate sources, and (5) transferring to combined hot leg/cold leg injection flow paths.

Calvert Cliffs EOPs that implement these actions include:

- EOP-5 “Loss of Coolant Accident”
- EOP-8 “Functional Recovery Procedure

2.3.2 Detection of Inadequate Strainer Flow

Calvert Cliffs has operational procedures to monitor the high pressure safety injection (HPSI) pump flow, discharge pressure, and amperage. By monitoring these operating parameters, control room personnel could properly diagnose the occurrence of cavitation, which would be an indication of sump clogging or significant deaeration. Control room personnel have been trained to evaluate this type of indication and take appropriate action such as reducing strainer flow rate by securing containment spray pumps.

2.3.3 Mitigation of Inadequate Recirculation Strainer Flow

Refueling Water Tank Refill and Realignment for Injection Flow – The Calvert Cliffs Emergency Response Plan Implementing Procedures (ERPIPs) provide guidance for refilling the RWT and realigning the SI system for injection flow. The limiting failure mode for the Calvert Cliffs emergency recirculation sump strainer is gas binding due to non-condensable gases released from the fluid due to the pressure drop across the debris bed. Refilling the RWT and realigning the SI system for injection flow will increase containment water level which will reduce the potential for deaeration. Also, terminating recirculation flow temporarily will allow buoyancy forces to eject the non-condensable gases inside the strainer effectively back-flushing and disrupting the debris bed. The disrupted debris bed would fall to the containment floor as agglomerated large clumps of debris which would not be expected to re-suspend in the flow and transport back to the strainer pockets.

In response to the Nuclear Regulatory Commission (NRC) Order EA-12-049, “Mitigation Strategies for Beyond-Design-Basis External Events (BDBEE)”, Calvert Cliffs developed diverse and flexible coping strategies (FLEX) to maintain RCS inventory control, RCS cooling, and containment integrity. Various modifications have been implemented such that non-emergency equipment can be credited during an event. For example, the FLEX RCS Makeup Pump can be used to inject coolant into the RCS should the emergency recirculation strainer fail.

2.3.4 Prevention of Inadequate Reactor Core Flow

Calvert Cliffs successfully demonstrated less than 15 grams per fuel assembly of fiber would enter the core which resolved the in-vessel downstream effects concern. In addition to this the following defense in depth measures are available.

2.3.5 Detection of Inadequate Reactor Core Flow

Inadequate core cooling due to debris blocking the core or boric acid precipitation would be indicated by an increase in core exit thermocouple temperature and a reduction in RCS subcooling.

2.3.6 Mitigation of Inadequate Reactor Core Flow

EOP-5 and EOP-8 provide operator guidance for commencing core flush to restore and maintain RCS subcooling. Also, as discussed in Section 2.3.3, the FLEX RCS Makeup Pump can be used to inject coolant into the RCS should the emergency recirculation strainer fail.

2.3.7 Implementation of SAMGs

Severe Accident Management Guidelines (SAMG) provide additional guidance and actions for addressing inadequate core flow conditions. Typically, SAMGs will be entered when directed by the EOPs and with the concurrence of the Technical Support Center (TSC). The SAMGs are used by the technical support staff in the TSC or Emergency Offsite Facility to evaluate alternative courses of action for a degrading condition. The SAMGs will provide guidance for flooding containment above the reactor vessel hot and cold leg nozzles thus covering the break location to provide for convective circulation cooling of the reactor vessel.

2.4 Training Related to the Proposed Change

The proposed change does not result in changes to the symptom–based response procedures and guidelines beyond those already implemented in response to Bulletin 2003–01 and GL 2004–02. Initial training on sump blockage issues was completed, and licensed operator classroom and simulator training on indications of, and responses to, degraded pump flow indications which may be caused by Containment Emergency Sump clogging is provided during initial and requalification training. Training has been conducted for Emergency Response Organization decision makers and evaluators in the TSC on indications of sump blockage and compensatory actions.

2.5 Barriers for Release of Radioactivity

The following evaluation demonstrates that the proposed change maintains sufficient safety margin for the current barriers for release of radioactivity, which are the fuel cladding, the RCS boundary, the containment, and the Emergency Plan (EP) actions. The evaluation concludes that the proposed licensing basis change:

- Does not affect or remove any of these levels of protection.
- Does not result in a significant increase in the existing challenges to the integrity of the barriers.
- Does not significantly change the failure probability of any individual barrier.
- Does not introduce new or additional failure dependencies among barriers that significantly increase the likelihood of failure when compared to the existing conditions.
- Does not change the overall redundancy and diversity features among the barriers that are sufficient to ensure compatibility with the risk acceptance guidelines.

2.5.1 Fuel Cladding

The fuel cladding barrier is maintained by the ECCS following a LOCA. After the initial phase of the accident mitigation, long term cooling is maintained post–LOCA by the ECCS and shutdown cooling system. The proposed licensing basis change for the change in methodology to use a RG 1.174 risk-informed approach for the effects of debris does not make any change to the previous analyses and testing programs that demonstrate the acceptability of the ECCS for the initial phase of providing core

cooling. The proposed licensing basis change shows that long term cooling is met for the additional accident mitigation and recovery phase for the LOCAs in the deterministic scope of the Calvert Cliffs GSI-191 evaluation. The evaluation of DID and safety margin provides confidence that adequate mitigation will be provided for the risk-informed scope of the Calvert Cliffs GSI-191 evaluation. The proposed license change does not involve any change to the design or design requirements of the current plant equipment associated with GSI–191. There is no change to the design and analysis requirements for the fuel.

2.5.1.1 Emergency Core Cooling

Calvert Cliffs has a system to provide abundant emergency core cooling. The system safety function is to transfer heat from the reactor core following any loss of reactor coolant at a rate such that: (1) fuel and clad damage that could interfere with continued effective core cooling is prevented and; (2) clad metal-water reaction is limited to negligible amounts. Suitable redundancy in components and features, and suitable interconnections, leak detection, isolation, and containment capabilities are provided to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.

2.5.1.2 Long Term Cooling

To comply with 10 CFR 50.46(b)(5), "Long-term cooling," the Calvert Cliffs RG 1.174 risk-informed approach for post–LOCA sump performance shows that after the successful initial operation of the ECCS, the core temperature is maintained at an acceptable low value and decay heat is removed for the extended period of time required by the long-lived radioactivity remaining in the core.

2.5.2 Reactor Coolant System Pressure Boundary

The integrity of the RCS pressure boundary is postulated to be broken for the GSI-191 sump performance evaluation that is concerned with post–LOCA debris effects. However, the proposed change does not make any change to the previous analyses and testing programs that demonstrate the integrity of the RCS. Since the proposed licensing basis change does not impact any design or programmatic requirements for the reactor coolant pressure boundary, the likelihood of a LOCA is not affected.

2.5.2.1 Inservice Inspection Program

The ISI program performs an important role in the prevention of pipe breaks. The integrity of the welds in ASME Class 1 piping and components are maintained at a high level of reliability through the ASME Section XI inspection program. Exelon procedure, ER-AA-330 [Reference (9)] and the Calvert Cliffs ISI Program Plan [Reference (10)], ensure that the following requirements of TRM 15.4.3 are satisfied:

- Verification of the structural integrity of ASME Class 1, 2, and 3 components are within the limits specified in the Inservice Inspection Program, and
- Verification of the structural integrity of the main steam and main feedwater piping is within the limits specified in the augmented Inservice Inspection Program.

2.5.2.2 RCS Dissimilar Metal Weld Mitigation

Calvert Cliffs has 27 dissimilar metal welds in ASME Class 1 piping in each unit, 19 of which are much smaller than the critical weld size in the simplified risk-informed analysis. Calvert Cliffs has eight (8) dissimilar metal welds in ASME Class 1 piping in each unit at the RCS cold leg to reactor coolant pumps. These welds are the critical weld size but are not necessarily welds producing sufficient debris to

threaten performance of the emergency recirculation strainer. These welds are not susceptible to primary water stress corrosion cracking (PWSCC) due to the temperature at which they operate. Additionally, the susceptibility of these welds to PWSCC has been mitigated through a zinc injection process.

2.5.2.3 RCS Leakage Detection

The leak detection program at Calvert Cliffs is capable of early identification of RCS leakage in accordance with RG 1.45 to provide time for appropriate operator action to identify and address RCS leakage. The effectiveness of this program is not reduced by the proposed licensing basis change to the risk–informed approach for GSI–191.

2.5.3 Containment Integrity

The evaluation of sump performance using a risk-informed approach is not a component of the analyses that demonstrates containment integrity. Previous analyses show that the containment structure can withstand the peak pressures calculated without loss of integrity. The containment remains a low leakage barrier against the release of fission products for the duration of the postulated LOCAs.

2.5.3.1 Containment Design Basis

The principal design basis for the containment is that it be capable of withstanding the internal pressure resulting from a LOCA with no loss of integrity. In this event, the total energy contained in the water of the RCS is assumed to be released into the containment structure through a break in the reactor coolant piping. Subsequent pressure behavior is determined by the building volume, engineered safety features, and the combined influence of energy sources and heat sinks.

2.5.3.2 Containment Heat Removal

The proposed license change does not involve any change to the design or design requirements of the current plant equipment associated with GSI–191. Thus, there is no change to any of the containment heat removal components needed to maintain containment integrity. Therefore, the proposed change does not significantly impact the structural capability and integrity of the containment as an effective fission product barrier post–LOCA. The Calvert Cliffs large, dry containments with safety–grade CACs are likely to survive a significant core damage event, even with a loss of the containment emergency recirculation sump.

CACs are designed to operate independently in the post–LOCA environment and are not directly affected by the loss of the recirculation sump or containment spray. This additional and independent capability to reject decay heat from containment ensures that the containment would not fail because of overpressure or overheating. Although core melt could be postulated, containment integrity would be maintained by operation of the CACs and the containment would continue to be maintained as an effective fission product barrier.

Energy released to the containment atmosphere from the postulated accidents is removed by the CS and CACs. Calvert Cliffs has four two speed cooling units located entirely within the containment. Service water is circulated through the air cooling coils. The CACs are designed to remove heat from the containment during both normal operation and accident conditions.

Upon receipt of a safety injection actuation signal (SIAS), any idle cooling unit is automatically started on the low speed setting and, simultaneously, any running fan is switched from the normally operating high speed setting to low speed operation. The CACs are supplied cooling water from the safety-related

service water system (SRW). The full flow SRW outlet valves for each cooler are opened upon receipt of a SIAS. The SRW inlet valves move to a throttled position upon receipt of a SIAS and return to the full open position upon receipt of a recirculation actuation signal.

The CACs remove thermal energy from inside the containment to reduce the containment atmosphere pressure and temperature following loss of offsite power (LOOP) or a design basis accident (DBA). The containment response analysis evaluated many single failure scenarios ranging from single component failure to complete train failure and allowable peak pressure and temperature of the containment was not reached following a DBA.

Other industry studies have indicated the ability of the containment systems to survive challenges of 2.5 to 3 times the design levels. The Zion Probabilistic Safety Study showed that the containment ultimate capacity was 2.55 to 2.86 times the design capacity.

2.5.3.3 Containment Testing

TS Surveillance Requirement 3.6.1.1 requires a Containment Leakage Rate Testing Program to be established to implement leakage rate testing of the containment as required by 10 CFR 50.54(o) [Reference (11)] and 10 CFR 50, Appendix J [Reference (12)], Option B, as modified by approved exemptions. This program is in accordance with the guidelines contained in RG 1.163 [Reference (13)].

The proposed change does not impact the requirements for structural integrity and leak-tightness of the containment and does not involve any changes to the containment leakage testing requirements for demonstrating the effectiveness of the containment as a low leakage barrier.

2.5.4 Emergency Plan Actions

The proposed change to the licensing basis to use the methodology of a risk-informed approach does not involve any changes to the Emergency Plan. There is no change to the strategies for prevention of core damage, for prevention of containment failure, or for consequence mitigation. The use of the risk-informed approach does not impose any additional operator actions or complexity. Implementation of the proposed change would not result in any changes to the response requirements for emergency response personnel during an accident. The Calvert Cliffs DID approach includes the ability to detect, prevent, and mitigate post–LOCA strainer debris blockage and in–vessel debris blockage.

3.0 SAFETY MARGIN

There are numerous conservatisms used throughout the Calvert Cliffs risk-informed GSI-191 evaluation. However, not all of these conservatisms were classified as safety margin. Some conservatisms were included to provide future operating margin (i.e., margin added to the current plant conditions to allow for future changes, discoveries, and flexibility in conducting maintenance or inspections). The key distinction between safety margin and operating margin is that safety margin cannot be reduced without approval from the NRC, whereas operating margin can be modified if necessary based on plant changes. Operating margins are discussed in Section 4.0.

The safety margin evaluation identifies margins and conservatisms in the design, analysis, construction, and operation of the plant to show that the proposed methodology change by this licensing submittal will maintain sufficient safety margins. Per the guidance stated in RG 1.174, the evaluation of the proposed change shows that sufficient safety margins exist to ensure:

- Codes and standards or their alternatives approved for use by the NRC are met.
- Safety analysis acceptance criteria in the UFSAR and supporting analyses are met or proposed revisions provide sufficient margin to account for analysis and data uncertainty.

3.1 Break Selection

The simplified risk informed approach used the BADGER (Break Accident Debris Generation EvaluatoR) software program. BADGER automates the zone of influence (ZOI) debris generation and analyzes each weld location for double-ended guillotine break spherical ZOI destruction, as well as partial-break hemispherical ZOI destruction. Fiber debris generation at each location and for each break size is compiled in a database. Since all weld locations in ASME Class 1 piping are analyzed for various break sizes there is no need to establish beforehand what the limiting breaks might be.

Calvert Cliffs has eight (8) dissimilar metal welds in ASME Class 1 piping in each unit at the RCS cold leg to reactor coolant pumps. These welds are the critical weld size but are not necessarily welds producing sufficient debris to threaten performance of the emergency recirculation strainer. These welds are not susceptible to PWSCC due to the temperature at which they operate. Additionally, the susceptibility of these welds to PWSCC has been mitigated through a zinc injection process.

3.2 Debris Generation

The Calvert Cliffs debris generation analysis was performed in accordance with approved methods documented in NEI 04-07 that include multiple levels of conservatism:

- The likelihood of a large rupture in pressurized water reactor coolant piping is less than $1x10^{-5}$ per year. Estimates for the frequency of a full double-ended rupture of the main coolant piping are on the order of $1x10^{-8}$ per year. Smaller piping ruptures, while still unlikely, provide a better measure of expected behavior.
- Break opening time and full offset displacement are instantaneous. The non-physical assumption of an instantaneous opening of a fully offset double-ended rupture leads to a significant overestimation of the debris generation potential for a postulated break. Even conservative estimates of minimum break opening times for large bore piping preclude formation of damaging pressure waves. The wide recognition that a large RCS pipe is more likely to leak and be detected by the plant's leakage monitoring systems long before cracks grow to unstable sizes is referred to as leak before break and is an accepted part of regulatory compliance with General Design Criterion 4 [Reference (14)].
- Full destruction of materials within a conservatively determined spherical ZOI based upon a conservative extrapolation of limited test data performed under non prototypic conditions, with limiting configurations. The sparse database on insulation destruction testing has forced the use of bounding results. For example: results based on aluminum jacketed insulation are applied to stainless steel jacketed insulation; all insulation is presumed to have a worst case seam orientation relative to the break. The ZOI for insulation materials is expected to be significantly smaller than that predicted by the NRC guidance due to real factors such as the absence of a damaging pressure wave, greater structural integrity than tested materials, non limiting seam orientations, etc.
- The debris generation analysis does not take credit for shielding within the ZOI by equipment (e.g. steam generators, reactor coolant pumps) and large piping.
- Instantaneous failure of 100% of the unqualified coatings inside containment as particulates is a very conservative assumption.

- Latent debris evaluations were completed in accordance with the approved guidance documented in NEI 02-01 [Reference (15)]. The results of the latent debris calculation conservatively determined the debris loading to be less than 150 lbm in each containment building.

3.3 Debris Transport

The Calvert Cliffs debris transport analysis was performed in accordance with approved methods documented in NEI 04-07, that include multiple levels of conservatism:

- All debris is assumed to wash down to the sump pool elevation with no holdup on structures. Although fine debris would be easily carried by draining spray flow, a significant quantity of larger debris would likely be retained on walls and structures above the containment pool due to incomplete spray coverage and hold up on structures and grating. Even in areas that are directly impacted by sprays, some amount of debris would agglomerate together and settle prior to reaching the strainer.
- All fine debris is assumed to transport to the surface of the strainer. Debris present or generated at the beginning of the event will generally be pushed by break and spray flows into quiescent regions and will reside as debris piles. At the start of recirculation, it would take substantially higher flow rate than what would actually occur to cause movement of these piles of debris. Even if these piles of debris were to move, there are numerous obstacles (supports, equipment, curbs, etc.) that would prevent debris from reaching the strainers.
- Approved guidance calls for uniform debris transport to and deposition on the strainer surfaces. Testing shows that debris transport to the surface of complex strainers will not be uniform, unless it is artificially induced in the testing. Some settling and uneven debris distribution is prototypical, which results in reduced head loss across the strainers.

3.4 Chemical Effects

The Calvert Cliffs chemical effects analysis was performed in accordance with approved guidance documented in WCAP-16530-NP-A [Reference (16)] that includes multiple levels of conservatism:

- WCAP-16530 relies largely upon short-term release rates (hours) for the determination of long-term releases (30 days). Long-term release rates of constituent materials are expected to be significantly lower than that predicted by design basis models due to surface passivation and formation of surface films.
- One hundred percent of chemical species of interest are assumed to precipitate. When solubility limits are taken into account, the predicted precipitation is reduced by one to two orders of magnitude. In addition, precipitates will form during periods when flow net positive suction head margins are greater.
- The WCAP-16530 models result in chemical precipitate formation that is readily transported to the sump screen. A significant portion of precipitate formation will occur on large surface areas in Containment, and in settled debris, all of which are remote from the strainer, and will not then be readily transported to the strainer.
- The approved testing methodology results in the chemical precipitates being pre-formed and overlaid upon the strainer debris bed as a whole, after fiber and particulates are placed into the test. This is conservative. In addition, some chemical precipitates will typically form in the debris bed itself on the fiber surfaces, instead of laying over the exterior top surface of the

strainer debris bed as a whole. This will result in lower strainer head loss and reduce the potential for deaeration.

Calvert Cliffs has taken many actions intended to reduce chemical effects in containment. These actions include:

- Replaced trisodium phosphate containment buffering agent with sodium tetraborate.
- Removed the telescoping aluminum ladder from the Polar Crane in Containment to reduce the aluminum content in Containment.
- Removed staged aluminum scaffolding materiel in Containment to reduce the aluminum content in Containment.
- Replaced a large percentage of the mineral wool and generic fiberglass insulation with stainless steel reflective metal insulation.

These actions eliminated the majority of aluminum in containment except the aluminum contained in the refueling machine, the equipment hatch hoist, air-operated valve components, and instrumentation. The maximum aluminum concentration in the Calvert Cliffs sump pool predicted by the WCAP-16530 for the break that produces the largest quantity of precipitate, is 3.39 ppm. Calvert Cliffs has demonstrated through chemical effects testing and analysis that WCAP-16530 predicted precipitates will not form until the sump pool temperature is reduced to 140°F.

3.5 Strainer Head Loss Testing

Calvert Cliffs performed strainer head loss testing in 2010. This test program was designed as a test for success campaign in which tests were performed with progressively smaller debris loads representing different insulation replacement options until a strainer head loss satisfying an acceptance criterion was achieved.

The Calvert Cliffs strainer head loss testing was performed in accordance with the NRC March 2008 guidance [Reference (17)] and included multiple levels of conservatism:

- During strainer head loss testing, only fiber fines were used to conservatively bound head loss as it was observed that small pieces of fiber reduced debris bed head loss. Should large quantities of debris be generated and transported to the strainer, it would be a mixture of fiber fines, small pieces, and large pieces.
- During head loss testing, fiber fines produced by erosion of small and large pieces of fibrous debris were conservatively assumed to arrive at the strainer at time t = 0, instead of hours or days later when head loss margin is greater. Fiber fines created by erosion will arrive at the strainer over a period of hours or even days. A significant portion of these fines will arrive after head loss margin has increased to the point where additional strainer head loss can be readily accommodated.
- During head loss testing, a full 30 day chemical precipitate load was assumed to arrive at the strainer at the earliest possible time with no credit for settling or nucleation on containment surfaces. The quantity of precipitate arriving at the strainer is expected to be significantly lower than tested amounts. In addition, the precipitate is expected to arrive or form in the debris bed gradually and the resultant head loss would be compensated by increased head loss margins.
- During head loss testing, all fiber and particulate debris was collected on the strainer prior to addition of chemical precipitates. The chemical precipitate coating on the debris bed observed

in head loss testing is not prototypical. In reality it would be less uniform than that achieved during testing since some of the precipitates would be expected to form in the debris bed, producing a less uniform deposit. A less uniform deposition of precipitates would yield a lower debris bed head loss.

- During head loss testing, repeated attempts were made to get debris that had settled in the immediate vicinity of the strainer back onto the strainer. The conservatism of debris transport calculations is clearly demonstrated in testing where non prototypic agitation must be employed to prevent natural settling of debris. Much of the debris that is predicted to transport to the strainer will settle in the immediate vicinity of the strainer and not become part of the strainer debris bed.
- During testing, metallic insulation debris was excluded from the tested debris bed in order to conservatively bound head loss. Some of the smaller metallic insulation debris will transport to the strainer and disrupt formation of a uniform fiber/particulate debris bed. This will result in lower strainer head loss.
- Metallic insulation debris that is predicted to enter the sump pool but not reach the strainer is excluded from testing to prevent capture of finer debris before it reaches the strainer. Any debris that enters the sump pool but does not transport to the strainer would capture some of the fine debris before it reaches the strainer.

A total of seven (7) tests were performed in 2010. Two of these tests were rejected; Test 1 was rejected as being non-conservative because it included small pieces of fibrous debris and had non-uniform debris deposition; and Test 6 was rejected due to improper and non-prototypical agitation being observed during the test. The maximum head loss results ranged from 0.38 ft-water to 4.98 ft-water and the conventional debris head loss, not considering the effects of chemical precipitates was always less than 0.08 ft-water.

One key conclusion from the testing was that debris deposition on the strainer was not uniform. Non-prototypical agitation was required to deposit most of the debris on the strainer. The combination of fine and small pieces of fibrous debris that were predicted to transport to the strainer produced a very thick and porous debris bed that produced negligible head loss. A photograph of the test strainer with the non-uniform debris bed is shown in Figure 1.

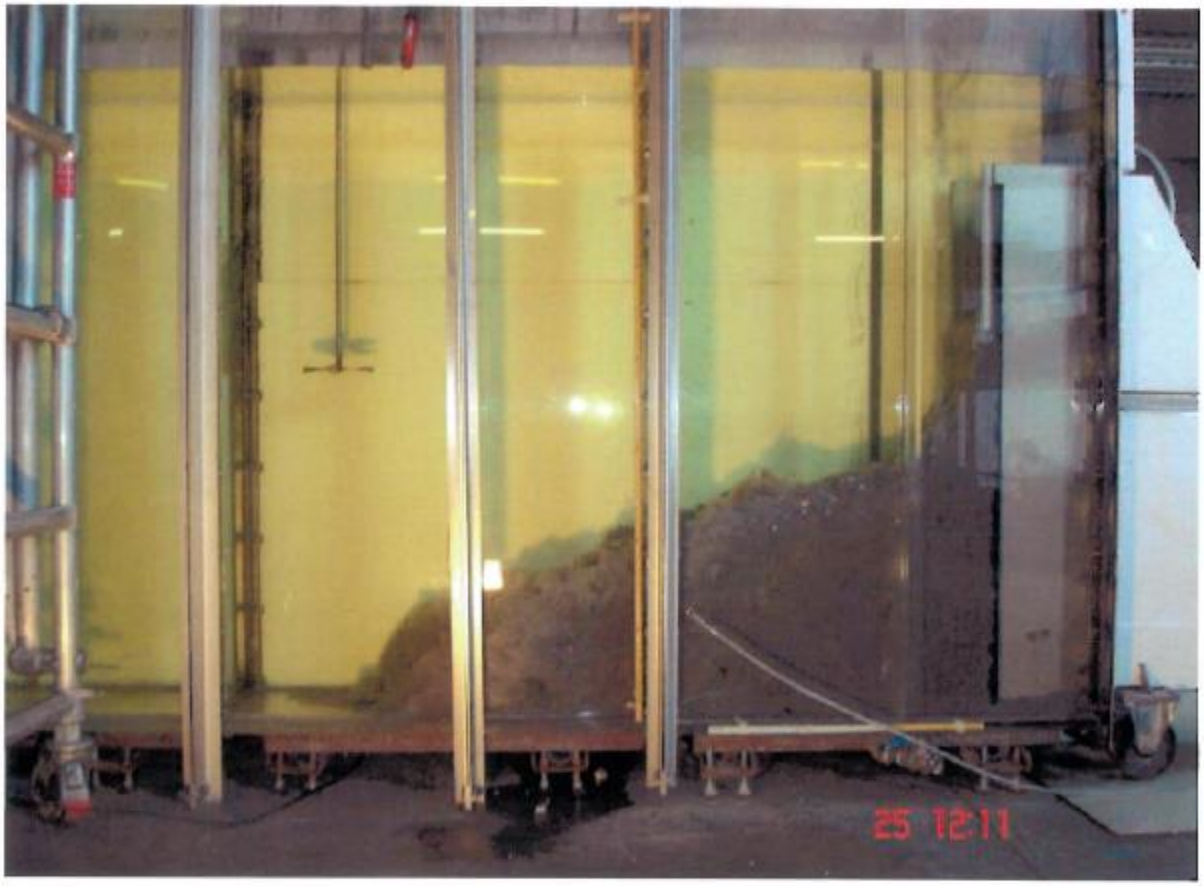

Figure 1: Non-Uniform Debris Deposition When Small Fiber Pieces Included

The maximum debris bed head loss from a test including small fiber pieces was less than 1.76 inches of water (0.06 psid). This head loss result includes the effects of chemical precipitates. This debris deposition is considered prototypical and is expected in the event that a large quantity of fibrous fines and small pieces is generated by a high energy line break, and transported to the strainer. However, it was concluded that additional head loss testing would be performed using fines only for the fibrous debris so that strainer head loss performance would be conservatively bounded by the testing.

Another key conclusion from the testing was that the strainers at Calvert Cliffs are not susceptible to the “thin-bed” effects. A thin-bed test was performed by adding 100% of the full particulate debris load followed by fine fibrous debris until full screen coverage was verified. Chemical precipitates were added after full screen coverage was verified. The maximum debris bed head loss from this test, including the effects of chemical precipitates, was less than 0.60 inches of water.

3.6 Strainer Performance

Strainer performance considerations include net positive suction head (NPSH), deaeration, flashing and structural qualification. These performance considerations are discussed in Attachment 1-2 of this submittal.

These strainer performance considerations were used to define maximum allowable strainer head loss values for different size LOCAs. The results of the Calvert Cliffs-specific strainer head loss test for

success program identified five (5) valid strainer head loss tests that were used to establish the debris acceptance criteria for identifying LOCA break sizes that result in head loss less or greater than allowable for each LOCA. The breaks that produce greater than allowable strainer head loss threaten strainer performance and are mitigated by the risk-informed approach. The breaks that produce less than allowable strainer head loss do not threaten strainer performance and are mitigated using NRC accepted methodologies.

The number of breaks that do not threaten strainer performance is much greater than the number of breaks that do threaten strainer performance. This provides a large amount of safety margin.

For example, Figure 2 shows debris generation example results for LOCA break sizes that do not threaten strainer performance sorted by decreasing quantity of fiber mass generated and transported to the strainer. The top 220 of over 17,700 of these breaks analyzed are presented. The example debris acceptance criterion for fiber mass is 800 pounds of fiber and is shown as the horizontal red line. The difference between quantity of debris generated by each break and the acceptance criterion represents safety margin in the analysis. As can be seen in Figure 2, the safety margin in the analysis increases for each LOCA size that satisfies the acceptance criterion.

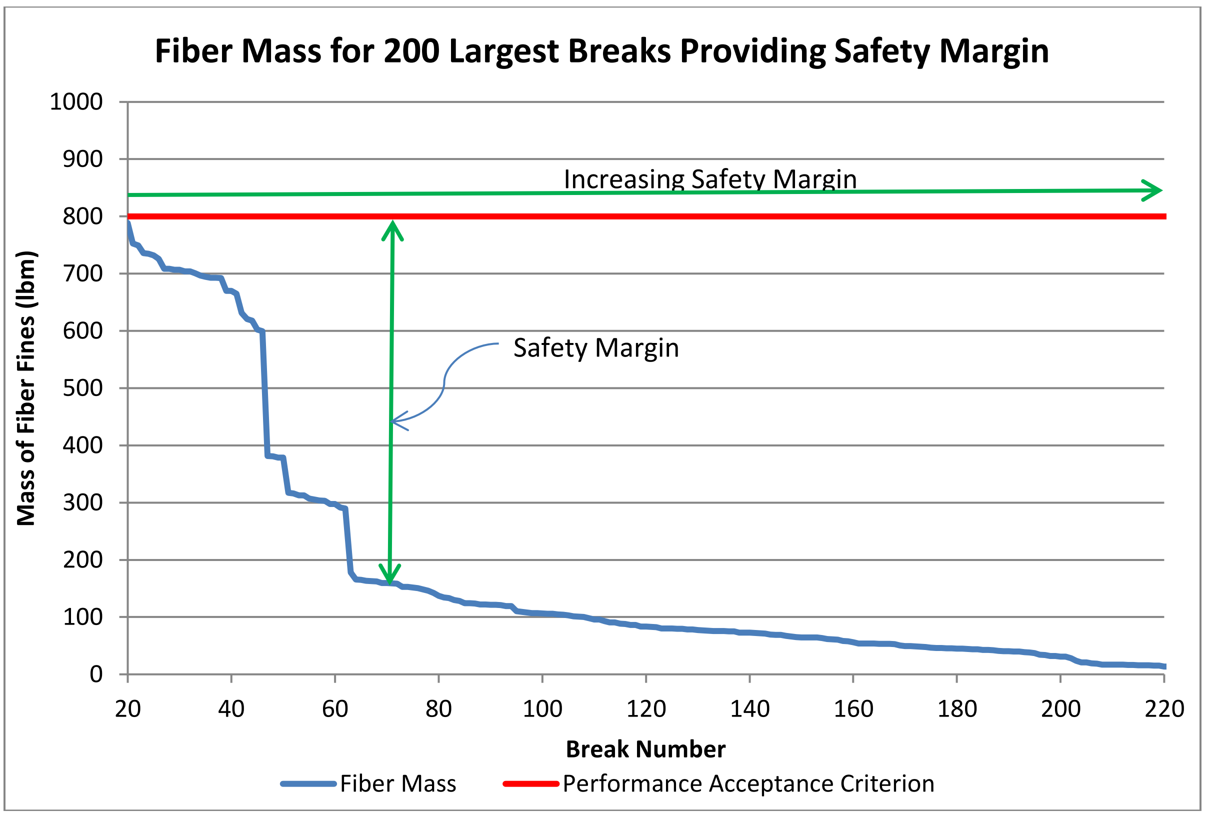

Figure 2: Strainer Performance Safety Margin

Table 1 describes the safety margins included in the risk-informed GSI-191 evaluation. As noted in this table, there are many conservatisms throughout the evaluation, which provide high confidence that successful end states are achieved, and that many end states that are assumed to fail would actually be successful.

Table 1: Description of Safety Margin

Topic	Conservatism Credited as Safety Margin	Realistic Condition	Impact on Evaluation
Thermal-Hydraulic Containment Response	Temperature and Pressure conditions based on bounding results of five design basis breaks.	Containment response actually based on individual break conditions.	Higher temperature maximized precipitant release and quantity of precipitate generated.
	Initial containment temperature assumed to be 125°F.	Maximum allowable containment temperature allowed by TS is 120°F.	Higher initial temperature results in higher containment response temperatures.
	Initial containment pressure assumed to be 1 psig.	Containment pressure allowed by TS to be -1 psig ≤ P ≤ 1 psig.	Higher initial pressure results in higher containment response pressures resulting in longer time until first Containment Spray Pump is secured.
	Bounding design basis containment response and sump temperature profiles used for all break sizes.	Containment response and sump temperature would be lower for Cold Leg and small breaks.	Chemical release and precipitate quantities are over-predicted and NPSH margin is under-predicted.
	No credit taken for containment accident pressure and minimal credit for subcooling in NPSH and deaeration calculations.	The post-LOCA containment pressure would be significantly higher than the saturation pressure.	NPSH margin is under-predicted and deaeration and flashing are over-predicted.
Scenario Frequency	All frequency of secondary system breaks is allocated to primary system breaks.	Smaller breaks in the Main Steam and Feedwater systems are much more likely than breaks in the primary RCS.	Increased frequency applied to breaks in the RCS resulting in larger ΔCDF and ΔLERF.
Debris Generation	Break opening time and full offset displacement for double-ended guillotine breaks are instantaneous.	Break opening would begin with a leak and then grow into a large break. Full off-set of large pipes is physically impossible.	Quantity of debris generated is over-predicted.

Topic	Conservatism Credited as Safety Margin	Realistic Condition	Impact on Evaluation
Debris Generation (continued)	With the exception of shadowing by concrete walls, no credit was taken for structures or restraints that would limit the quantity of debris generated within a break ZOI.	Full offset of pipe DEGBs (especially on the primary loop piping) would be significantly limited due to physical restraints; also, insulation and qualified coatings would not be completely destroyed within a given ZOI due to the shielding effects of equipment and other structures.	Quantity of debris generated inside the ZOI is over-predicted.
	100% failure of unqualified coatings for all breaks.	Some unqualified coatings may have a lower failure fraction.	Particulate debris quantity on strainers is over-predicted.
	Unqualified coatings fail at the start of the accident.	Unqualified coatings would fail gradually and may not fail until much later in the event.	Particulate debris quantity on strainers is over-predicted early in the event.
Debris Transport	All debris dislodged from targets is assumed to be in the sump pool.	In reality, a large fraction of the debris would be captured in upper containment.	Debris transport to the pool is over-predicted.
	100% of fine fibrous, particulate, and chemical precipitate is assumed to transport to the strainer.	Some fine fibrous and particulate debris would settle and be retained in stagnant regions of the recirculation pool.	Debris transported to the strainer is over-predicted.
Chemical Effects	All insulation debris is assumed to be in the sump for the chemical release and precipitation calculation	In reality, a large fraction of the debris would be captured in upper containment.	Chemical precipitation quantities are over-predicted.
	100% of the chemical precipitate is assumed to be deposited on the strainer.	A significant portion of precipitate formation will occur on large surface areas in containment, and in settled debris, all of which are remote from the strainer, and will not then be readily transported to the strainer.	Chemical head loss is over-predicted.

Topic	Conservatism Credited as Safety Margin	Realistic Condition	Impact on Evaluation
Head Loss Testing	Only fiber fines were used in head loss testing.	Small pieces of fibrous debris would also transport to the strainer resulting in non-uniform debris deposition and much lower strainer head loss.	Strainer head loss is over-predicted.
	Fiber fines due to erosion of larger pieces are assumed to arrive on the strainer immediately.	Fiber fines created by erosion will arrive at the strainer over a period of hours or even days.	Strainer head loss is over-predicted.
	The full 30 day chemical precipitate load is assumed to arrive at the strainer at the earliest possible time with no credit for settling or nucleation on containment surfaces.	The precipitate is expected to arrive or form in the debris bed gradually.	Strainer head loss is over-predicted.
	The chemical precipitate coating on the debris bed observed in head loss testing is not prototypical.	Much of the precipitates would form in the debris bed producing a less uniform deposit.	Strainer head loss is over-predicted.
	Head loss test procedures were designed to assure uniform debris distribution on the strainer to maximize debris bed head loss.	The design and physical layout of the Calvert Cliffs strainer promotes non-uniform debris distribution.	Strainer head loss is over-predicted.
	Debris types demonstrated to reduce debris bed head loss such as lead shielding blanket and metallic insulation debris were excluded from the tested debris.	Lead shielding blanked and metallic insulation debris would be included in the debris bed on the strainer.	Strainer head loss is over-predicted.

4.0 OPERATING MARGIN

As previously discussed, there are numerous conservatisms used throughout the Calvert Cliffs risk-informed GSI-191 evaluation. However, not all of these conservatisms were classified as safety margin. Some conservatisms were included to provide future operating margin (i.e., margin added to the current plant conditions to allow for future changes, discoveries, and flexibility in conducting maintenance or inspections). The key distinction between safety margin and operating margin is that safety margin cannot be reduced without approval from the NRC, whereas operating margin can be modified if necessary based on plant changes. Operating margins for various debris types are given in Table 2 below.

Table 2: Description of Operating Margins

Item	Actual Value	Maximum Value Used in Analyses	Operating Margin
Insulation fiber Fines	182 lbs.	380 lbs[2].	198 lbs.
Aluminum Surface Area	86.945 ft^2	150 ft^2	65 ft^2
Latent Debris	65 lbs. to 145 lbs.	150 lbs.	5 lbs.
Tags & Labels	278.62 ft^2	500 ft^2	221.38 ft^2
Degraded-Qualified Epoxy	0.3779 ft^3	1.0966 ft^3	0.7187 ft^3
Degraded-Qualified IOZ	0.1889 ft^3	0.5482 ft^3	0.3593 ft^3

Note 1: Insulation Fiber Fines includes NUKON, Thermal Wrap, Generic Fiberglass, Temp-Mat, Nuke-Tape, and Lead Shielding Blanket Cover debris

Note 2: Insulation Fiber Fines Values are for the Alternate Break Size (12 Inch Break) to be used in Operability Determinations.

5.0 REFERENCES

(1) NRC Bulletin 2003-01: Potential Impact of Debris Blockage on Emergency Sump Recirculation at Pressurized-Water Reactors, June 9, 2003.

(2) NRC Generic Letter 2004-02: Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors, September 13, 2004.

(3) Technical Normal Condition (TNC) 15.6.2, Containment Closeout, Revision 22.

(4) Regulatory Guide 1.174, “An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions On Plant-Specific Changes to the Licensing Basis”, Revision 2, Nuclear Regulatory Commission, Washington, DC, May 2011.

(5) Regulatory Guide 1.45, Guidance on Monitoring and Responding to Reactor Coolant System Leakage, Revision 1, Nuclear Regulatory Commission, Washington, DC, May 2, 2008.

(6) NEI 04-07, Revision 0, December 2004, “Pressurized Water Reactor Sump Performance Evaluation Methodology,” Volume 1 and Volume 2.

(7) 10 CFR 50.46, Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors.

(8) Letter from John C. Butler (NEI) to Mr. Stewart N. Bailey (NRC), “Defense-In-Depth Measures in Support of GSI-101 Resolution Options, March 5, 2012, ML120730661.

(9) Exelon procedure, ER-AA-330, Revision 14, Conduct of Inservice Inspection Activities.

(10) Fourth Interval In-Service Inspection Program Plan for Calvert Cliffs Nuclear Power Plant Units 1 and 2, 10150819-00017, Revision 2, August 19, 2015.

(11) 10 CFR 50.54(o); Conditions of licenses.

(12) 10 CFR 50, Appendix J, Primary Reactor Containment Leakage Testing for Water-Cooled Power Reactors.

(13) Regulatory Guide 1.163, Performance-Based Containment Leak-Test Program, Nuclear Regulatory Commission, Washington, DC, September 1995.

(14) 10 CFR 50, Appendix A, General Design Criterion 4, Environmental and dynamic effects design basis.

(15) NEI 02-01, Revision 1, September 2002, “Condition Assessment Guidelines: Debris Sources Inside PWR Containments”.

(16) WCAP-16530-NP-A, Revision 0, dated March 2008, “Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191.

(17) NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing, dated March 2008.

ATTACHMENT (3)

SUPPLEMENTAL RESPONSE TO GENERERIC LETTER 2004-02

License Amendment Request

License Amendment Request

1.0 SUMMARY DESCRIPTION

Exelon Generation Company, LLC (Exelon) requests an amendment to Renewed Licenses DPR-53 and DPR-69 for Calvert Cliffs Nuclear Power Plant (CCNPP) Units 1 and 2 pursuant to 10CFR50.90. The proposed amendment will:

1. Revise the licensing basis as described in the CCNPP Updated Final Safety Analysis Report (UFSAR) to allow the use of a risk-informed approach to address safety issues discussed in Generic Safety Issue (GSI) -191, "Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance". The risk-informed approach is consistent with the guidance of NRC Regulatory Guide (RG) 1.174 [Reference (1)].

2. Revise the Technical Specifications (TS) for the Emergency Core Cooling System (ECCS) by eliminating Surveillance Requirement (SR) 3.5.2.8.

3. Revise TS 3.5.3 by removing SR 3.5.2.8 from SR 3.5.3.1.

4. Add a new TS 3.6.9 "Containment Emergency Sump" with a required action and completion time specific to the effects of debris.

5. Revise TS 5.5.15, "Safety Function Determination Program (SFDP)".

The proposed TS changes will align the TS with the risk-informed methodology change.

The proposed changes will apply only for the effects of debris as described in NRC Generic Letter (GL) 2004-02 [Reference (2)].

2.0 DETAILED DECRIPTION

The proposed change in methodology is to use a risk-informed approach to address the effects of Loss of Coolant Accident (LOCA) debris on the Containment Emergency Sump instead of a traditional deterministic approach. The debris analysis covers a full spectrum of postulated LOCAs of all pipe sizes up to and including the design basis accident LOCA (double-ended guillotine breaks of main Reactor Coolant system (RCS) piping) to provide assurance that the most severe postulated loss-of-coolant accidents are evaluated. The deterministic current licensing basis (CLB) will continue to apply to LOCA break sizes that result in strainer head loss less than or equal to allowable based on plant-specific strainer head loss testing. The proposed methodology change will apply for LOCAs that can result in a strainer head loss higher than the allowable head loss based on plant-specific testing. Calvert Cliffs conservatively assumes Containment Emergency Sump strainer failure for any LOCA break size/location where the amount of strainer debris predicted exceeds the amount that can be proven acceptable by comparison to strainer head loss test results.

Calvert Cliffs applies NUREG 1829 [Reference (3)] to determine the break frequency for the smallest of those break sizes which fail the strainer to obtain the highest frequency, and then apportions that frequency across all breaks that result in strainer failure to determine the ΔCDF (Core Damage Frequency) and ΔLERF (Large Early Release) for comparison to the criteria in RG 1.174. The results of the evaluation show that the risk from the proposed change of not removing fibrous insulation to eliminate strainer failure for all LOCA break sizes is "very small" in that it is in Region III of RG 1.174. The details of the approach are provided in Attachment 1-3, "Risk Informed Basis."

System redundancy, independence, and diversity features are not changed for those safety systems credited in the accident analyses. Additionally, no new programmatic compensatory activities or reliance on manual operator actions are required to implement this change.

The proposed amendment adds a new TS 3.6.9, "Containment Emergency Sump," and adds Actions to address the condition of the Containment Emergency Sump made inoperable due to containment accident generated and transported debris exceeding the analyzed limits. The Actions provide time to correct or evaluate the condition in lieu of an immediate plant shutdown.

- Required Action A.1 mandates immediate action to be initiated to mitigate the condition. The proposed TS Bases for Required Action A.1 provides examples of mitigating actions.
- Required Action A.2 mandates performance of SR 3.4.13.1, "RCS Water Inventory Balance," to be performed at a frequency of once per 24 hours. An unexpected increase in RCS leakage could be indicative of an increased potential for an RCS pipe break which could result in debris being generated and transported to the containment sump.
- Required Action A.3 requires the inoperable Containment Emergency Sump to be restored to operable status within 90 days. Ninety days is consistent with the time frame determined to be acceptable in TSTF-567 (Reference 6).
- Required Action B.1 requires restoration of the Containment Emergency Sump within 72 hours, and is modified by two Notes which direct entering the applicable Limiting Condition for Operation (LCO) for ECCS and Containment Spray and Cooling Systems.
- Required Action C.1 requires the Unit to be in MODE 3 in 6 hours followed by MODE 5 in 36 hours if operators are unable to restore the Containment Emergency Sump to operable status under Condition A or B.

The existing Surveillance Requirement (SR), SR 3.5.2.8, to visually inspect the Containment Emergency Sump is removed from TS 3.5.2, is modified to reflect the verbiage in TSTF-567 (Reference 6), and becomes SR 3.6.9.1. The SR will be performed in accordance with the Surveillance Frequency Control Program. The requirement to perform the SR in TS 3.5.3 is deleted.

The proposed amendment also revises TS 5.5.15, "Safety Function Determination Program (SFDP)" to clarify its application when a supported system is made inoperable by the inoperability of a single TS support system. When a loss of safety function is caused by the inoperability of a single Technical Specification support system, the appropriate Conditions and Required Actions to enter are those of the support system.

Upon approval of the licensing basis changes, Exelon will make conforming changes to UFSAR Chapter 6 that describe the Containment Emergency Sump and how the GSI-191 issues are addressed. The UFSAR markups associated with the license amendment request are attached for the staff's information. In addition, conforming changes to the TS Bases are provided in this Attachment for information only, to be implemented following NRC approval of the LAR.

3.0 TECHNICAL EVALUATION

3.1 Current System Descriptions

The methodology change affects the analysis of systems and functions that are susceptible to the effects of LOCA debris. The affected systems are those that are supported by the emergency recirculation strainer and sump during the recirculation phase of LOCA mitigation, which are the

High Pressure Safety Injection System (HPSI) and Containment Spray (CSS) System. The associated functions are:

- Core Cooling
- Containment Heat Removal
- Containment Atmosphere Cleanup

3.1.1 High Pressure Safety Injection System

The HPSI System is designed to deliver emergency coolant to the reactor core and provide shutdown capability after the following accident conditions:

1. Large and small break LOCA.
2. Main steam line break.

It is designed to tolerate a single active failure in the short term or a single active or passive failure in the long term. The system meets its minimum required performance level with onsite or offsite electrical power. During recirculation, one HPSI pump has sufficient capacity to maintain the water level in the reactor vessel above the core.

HPSI is a subsystem of the ECCS at Calvert Cliffs. The safety injection tanks (SITs) and low pressure safety injection (LPSI) system are the other subsystems of the ECCS. The SITs and LPSI do not operate in recirculation mode and are not subject to the effects of debris.

The ECCS injects borated water into the RCS. The system supplies emergency core cooling to limit fuel rod damage and fission product release and ensure adequate shutdown margin regardless of temperature. The injection system also supplies continuous long-term post-accident cooling of the core by recirculation of borated water from the Containment Emergency Sump.

3.1.2 Containment Heat Removal

The containment heat removal function is provided by two diverse systems. The function of the Containment Spray and the Containment Air Recirculation and Cooling systems is to limit the containment atmospheric pressure and temperature after a LOCA, and thus reduce the possibility of leakage of airborne radioactivity to the outside environment. The Containment Air Recirculation and Cooling system does not rely on recirculation through the emergency recirculation strainer. The Containment Spray system does rely on recirculation through the emergency recirculation strainer.

3.1.3 Containment Atmosphere Cleanup

The Containment Spray system at Calvert Cliffs is credited with reduction in containment airborne radioactivity in the UFSAR Safety Analysis. Each Unit is equipped with two 50-percent spray trains taking suction from the Containment Emergency Sump. Each Containment Spray train is supplied power from a separate bus. Each bus is connected to both the offsite and the onsite power supply systems. This assures that for onsite or for offsite electrical power failure, the Containment Spray safety function can be accomplished, assuming a single failure. The Containment Spray system does rely on recirculation through the emergency recirculation strainer.

3.1.4 Containment Emergency Sump

The Containment Emergency Sump consists of strainer modules, a radial duct, and a sump pit. The strainer contains 6,060 ft^2 of filtration surface area (nominal) amongst the 33 strainer modules that

are divided among three strainer rows. These modules are approximately 3 ft high, and contain 324 pockets in 29 of the strainer modules, and 252 pockets in four of the strainer modules. The strainer rows tie into a common radial duct which directs the flow to the containment emergency sump pit. The sump pit structure consists of a concrete curb and stainless-steel plates reinforced by structural steel. The two suction recirculation headers are located within this single Containment Emergency Sump pit.

The Containment Emergency Sump also includes the refueling cavity drains and accompanying trash rack strainers which are credited as a containment drainage flow path in the water level analysis. These drains allow containment spray flow to drain into the containment basement thus increasing the water level and improving strainer performance. The trash rack strainers over the cavity drains are credited with preventing large accident-generated debris from clogging the cavity drains.

The strainer is of robust design and complies with RG 1.82, Rev. 3 [Reference (4)] with the following exceptions:

1. The redundant sump is not physically separated by a redundant barrier.
2. The floor in the vicinity of the sump slopes toward the sump.

The Containment Emergency Sump is located in the lowest elevation of containment. The sump and strainer are designed to withstand the safe-shutdown earthquake (SSE) without loss of structural integrity.

At the beginning of the recirculation phase, the minimum water level above the strainer is adequate to provide the required NPSH for the HPSI and Containment Spray pumps.

The Containment Emergency Sump is inspected periodically as delineated in SR 3.2.5.8 which Exelon is proposing to move to a new SR 3.6.9.1 for the Containment Emergency Sump.

3.2 Background

GSI-191 concerns the possibility that debris generated during a LOCA could increase the head loss across the containment sump strainers in pressurized-water reactors resulting in a loss of Net Positive Suction Head (NPSH) margin for the ECCS and Containment Spray pumps. GL 2004-02 requested licensees to address GSI-191 issues which was focused on demonstrating compliance with the ECCS acceptance criteria in 10CFR50.46. GL 2004-02 requested licensees to perform new analyses using an NRC-approved methodology to confirm the functionality of the ECCS and Containment Spray during design basis accidents that require Containment Emergency Sump recirculation.

The current design for the Containment Emergency Sump strainer was assessed in response to NRC GL 2004-02. Calvert Cliffs provided specific information regarding the deterministic methodology for demonstrating compliance by applying industry and NRC guidance. However, since the results of this analysis have shown that further modifications (e.g., removal of fibrous insulation) are needed to show compliance with 10 CFR 50.46, a risk-informed approach using the guidance in RG 1.174 is being used to evaluate the safety significance of LOCA debris loads on the containment emergency recirculation sump strainer exceeding allowable limits for certain break sizes and locations.

The Calvert Cliffs risk-informed approach maintains the defense-in-depth measures as described in Attachment 1-4. These measures include those identified in response to NRC Bulletin 2003-01 [Reference (5)] and GL 2004-02.

3.3 Engineering Analysis Evaluation Overview

The design and licensing basis descriptions of accidents requiring ECCS and Containment Spray operation, including analysis methods, assumptions, and results provided in UFSAR Chapters 6 and 14 remain unchanged. This is based on the functionality of the ECCS and Containment Spray during design basis accidents being confirmed by demonstrating that safety margin and defense-in-depth are maintained with high probability.

The methodology for calculating the risk associated with GSI-191 concerns evaluates a full spectrum of breaks up to and including double-ended guillotine breaks, for all RCS pipe sizes. The risk-informed debris evaluation is performed assuming that the plant is at-power when the initiating event occurs. Consequently, the debris generation and transport are based on normal operating temperature and pressure conditions. Those conditions maximize the break zones of influence and initial decay heat. The results show the risk associated with GSI-191 concerns for Calvert Cliffs Units 1 and 2 is "very small" as defined by Region III in RG 1.174.

This LAR is requested to address LOCA break sizes and locations that can result in a strainer head loss higher than allowable based on plant-specific testing. In Attachments 1-2 and 1-3, Calvert Cliffs determined that only large breaks in the primary reactor coolant piping were in this scope and listed 72 examples. Based on evaluation of defense-in-depth, safety margin, and a high probability of successful performance, the functionality of the ECCS and Containment Spray is confirmed. Exelon is requesting a change to the licensing basis for this scope of breaks to allow evaluation of the debris effects using a risk-informed methodology.

3.4 Technical Specification Changes

Exelon is proposing changes to TS 3.5.2, "ECCS – Operating" and TS 3.5.3, "ECCS – Shutdown" and a new TS 3.6.9 for the Containment Emergency Sump. The proposed amendment also revises the Safety Function Determination Program to clarify its application when a supported system is made inoperable by the inoperability of a single Technical Specification support system.

3.4.1 Change to TS 3.5.2, ECCS – Operating

The change to TS 3.5.2 is to remove SR 3.5.2.8 to *verify, by visual inspection, each ECCS train containment sump suction inlet is not restricted by debris and the suction inlet strainers show no evidence of structural distress or abnormal corrosion.* The SR will be revised and relocated to the proposed new TS 3.6.9.

3.4.2 Change to TS 3.5.3, ECCS – Shutdown

The change to TS 3.5.3 is to remove SR 3.5.2.8 from SR 3.5.3.1 as this SR is being relocated to the proposed new TS 3.6.9.

3.4.3 New TS 3.6.9, Containment Emergency Sump

The new proposed TS 3.6.9 applies in MODES 1, 2, 3, and 4 which aligns with the ECCS and Containment Spray TS.

The new TS 3.6.9 required actions are shown in the table below.

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Containment emergency sump inoperable due to containment accident generated and transported debris exceeding the analyzed limits.	A.1 Initiate action to mitigate containment accident generated and transported debris. AND	Immediately
	A.2 Perform SR 3.4.13.1. AND	Once per 24 hours
	A.3 Restore the containment emergency sump to OPERABLE status	90 days

CONDITION	REQUIRED ACTION	COMPLETION TIME
B. Containment emergency sump inoperable for reasons other than Condition A.	B.1 --------------NOTES-------------- 1. Enter applicable Conditions and Required Actions of LCO 3.5.2, "ECCS - Operating," and LCO 3.5.3, "ECCS - Shutdown," for emergency core cooling trains made inoperable by the Containment Emergency Sump. 2. Enter applicable Conditions and Required Actions of LCO 3.6.6, "Containment Spray and Cooling Systems," for containment spray trains made inoperable by the Containment Emergency Sump. -------------------------------------- Restore the Containment Emergency Sump to OPERABLE status	72 hours
C. Required Action and associated Completion Time not met	C.1 Be in MODE 3.	6 hours
	<u>AND</u>	
	C.2 Be in MODE 5.	36 hours

TS 3.6.9 will contain a surveillance requirement, SR 3.6.9.1, that replaces current SR 3.5.2.8. The SR is reworded to reflect visual inspection of the credited Containment Emergency Sump system. In addition to the Containment Emergency Sump itself, this system consists of the drainage flow paths from both refueling pool cavities and the associated trash rack over each refueling pool cavity drain. The Calvert Cliffs TS contain a Surveillance Frequency Control Program. Therefore, the Frequency for the new SR 3.6.9.1 is "In accordance with the Surveillance Frequency Control Program."

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.6.9.1	Verify, by visual inspection, the containment emergency sump does not show structural damage, abnormal corrosion, or debris blockage.	In accordance with the Surveillance Frequency Control Program

The proposed amendment also revises the Safety Function Determination Program to clarify its application when a supported system is made inoperable by the inoperability of a single Technical Specification support system. The following statement is added to the end of TS 5.5.15, "Safety Function Determination Program (SFDP):"

> "When a loss of safety function is caused by the inoperability of a single Technical Specification support system, the appropriate Conditions and Required Actions to enter are those of the support system."

The changes proposed above are consistent with TSTF-567, Rev 1 and the associated NRC Safety Evaluation [Reference (6)]. The technical evaluation of the risk informed approach is described in detail in Attachments 1-2, 1-3 and 1-4.

3.5 Reporting and Corrective Action

The proposed UFSAR Table 6-12 provides Containment Emergency Sump Debris Limits. If these debris limits are exceeded, Condition A of the new Technical Specification Limiting Condition for Operation 3.6.9 is entered and the required actions for this condition are followed. Reportability will be in accordance with the requirements of 10 CFR 50.72 and 50.73 and will follow the criteria contained in NUREG-1022.

Calvert Cliffs has multiple defense-in-depth features. Defense-in-depth features specifically related to GSI-191 are:

- Prevention of Inadequate Recirculation Strainer Flow.
- Detection of Inadequate Strainer Flow.
- Mitigation of Inadequate Recirculation Strainer Flow.
- Prevention of Inadequate Reactor Core Flow.
- Detection of Inadequate Reactor Core Flow.
- Mitigation of Inadequate Reactor Core Flow.
- Implementation of SAMGs.

The criterion for unacceptable change in defense-in-depth is elimination of one or more of these features. Reportability to the NRC is in accordance with 10 CFR 50.72 or 50.73.

Calvert Cliffs has multiple safety margin features. Safety margin features specifically related to GSI-191 are described in Attachment 1-4, Table 1 as conservatisms used in the analyses. The criterion for unacceptable changes in safety margin is reduction of one or more of these conservatisms. Reportability to the NRC is in accordance with 10 CFR 50.72 or 50.73.

3.6 Evaluation of Defense-in-Depth (DID) and Safety Margin

Detailed evaluation of DID and Safety Margin are presented in Attachment 1-4 and can be applied to both the methodology change and the Technical Specification change.

3.7 Technical Evaluation Conclusion

The technical evaluation shows that the functionality of the ECCS and Containment Spray during design basis accidents is confirmed by demonstrating that safety margin and defense-in-depth are maintained with high probability.

4.0 REGULATORY EVALUATION

4.1 Applicable Regulatory Requirements

RG 1.174 provides the NRC staff's recommendations for using risk information in support of licensee-initiated Licensing Basis changes to a nuclear power plant that require NRC review and approval. This regulatory guide describes an acceptable approach for assessing the nature and impact of proposed Licensing Basis changes by considering engineering issues and applying risk insights.

In implementing risk-informed decision making, Licensing Basis changes are expected to meet a set of key principles. These principles include the following:

1. *The proposed change meets the current regulations unless it is explicitly related to a requested exemption (i.e., a specific exemption under 10CFR50.12, "Specific Exemptions").*

   Attachment 2 documents a request for exemption from 10 CFR 50.46(a)(1) in support of the risk-informed approach.

2. *The proposed change is consistent with a defense-in-depth philosophy.*

   Defense-in-depth is presented in detail in Attachment 1-4. The proposed change is consistent with the defense-in-depth philosophy in that the following aspects of the facility design and operation are unaffected:

   - Functional requirements and the design configuration of systems
   - Existing plant barriers to the release of fission products
   - Design provisions for redundancy, diversity, and independence
   - Plant's response to transients or other initiating events
   - Preventive and mitigative capabilities of plant design features

   The Calvert Cliffs risk-informed approach analyzes a full spectrum of LOCAs of all piping sizes up to and including a double-ended guillotine break of the largest pipe in the reactor coolant system. By requiring that mitigative capability be maintained in a realistic and risk-informed evaluation of GSI-191 for a full spectrum of LOCAs, the approach ensures that defense-in-depth is maintained.

3. *The proposed change maintains sufficient safety margins.*

   As described in Attachment 1-4, sufficient safety margins associated with the design will be maintained by the proposed change. Safety margin is provided by the many levels of

conservatism in the GSI-191 testing and analyses. Additional safety margin is provided in that the vast majority of LOCA events produce significantly less debris than that generated by the critical break size.

4. *When proposed changes result in an increase in CDF or risk, the increases should be small and consistent with the intent of the Commission's Safety Goal Policy Statement.*

   The risk associated with this change has been calculated and shown to be "very small" as defined by Region III in RG 1.174 and is therefore consistent with the Commission's Safety Goal Policy Statement.

5. *The impact of the proposed change should be monitored using performance measurement strategies.*

   The SR proposed by the new TS provides adequate performance monitoring of the Containment Emergency Sump. Additional programmatic controls that provide performance monitoring associated with GSI-191 are discussed in Attachment 1-1, Section 5.0.

NRC RG 1.200 [Reference (7)] describes one acceptable approach for determining whether the quality of the PRA, in total or the parts that are used to support an application, is sufficient to provide confidence in the results, such that the PRA can be used in regulatory decision-making for light-water reactors. The Calvert Cliffs PRA model used for the risk-informed approach for addressing GSI-191 concerns is in compliance with Revision 2 of RG 1.200.

4.2 Precedents

As discussed throughout this submittal, the South Texas Project Nuclear Operating Company (STP) submitted a risk-informed approach for closure of GL 2004-02 for STP Units 1 and 2 [References (8) and (9)]. The Calvert Cliffs risk informed approach for resolution of GSI-191 and closure of GL 2004-02 is modeled after the STP submittal. The following differences exist between the Calvert Cliffs approach and the STP approach:

- Ex-vessel downstream effects are not addressed in the Calvert Cliffs risk-informed evaluation of GSI-191. Instead Calvert Cliffs used WCAP-16406, considering the Limitations and Conditions presented in the NRC Safety Evaluation for the WCAP to deterministically address ex-vessel downstream effects.

- In-vessel downstream effects are not addressed in the Calvert Cliffs risk-informed evaluation of GSI-191. Instead Calvert Cliffs used WCAP-16793, considering the Limitations and Conditions presented in the NRC Safety Evaluation for the WCAP, to deterministically address in-vessel downstream effects.

4.3 No Significant Hazards Consideration Determination

Exelon has evaluated whether or not a significant hazards consideration is involved with the proposed amendment by focusing on the three standards set forth in 10CFR50.92, "Issuance of amendment," as discussed below:

1. **Does the proposed change involve a significant increase in the probability or consequences of an accident previously evaluated?**

Response: No

The proposed changes add a new Technical Specification for the Containment Emergency Sump, moves and modifies an existing SR from the ECCS TS to the new Containment Emergency Sump TS, and modifies an associated TS (TS 5.5.15). The proposed changes are associated with a methodology change for the assessment of debris effects from LOCAs that are already evaluated in the Calvert Cliffs UFSAR, an extension of TS required completion time for potential LOCA debris related effects on ECCS and Containment Spray, and associated administrative changes to the TS.

The proposed changes include revisions to the Technical Specification (TS) associated with implementing a risk-informed approach for addressing Generic Safety Issue 191. A new Containment Emergency Sump TS is proposed with actions to be taken when the sump is inoperable due to the potential containment accident generated and transported debris exceeding acceptable limits. The new TS requires immediate initiation of mitigating actions, and periodic performance of RCS water inventory balance (every 24 hours), while providing time to evaluate and correct the condition in lieu of requiring immediate plant shutdown. Examples of mitigating actions are provided to the operators in the TS Bases. The mitigating actions place urgency on resolving the identified condition, and the examples provide direction to the operating staff. The mitigating action to increase RCS inventory surveillance would identify unexpected increased leakage that could be indicative of a potential RCS pipe break.

There is no increase in the probability of an accident previously evaluated. The proposed changes address mitigation of loss of coolant accidents and have no effect on the probability of the occurrence of a LOCA. No structures, systems, or components are being modified, and no changes in plant operation are being implemented that could lead to a different kind of accident

The risk-informed approach to addressing GSI-191 confirmed that required SSCs supported by the Containment Emergency Sump will continue to perform their safety functions as required with high probability using conservative analyses. The safety analyses as presented in the UFSAR Chapter 14 are not changed. Adequate safety margin and defense-in-depth are maintained. The increase in risk associated with implementing the risk-informed approach is very small and within the acceptance guidelines stated in RG 1.174.

Therefore, the proposed changes do not involve a significant increase in the probability or consequences of any accident previously evaluated in the UFSAR.

2. **Does the proposed change create the possibility of a new or different kind of accident from any accident previously evaluated?**

Response: No

The proposed changes add a new Technical Specification for the Containment Emergency Sump, moves and modifies an existing SR from the ECCS TS to the new Containment Emergency Sump TS, and modifies an associated TS (TS 5.5.15). The proposed changes are associated with a methodology change for assessment of debris effects from LOCAs that are already evaluated in the Calvert Cliffs UFSAR, an extension of TS required completion time for potential LOCA debris related effects on ECCS and Containment Spray and associated administrative changes to the TS. No new or different kind accident is being evaluated. None of the changes install or remove any

plant equipment, or alter the design, physical configuration, or mode of operation of any plant structure, system or component. The proposed changes do not introduce any new failure mechanisms or malfunctions that can initiate an accident. The proposed changes do not introduce failure modes, accident initiators, or equipment malfunctions that would cause a new or different kind of accident. The proposed change clarifies the Safety Function Determination Program when a supported system is made inoperable by the inoperability of a single TS support system. The proposed change does not alter the current intent of the TS and will not result in any change to the design or design function of an SSC.

Therefore, the proposed changes do not create the possibility for a new or different kind of accident from any previously evaluated.

3. Does the proposed change involve a significant reduction in a margin of safety?

Response: No

The proposed changes add a new Technical Specification for the Containment Emergency Sump, moves and modifies an existing SR from the ECCS TS to the new Containment Emergency Sump TS, and modifies an associated TS (TS 5.5.15). The proposed changes are associated with a methodology change for assessment of debris effects from LOCAs that are already evaluated in the Calvert Cliffs UFSAR, an extension of TS required completion time for potential LOCA debris related effects on ECCS and Containment Spray, and associated administrative changes to the TS. The sump strainer debris loads from a full spectrum of LOCAs of all piping sizes up to and including double-ended guillotine breaks of the largest pipe in the reactor coolant system are analyzed. Appropriate redundancy and consideration of loss of offsite power and worst case single failure are retained such that defense-in-depth is maintained.

Application of the risk-informed methodology showed that the increase in risk from the contribution of the analyzed debris effects is very small as defined by RG 1.174 and that there is adequate defense in depth and safety margin. Consequently, Calvert Cliffs determined that the risk-informed method does not involve a significant reduction in margin of safety and demonstrated that the containment emergency sump will continue to support the ability of safety related components to perform their design functions when the effects of debris are considered. The proposed change does not alter the manner in which safety limits are determined or acceptance criteria associated with a safety limit. The proposed change does not implement any changes to plant operation and does not significantly affect SSCs that respond to safely shutdown the plant and to maintain the plant in a safe shutdown condition. The proposed change does not affect the existing safety margins in the barriers for the release of radioactivity. There are no changes to any of the safety analyses in the UFSAR.

Defense in depth and safety margin were extensively evaluated for the methodology change and the associated TS changes. The evaluation determined that there continues to be adequate defense in depth and safety margin that provide a high level of confidence that the calculated risk for the methodology and TS changes is acceptable.

Therefore, the proposed change does not involve a significant reduction in a margin of safety.

Based on the above, Exelon concludes that the proposed amendments do not involve a significant hazards consideration under the standards set forth in 10CFR50.92(c), and accordingly, a finding of "no significant hazards consideration" is justified.

4.4 Conclusion

Based on the considerations discussed above, (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations contingent upon approval of the exemption requested in Attachment 2 to this letter, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

5.0 ENVIRONMENTAL CONSIDERATION

A review has determined that the proposed amendment would change a requirement with respect to installation or use of a facility component located within the restricted area, as defined in 10 CFR 20. However, the proposed amendment does not involve (i) a significant hazards consideration, (ii) a significant change in the types or a significant increase in the amounts of any effluents that may be released offsite, or (iii) a significant increase in individual or cumulative occupational radiation exposure. Accordingly, the proposed amendment meets the eligibility criterion for categorical exclusion set forth in 10CFR51.22(c)(9). Therefore, pursuant to 10CFR51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with the proposed amendment.

6.0 REFERENCES

(1) Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions On Plant-Specific Changes to the Licensing Basis", Revision 2, Nuclear Regulatory Commission, Washington, DC.

(2) NRC Generic Letter 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors, September 13, 2004.

(3) NUREG-1829, "Estimating Loss-of-Coolant Accident (LOCA) Frequencies Through the Elicitation Process", April 2008.

(4) Regulatory Guide 1.82, Revision 3, Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident, November 2003.

(5) NRC Bulletin 2003-01: Potential Impact of Debris Blockage on Emergency Sump Recirculation at Pressurized-Water Reactors, June 9, 2003.

(6) TSTF-567-A, Technical Specifications Task Force Improved Standard Technical Specifications Change Traveler, Revision 1, July 2018.

(7) NRC Regulatory Guide 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities," Revision 2, March 2009.

(8) NOC-AE-15003241, "Supplement 2 to STP Pilot Submittal and Requests for Exemptions and License Amendment for a Risk-Informed Approach to Address Generic Safety Issue (GSI)-191 and Respond to Generic Letter (GL) 2004-02," August 20, 2015 (ML15246A126 – A129).

(9) NOC-AE-16003401, "Supplement 3 to STP Pilot Submittal and Requests for Exemptions and License Amendment for a Risk-Informed Approach to Address Generic Safety Issue (GSI)-191 and Respond to Generic Letter (GL) 2004-02," October 20, 2016 (ML16302A015).

Attachment 3-1

Technical Specification Page Markups

3.5 EMERGENCY CORE COOLING SYSTEMS (ECCS)

3.5.2 ECCS - Operating

LCO 3.5.2 Two ECCS trains shall be OPERABLE.

APPLICABILITY: MODES 1 and 2,
MODE 3 with pressurizer pressure ≥ 1750 psia.

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. One or more trains inoperable. <u>AND</u> At least 100% of the ECCS flow equivalent to a single OPERABLE ECCS train available.	A.1 Restore train(s) to OPERABLE status.	72 hours OR In accordance with the Risk Informed Completion Time Program
B. Required Actions and associated Completion Time for Condition A not met.	B.1 Be in MODE 3. <u>AND</u> B.2 Reduce pressurizer pressure to < 1750 psia.	6 hours 12 hours

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.5.2.1	Verify the following valves are in the listed position with power to the valve operator removed. <u>Valve Number</u> <u>Position</u> <u>Function</u> MOV-659 Open Mini-flow Isolation MOV-660 Open Mini-flow Isolation CV-306 Open Low Pressure Safety Injection Flow Control	In accordance with the Surveillance Frequency Control Program
SR 3.5.2.2	---------------------------NOTE--------------------------- Not required to be met for system vent flow paths opened under administrative control --- Verify each ECCS manual, power operated, and automatic valve in the flow path, that is not locked, sealed, or otherwise secured in position, is in the correct position.	In accordance with the Surveillance Frequency Control Program
SR 3.5.2.3	Verify each high pressure safety injection – and low pressure safety injection pump's developed head at the test flow point is greater than or equal to the required developed head.	In accordance with the Inservice Testing Program
SR 3.5.2.4	Deleted	
SR 3.5.2.5	Verify each ECCS automatic valve that is not locked, sealed, or otherwise secured in position, in the flow path actuates to the correct position on an actual or simulated actuation signal.	In accordance with the Surveillance Frequency Control Program

SURVEILLANCE		FREQUENCY
SR 3.5.2.6	Verify each ECCS pump starts automatically on an actual or simulated actuation signal.	In accordance with the Surveillance Frequency Control Program
SR 3.5.2.7	Verify each low pressure safety injection pump stops on an actual or simulated actuation signal.	In accordance with the Surveillance Frequency Control Program
SR 3.5.2.8	Deleted	Deleted
SR 3.5.2.9	Verify the Shutdown Cooling System open-permissive interlock prevents the Shutdown Cooling System suction isolation valves from being opened with a simulated or actual Reactor Coolant System pressure signal of $\geq$ 309 psia.	In accordance with the Surveillance Frequency Control Program
SR 3.5.2.10	Verify ECCS locations susceptible to gas accumulation are sufficiently filled with water.	In accordance with the Surveillance Frequency Control Program

3.5 EMERGENCY CORE COOLING SYSTEMS (ECCS)

3.5.3 ECCS - Shutdown

LCO 3.5.3 One high pressure safety injection (HPSI) train shall be OPERABLE.

-- NOTE --
When Reactor Coolant System cold leg temperatures are < 385°F (Unit 1), < 325°F (Unit 2) during heatup or cooldown and when ≤ 365°F (Unit 1), ≤ 301°F (Unit 2), during other conditions, the HPSI train is not required to be capable of automatically starting on an actuation signal.

APPLICABILITY: MODE 3 with pressurizer pressure > 1750 psia,
Mode 4.

ACTIONS

-- NOTE --
LCO 3.0.4.b is not applicable to ECCS High Pressure Safety Injection subsystem when entering MODE 4.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Required HPSI train inoperable.	A.1 Restore required HPSI train to OPERABLE status.	1 hour
B. Required Actions and associated Completion Time not met.	B.1 Be in MODE 5.	24 hours

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.5.3.1	The HPSI train related portions of the train following Surveillance Requirements are applicable: SR 3.5.2.1 SR 3.5.2.5 SR 3.5.2.10 SR 3.5.2.2 SR 3.5.2.6 SR 3.5.2.3	In accordance with the Surveillance Frequency Control Program

and

d. Other appropriate limitations and remedial or compensatory actions.

A loss of safety function exists when, assuming no concurrent single failure, a safety function assumed in the accident analysis cannot be performed. For the purpose of this program, a loss of safety function may exist when a support system is inoperable, and:

a. A required system redundant to system(s) supported by the inoperable support system is also inoperable; or

b. A required system redundant to system(s) in turn supported by the inoperable supported system is also inoperable; or

c. A required system redundant to support system(s) for the supported systems (a) and (b) above is also inoperable.

The SFDP identifies where a loss of safety function exists. If a loss of safety function is determined to exist by this program, the appropriate Conditions and Required Actions of the LCO in which the loss of safety function exists are required to be entered. When a loss of safety function is caused by the inoperability of a single Technical Specification support system, the appropriate Conditions and Required Actions to enter are those of the support system.

5.5.16 Containment Leakage Rate Testing Program

A program shall be established to implement the leakage testing of the containment as required by 10 CFR 50.54(o) and 10 CFR Part 50, Appendix J, Option B. This program shall be in accordance with the guidelines contained in Nuclear Energy Institute (NEI) 94-01, "Industry Guideline for Implementing Performance Based Option of 10 CFR Part 50, Appendix J," Revision 3-A, dated July 2012, and the conditions and limitations specified in NEI 94-01, Revision 2-A dated October 2008.

The peak calculated containment internal pressure for the design basis loss-of-coolant accident, P_a, is 49.7 psig. The containment design pressure is 50 psig.

3.6 CONTAINMENT SYSTEMS

3.6.9 Containment Emergency Sump

LCO 3.6.9 The containment emergency sump shall be OPERABLE.

APPLICABILITY: MODES 1, 2, 3, and 4

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Containment emergency sump inoperable due to ~~potential~~ containment accident generated and transported debris exceeding the analyzed limits.	A.1 Initiate action to mitigate containment accident generated and transported debris.	Immediately
	AND	
	A.2 Perform SR 3.4.13.1.	Once per 24 hours
	AND	
	A.3 Restore the containment emergency sump to OPERABLE status	90 days

CONDITION	REQUIRED ACTION	COMPLETION TIME
B. Containment emergency sump inoperable for reasons other than Condition A.	B.1 ----------NOTES----------- 1. Enter applicable Conditions and Required Actions of LCO 3.5.2, "ECCS - Operating," and LCO 3.5.3, "ECCS - Shutdown," for emergency core cooling trains made inoperable by the containment emergency sump. 2. Enter applicable Conditions and Required Actions of LCO 3.6.6, "Containment Spray and Cooling Systems," for containment spray trains made inoperable by the containment emergency sump. --------------------------------- Restore the containment emergency sump to OPERABLE status.	72 hours
C. Required Action and associated Completion Time not met.	C.1 Be in MODE 3. AND C.2 Be in MODE 5.	6 hours 36 hours

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.6.9.1	Verify, by visual inspection, the containment emergency sump does not show structural damage, abnormal corrosion, or debris blockage.	In accordance with the Surveillance Frequency Control Program

Attachment 3-2

Technical Specification Bases Page Markups (Information Only)

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Society of Mechanical Engineers Code. American Society of Mechanical Engineers Code provides the activities and Frequencies necessary to satisfy the requirements.

SR 3.5.2.4

The Surveillance Requirement was deleted in Amendment Nos. 260/237.

SR 3.5.2.5, SR 3.5.2.6, and SR 3.5.2.7

These SRs demonstrate that each automatic ECCS valve actuates to the required position on an actual, or simulated SIAS, and on a recirculation actuation signal; that each ECCS pump starts on receipt of an actual or simulated SIAS; and that the LPSI pumps stop on receipt of an actual or simulated recirculation actuation signal. This Surveillance is not required for valves that are locked, sealed, or otherwise secured in the required position under administrative controls. In order to assure the results of the low temperature overpressure protection analysis remain bounding, whenever flow testing into the RCS is required at RCS temperatures ≤ 365°F (Unit 1), ≤ 301°F (Unit 2), the HPSI pump shall recirculate RCS water (suction from the RWT isolated) or the requirements of LCO 3.4.12, shall be satisfied. The Surveillance Frequency is controlled under the Surveillance Frequency Control Program. The actuation logic is tested as part of the Engineered Safety Feature Actuation System testing, and equipment performance is monitored as part of the INSERVICE TESTING PROGRAM.

SR 3.5.2.8

The Surveillance Requirement was deleted in Amendment Nos [TBD}.
DELETED

SR 3.5.2.9

Verifying that the SDC System open-permissive interlock is OPERABLE ensures that the SDC suction isolation valves are prevented from being remotely opened when RCS pressure, is at or above, the SDC System design suction pressure of 350 psia. The suction piping of the LPSI pumps, is the SDC

B 3.6 CONTAINMENT SYSTEMS

B 3.6.9 Containment Emergency Sump

Bases

BACKGROUND

A Containment Emergency Sump is provided to support Design Basis Events that require ECCS recirculation to support long-term core cooling and decay heat removal. The Containment Emergency Sump consists of strainer modules, strainer ducting, and a sump pit. The strainer modules provide6,060 ft^2 of filtration surface area (nominal) amongst 33 strainer modules that are divided among 3 strainer rows. The strainer rows tie into a common radial duct which directs recirculation flow to the sump pit where the entrance to the ECCS Recirculation Headers is located.

During Design Basis Events the Containment Emergency Sump filters debris from the sump pool water prior to entering the ECCS recirculation headers. The debris filtration provided must be sufficient to ensure that decay heat removal from the reactor core is not adversely impacted, and that ECCS piping components do not become clogged, or suffer unacceptable wear.

The Containment Emergency Sump supplies both trains of the Emergency Core Cooling System (ECCS) and the Containment Spray System (CSS) during the recirculation mode of operation which is initiated on low Refueling Water Tank (RWT) level. The use of a single Containment Emergency Sump to supply both trains of the ECCS and CSS is acceptable since the containment emergency sump is a passive component, and passive failures are not required to be assumed to occur coincident with Design Basis Events.

Debris accumulation on the Containment Emergency Sump's strainer filtration surface

area can lead to increased hydraulic friction losses which in turn can result in undesirable effects including deaeration of the fluid, reduced net positive suction head (NPSH) at pump suction, strainer structural damage, and air ingestion via vortexing. Therefore, material sources inside containment that could become strainer debris during a Design Basis Event are strictly controlled. Potential strainer debris sources include, but are not limited to insulation, coatings, aluminum, tags and labels, fire barrier materials, and general area dirt and dust.

Included in the Containment Emergency Sump design basis are the refueling cavity drains and accompanying trash rack strainers. These items allow containment spray flow which falls in the refueling pool to drain into the containment basement. This increases the sump pool water level and improves strainer performance. The trash rack strainers over the cavity drains are credited with preventing large debris from clogging the cavity drains.

APPLICABLE SAFETY ANALYSES

LOCA is the only Design Bases Event that requires recirculation from the Containment Emergency Sump. In the LOCA analysis is assumed that the containment emergency sump is OPERABLE so that long-term operation of the Safety Injection and Containment Spray Systems can be maintained. As such, it supports emergency core cooling and containment cooling during an accident. It also provides a source of negative reactivity (Ref. 2). The design basis transients and applicable safety analyses concerning each of these systems are discussed in the Applicable Safety Analyses section of B 3.5.2, "ECCS - Operating," B 3.5.3, "ECCS - Shutdown," and B 3.6.6, "Containment Spray and

Bases

Cooling Systems."

UFSAR Section 14.17 (Ref. 2) describes evaluations that confirm long-term core cooling is assured following any accident that requires recirculation from the containment emergency sump.

The containment emergency sump satisfies Criterion 3 of 10 CFR 50.36(c)(2)(ii).

LCO

The Containment Emergency Sump is required to ensure successful recirculation operation to support ECCS and Containment Spray System OPERABILITY. A Containment Emergency Sump consists of the containment drainage flow paths, the Containment Emergency Sump strainer filtration surface area, internal strainer ducting, and a sump pit containing the inlet to the ECCS and CSS piping. An OPERABLE Containment Emergency Sump has no structural damage or abnormal corrosion that could prevent recirculation of coolant, or allow oversized debris to enter the recirculation headers. Also, during a postulated design basis event an OPERABLE Containment Emergency Sump will not accumulate more debris on the filtration surface beyond that analyzed as being acceptable, and will limit fiber that passes through the strainer filtration surface area to less than 15 grams per fuel assembly.

Debris that might transport to the Containment Emergency Sump consists of the following (Ref. 1):

a. Accident generated debris sources - Insulation, coatings, and other materials which are damaged by the high-energy line break (HELB) and transported to the Containment Emergency Sump. This includes materials within the HELB zone of influence and other materials (e.g., unqualified coatings) that fail due to the post-

Bases

accident containment environment following the accident;

b) Latent debris sources - Pre-existing dirt, dust, paint chips, fines or shards of insulation, and other materials inside containment that are washed to the sump pool by the Containment Spray flow; and Chemical product debris sources - Aluminum and non-metallic materials such as paints, thermal insulation, and concrete that are susceptible to chemical reactions within the post-accident containment environment leading to corrosion products that are generated within the containment sump pool or are generated within containment and transported to the containment emergency sump.

Containment debris limits are defined in UFSAR Section 6.3 (Ref. 3).

APPLICABILITY

In MODEs 1, 2, 3, and 4, Containment Emergency Sump OPERABILITY requirements are dictated by the ECCS and containment spray OPERABILITY requirements. Containment spray has no OPERABILITY requirements in MODEs 3 with RCS pressure < 1750 psia, and MODE 4.

In MODEs 5 and 6, the probability and consequences of these events are reduced due to the pressure and temperature limitations of these MODES. Thus, the Containment Emergency Sump is not required to be OPERABLE in MODES 5 or 6.

ACTIONS

A.1, A.2, and A.3

Condition A is applicable when there is a condition which could result in containment accident generated and transported debris exceeding the analyzed limits. Containment debris

limits are defined in Reference 3.

Immediate action must be initiated to mitigate the condition. Examples of mitigating actions are:

- Removing the debris source from containment or preventing the debris from being transported to the Containment Emergency Sump;
- Evaluating the debris source against the assumptions in the analysis;
- Deferring maintenance that would affect availability of the affected systems and other LOCA mitigating equipment;
- Deferring maintenance that would affect availability of primary defense-in-depth systems, such as containment coolers;
- Briefing operators on LOCA debris management actions; or
- Applying an alternative method to establish new limits.

While in this condition, the RCS water inventory balance, SR 3.4.13.1, must be performed at an increased Frequency of once per 24 hours. An unexpected increase in RCS leakage could be indicative of an increased potential for an RCS pipe break, which could result in debris being generated and transported to the Containment Emergency Sump. The more frequent monitoring allows operators to proactively minimize the potential for an RCS pipe break while the Containment Emergency Sump is inoperable.

The inoperable Containment Emergency Sump must be restored to OPERABLE status in 90 days. A 90-day Completion Time is reasonable for emergent conditions that involve debris in

excess of the analyzed limits that could be generated and transported to the Containment Emergency Sump under accident conditions. The likelihood of an initiating event in the 90-day Completion Time is very small and there is margin in the associated analyses. The mitigating actions of Required Action A.1 provide additional assurance that the effects of debris in excess of the analyzed limits will be mitigated during the Completion Time.

B.1

When the Containment Emergency Sump is inoperable for reasons other than Condition A, such as blockage, structural damage, or abnormal corrosion that could prevent recirculation of coolant, it must be restored to OPERABLE status within 72 hours. The 72-hour Completion Time takes into account the reasonable time for repairs, and low probability of an accident that requires the Containment Emergency Sump occurring during this period.

Required Action B.1 is modified by two Notes. The first Note indicates that the applicable Conditions and Required Actions of LCO 3.5.2, "ECCS - Operating," and LCO 3.5.3, "ECCS - Shutdown," should be entered if an inoperable Containment Emergency Sump results in an inoperable ECCS train. The second Note indicates that the applicable Conditions and Required Actions of LCO 3.6.6, "Containment Spray and Cooling Systems," should be entered if an inoperable Containment Emergency Sump results in an inoperable CSS train. This is an exception to LCO 3.0.6 and ensures the proper actions are taken for these components.

C.1 and C.2

If the Containment Emergency Sump cannot be restored to OPERABLE status within the

associated Completion Time, the plant must be brought to a MODE in which the LCO does not apply. To achieve this status, the plant must be brought to at least MODE 3 within 6 hours and to MODE 5 within 36 hours. The allowed Completion Times are reasonable, based on operating experience, to reach the required plant conditions from full power conditions in an orderly manner and without challenging plant systems.

SURVEILLANCE REQUIREMENTS

SR 3.6.9.1

Periodic inspections are performed to verify the Containment Emergency Sump does not show current or potential debris blockage, structural damage, abnormal corrosion, or contain openings larger than those specified in the design. This is to ensure the operability and structural integrity of the Containment Emergency Sump strainer, and associated structures as well as the operability of the ECCS and Containment Spray systems (Ref. 4).

The Surveillance Frequency is controlled under the Surveillance Frequency Control Program.

REFERENCES

1. Regulatory Guide 1.82, Revision 4, “Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident,” March 2012.
2. UFSAR Chapter 14.17 (“Loss-of-Coolant Accident”).
3. UFSAR Section 6.3 (“Safety Injection”).
4. STP M-661-1(2), “Containment Emergency Sump Inspection.”

Attachment 3-3

Calvert Cliffs UFSAR Page Markups (Information Only)

June 7, 2019

UFSAR CHANGE MARKUPS

Insert 6.3.2.7

6.3.2.7 Containment Emergency Sump

The Containment Emergency Sump strainer has 6,060 ft^2 filtration surface area (nominal). There are 33 strainer modules, each approximately 3 ft high, and are divided among three strainer rows. There are 324 pockets in 29 of the strainer modules, and 252 pockets in four of the strainer modules. The pocket dimensions are 84 mm x 90 mm in cross-section, and 200 mm deep. The hole size through the strainer filtration surface is 1.6 mm (1/16") with no more than 3% larger holes and no holes larger than 2 mm. The strainer rows tie into a common duct which directs sump recirculation flow to the containment emergency sump pit. The sump pit is a concrete curb with a roof made of steel plates. The sump pit contains the inlet to both ECCS recirculation headers. Figure 6-12 provides the strainer arrangement. Drawing series 15960 also provides details of the containment emergency sump strainer design.

The strainer is classified as a Seismic Category 1 component and was analytically qualified to safe shutdown earthquake loadings. There are no curbs of sufficient dimension to impact water flow to the sump. Analyses demonstrated that the safety injection and containment spray systems and components are not susceptible to blockage, plugging or excessive wear and will perform their design functions for their intended mission times with high probability while operating with debris-laden fluid following a LOCA.

Debris transport to the strainer and any associated clogging of the strainer have been evaluated as part of the response to Generic Letter 2004-02 (Reference 1). Technical Specifications govern operability of the containment emergency sump and associated containment debris limits are listed in Table 6-12. The acceptable and allowable increase in risk associated with containment accident generated and transported debris is defined in terms of ΔCDF and ΔLERF, and the acceptance criteria are defined as the upper threshold for RG 1.174 Region III (i.e., 1x10-6 for ΔCDF and 1x10-7 for ΔLERF).

The containment emergency sump also includes plant design features upstream of the sump that are credited in the GSI-191 analysis. The refueling cavity drains and trash rack strainers are a containment drainage flow path that is credited in the analysis with allowing containment spray flow to drain into the containment basement increasing the water level in the sump and improving strainer performance. The trash rack strainers over the cavity drains are credited with preventing large accident-generated debris from clogging the cavity drains.

Insert 6.3.4

Generic Letter 2004-02 (Reference 1) required licensees to perform an evaluation of the ECCS and Containment Spray System cooling functions and the flow paths necessary to support those functions during recirculation from the containment emergency sump. This included the potential susceptibility of sump screens to debris blockage during design basis accidents requiring recirculation operation of ECCS or Containment Spray Systems. To ensure system function, the containment emergency sump design was modified as described in Section 6.3.2.7.

The plant licensing basis considers long-term core cooling following a LOCA as identified in 10CFR50.46. Long-term cooling is supported by the HPSI and the Containment Spray systems. These systems are subject to the effects of debris generated during the blowdown phase of a LOCA because they rely on the containment emergency sump during the recirculation mode of long-term core cooling.

Reference 1 sump performance evaluation activities included the following:

- Containment walkdowns to identify and quantify sources of debris
- Debris generation analysis
- Calculation of required and available net positive suction head for Safety Injection and Containment Spray pumps
- Containment Emergency Sump Strainer requirements
- Containment Emergency Sump Strainer structural analyses
- Operations procedures
- Debris effects downstream of the strainers and sump, including effect on core flow
- Debris effects upstream of the strainers and sumps
- Chemical effects associated with debris
- Plant-specific testing
- Risk-informed evaluation of debris effects not bounded by plant-specific testing

A deterministic evaluation supplemented by a risk-informed evaluation was performed to respond to Reference 1. The evaluations provide confidence that the sump design supports long-term core cooling following a design basis LOCA. The risk-informed evaluation meets the acceptance guidelines for a very small change as defined in Regulatory Guide 1.174 (Reference 2). These evaluations were described to the NRC in Reference 4.

The deterministic evaluation used plant-specific analysis and testing. Plant specific analyses were used to determine both the composition and amount of debris which might transport to the strainer. Plant specific testing was used to determine the strainer head loss caused by this transported debris. Plant specific testing and analysis was used to determine the quantity and effect of debris passing through the sump strainer and going into the reactor vessel core and into the ECCS and Containment Spray systems. The evaluation of debris effects on the fuel demonstrated acceptable deposition thickness and acceptable long-term core cooling, and the evaluation of debris effects on ECCS Containment Spray system components demonstrated that system function was not adversely impacted.

The approved method (Reference 3) for determining the effects of potential chemical precipitates on the emergency sump strainer was refined by delaying the formation of aluminum based precipitates until the sump pool temperature drops below 140°F.

The results of the risk-informed analysis determined that the strainer head loss could exceed acceptable values for certain larger LOCA break sizes. For those break sizes that generate debris loads resulting in strainer head losses greater than what is acceptable, the risk significance of those breaks is evaluated in accordance with the guidance of Reference 2. The results of these risk-informed evaluations demonstrate that the risk contribution of these pipe breaks is very low.

The debris quantities presented in Table 6-12 are the maximum quantities used in the risk-informed analysis that provide the licensing basis for the containment emergency recirculation

strainer. These quantities include operating margin and provide the operable basis for Technical Specification 3.6.9.

6.3.7 REFERENCES

1. Generic Letter 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors, September 13, 2004
2. Regulatory Guide 1.174, An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis, Revision 3, January 2018
3. WCAP 16530-NP-A, Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191, March 2008
4. Letter from Exelon Corporation to NRC Document Control Desk, dated August 13, 2018, Supplemental Response to Generic Letter 2004-02

Table 6-12

Containment Emergency Sump Debris Limits

Debris Type	Analyzed Limit
[1] Insulation Fiber Fines	[3]380 lbm.
Cal-Sil and Marinite	9.2 lbm.
Aluminum Surface Area	150 ft^2
Latent Debris	150 lbm.
Tags & Labels	500 ft^2
Qualified IOZ	0.94 ft^3
Qualified Epoxy	1.41 ft^3
Unqualified Alkyds	2.0181 ft^3
Unqualified Epoxy	3.4749 ft^3
Unqualified IOZ[2]	0.4581 ft^3
Unqualified Organic Zinc	0.0788 ft^3
Degraded-Qualified Epoxy	1.0966 ft^3
Degraded-Qualified IOZ	0.5482 ft^3

Note 1: Includes NUKON, Thermal Wrap, Generic Fiberglass, Temp-Mat, Nuke-Tape, Mineral Wool, and Lead Shielding Blanket Cover debris

Note 2: IOZ = In-Organic Zinc

Note 3: Insulation value is for the Alternate Break Size (12 Inch Break) to be used in Operability Determinations

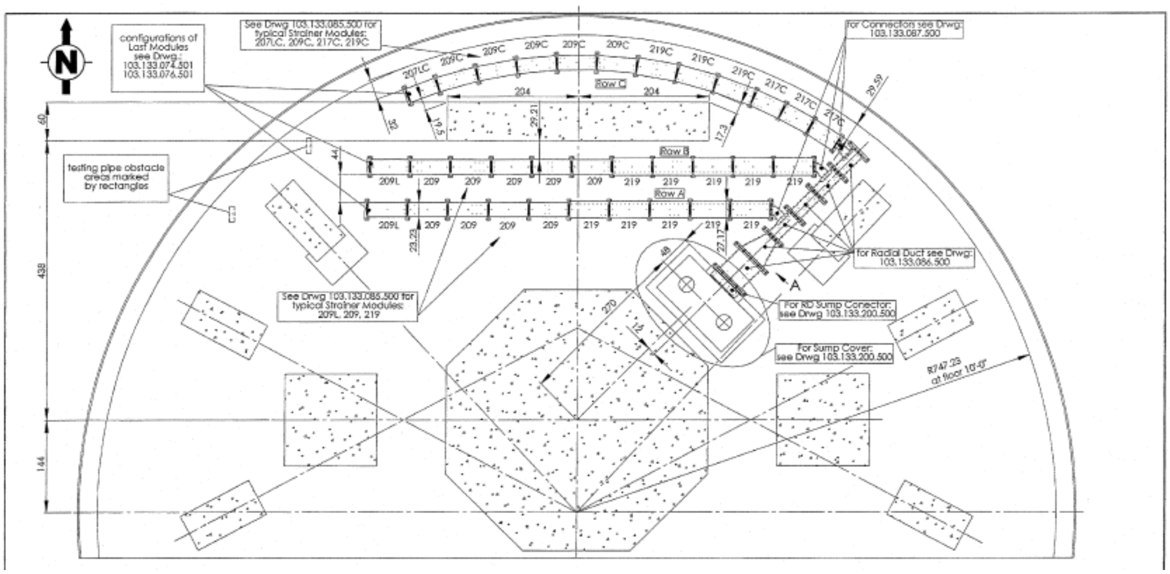

Figure 6-12

Containment Emergency Sump Arrangement