Introduction

Section 6 of the NEI 04-07 describes an alternate evaluation methodology for demonstrating acceptable containment sump performance. In using the alternate evaluation framework of NEI 04-07 (Option B in Figure 1), licensees would perform design-basis, long-term cooling evaluations and satisfy design-basis criteria for all LOCA break sizes up to a new debris generation break size (DGBS) that would be smaller than a double-ended guillotine break (DEGB) of the largest pipe in the RCS. This analysis space is referred to as Region I. Long-term cooling must also be assured for breaks between the new DGBS and the double-ended rupture of the largest pipe in the RCS, but the evaluation may be more realistic than a customary design-basis evaluation, consistent with the small likelihood of the break occurring. For breaks larger than the DGBS, licensees may apply more realistic models and assumptions. This analysis space is referred to as Region II.

The DGBS to distinguish between customary and more realistic design basis analyses is as follows:

1. For all ASME Code Class 1 PWR auxiliary piping (attached to RCS main loop piping) up to and including a DEGB of any of these lines, the design-basis rules apply.
2. For RCS main-loop piping (hot, cold, and crossover piping) up to a size equivalent to the area of a DEGB of a 14 in. schedule 160 pipe (approximately 196.6 square inches), the design-basis rules apply.
3. For breaks in the RCS main-loop piping (hot, cold, and crossover piping) greater than the above size (approximately 196.6 square inches), and up to the DEGB, licensees must demonstrate mitigative capability, but design-basis rules may not necessarily apply.

Implementation of the alternate evaluation methodology involves two separate analysis steps:

1. Region I – For pipe breaks up to the DGBS, analyses of the containment sump performance use conservative analysis methodologies (traditional analyses)

2. Region II – For pipe breaks larger than the alternate break size, analyses of the containment sump performance use risk insights and/or more realistic analysis methodologies

In implementing the alternate evaluation approach, it is necessary to demonstrate that reasonable assurance of mitigation capability is retained for break sizes between the alternate break size and the double-ended guillotine break of the largest pipe in the reactor coolant system. This Region II recirculation performance analysis is performed using more realistic analysis methods and assumptions.

The alternate methodology calls for a risk impact calculation to be performed when changes to the existing facility design are necessary to meet the acceptance criteria (e.g., plant modifications, operator actions). The risk impact calculation is used to ensure that the changes to the facility design have sufficient reliability to provide reasonable assurance that they will perform their intended function. This risk calculation only applies for cases where active components and/or operator actions are considered and reliability can be measured. The risk impact is not calculated for passive components since they typically can be assumed to perform their function with a high degree of reliability based on design margins, etc. In cases where a measurable and inspectable reliability can be ascribed to a passive component, the risk assessment may be applicable.

Application to Debris Generation ZOI

Section 6 of NEI 04-07 provides a number of more realistic method and assumption examples for use in Region II analyses. These are focused primarily on potential credit for operator actions and use of more realistic calculation of NPSH. There is no guidance in NEI 04-07 for more realistic modeling of debris generation Zones of Influence (ZOI) for determination of debris generation due to the absence of experimentally based data needed to support more realistic modeling. As noted in the Safety Evaluation Report for NEI 04-07:

NRC SER Page 119:

The ZOI models and assumptions to be applied for Region II analyses are those described in Sections 3 and 4 of the GR. There are a number of known conservatisms in the ZOI model presented in Sections 3 and 4. However, because development of a technically sound model to more realistically model the ZOI based on existing experimental and analytical data is quite complex and has not been initiated, the GR relies on the models described in Sections 3 and 4.

A number of debris generation tests have since been performed to support ZOI reductions from the conservative modeling in NEI 04-07. The results of these tests demonstrate the high level of conservatism in the ZOI models provided in Sections 3 and 4 of NEI 04-07.

NRC, in their review of ZOI reduction tests, has identified areas of modeling/experimental uncertainty and has been reluctant to fully accept some of the ZOI test results for use in evaluation models covering the full range of postulated breaks.

These cases present an opportunity to utilize the alternate evaluation framework of NEI 04-07 as a means to reach closure on evaluation models and assumptions. As noted above, the alternate evaluation methodology provides a means to treat the more likely spectrum of breaks in the traditional fashion, with full levels of conservatism (Region I analysis) and the less likely spectrum of breaks can be treated in a more realistic fashion (Region II).

The application of the alternate evaluation framework, as proposed in this paper, would generally be limited to ZOI debris generation modeling for specific debris materials. Few, if any, evaluation model changes from the baseline model beyond the ZOI model would be employed in the Region II analysis. Thus Region I and Region II evaluation models would essentially be the same, except for differences in ZOI modeling, and the Region II analysis would retain, as defense-in-depth, the same conservatisms present in the Region I analysis.

An example application of the alternative evaluation methodology is provided below for the purpose of demonstration.

Example:
Plant X utilizes NUKON jacketed insulation. NEI 04-07 provides a debris generation ZOI for NUKON insulation (jacketed and unjacketed) of 17D. Based on additional testing of NUKON jacketed insulation, the licensee proposed a reduced ZOI of 7D. Following NRC review, uncertainties remain on application of the 7D ZOI for the full break spectrum. In applying the alternate evaluation methodology, Plant X could use the full 17D ZOI for Region I breaks and apply the 7D ZOI to Region II breaks only.

Use of the alternate evaluation framework in this manner is fully consistent with Commission intent. As noted in the NRC SER for NEI 04-07:

Specific to GSI-191, the Commission recently requested the staff to, "implement an aggressive, realistic plan to achieve resolution and implementation of actions related to PWR ECCS sump concerns." One such resolution path involves the LOCA break size used in PWR sump analyses. For example, it is well understood that the amount of debris generation to be expected following a LOCA is dependent on the break size, and generally that less debris would be generated with a smaller LOCA break size (although less debris generation may be worse in certain situations when considering debris type and break location). The staff is already working to risk-inform 10 CFR 50.46 to redefine the design-basis LBLOCA break size based on expected LOCA frequencies. A comparable approach for use in GSI-191 resolution would identify a debris generation break size (DGBS) which would be used to distinguish between customary and realistic design-basis analyses. However, it is very important to note that an alternative approach for resolving GSI-191 would not redefine the design-basis LOCA break size in advance of the 10 CFR 50.46 rulemaking effort. In developing an alternate approach for resolving GSI-191, the staff intends to remain at least as conservative as, and consistent with, any forthcoming revision to 10 CFR 50.46.

In support of the application of the alternate evaluation framework, it is anticipated that an applicant would identify key conservatisms that remain in the Region II analysis. These conservatisms serve to identify the defense-in-depth retained in the analysis methodology. While the conservatisms will be specific to the plant analysis, a listing of typical conservatisms found in many PWR analyses is provided in Table 1.

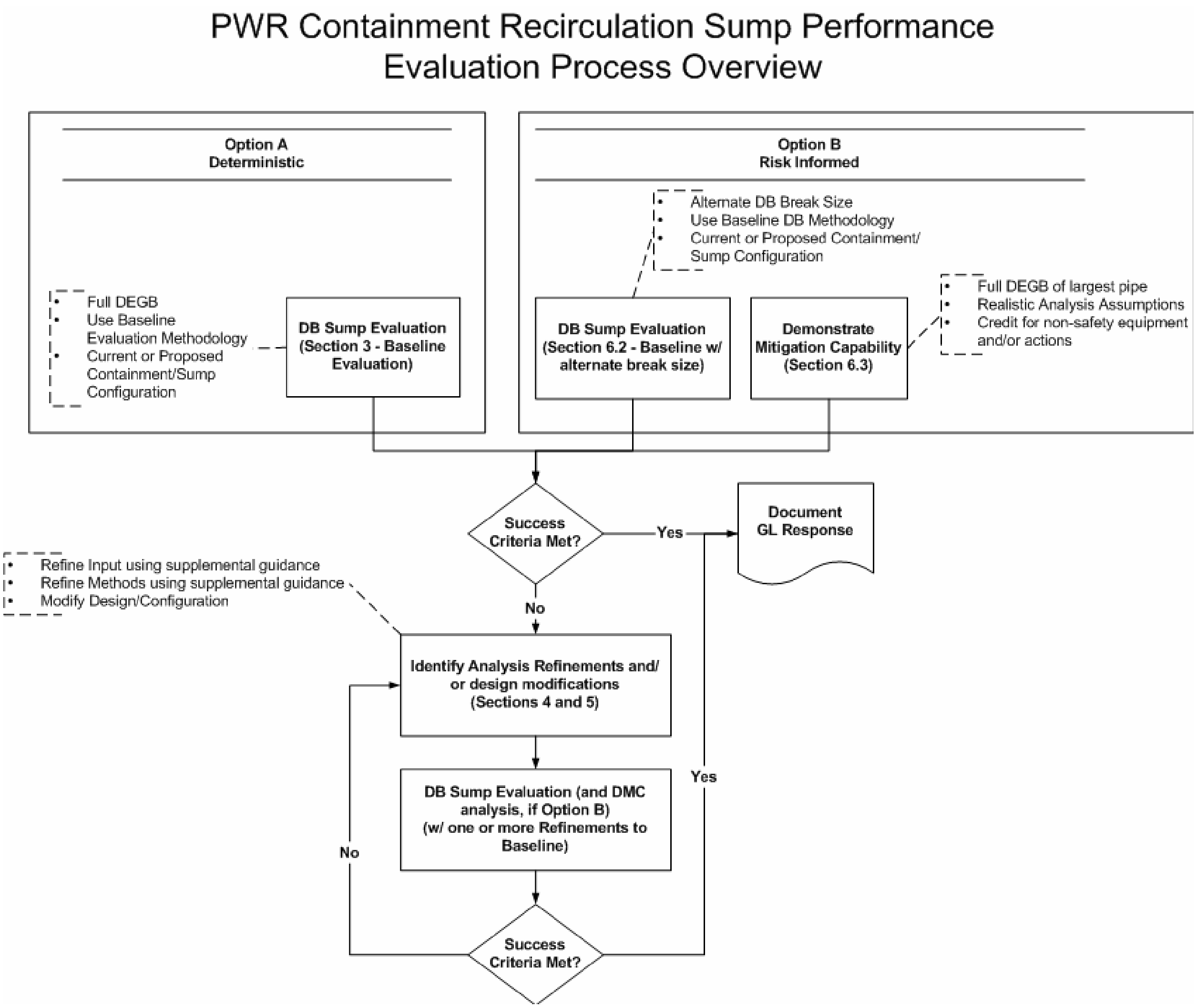
PWR Containment Recirculation Sump Performance
Evaluation Process Overview
Option A
Deterministic
Full DEGB
Use Baseline Evaluation Methodology
Current or Proposed Containment/Sump Configuration
DB Sump Evaluation (Section 3 - Baseline Evaluation)
Option B
Risk Informed
Alternate DB Break Size
Use Baseline DB Methodology
Current or Proposed Containment/ Sump Configuration
DB Sump Evaluation (Section 6.2 - Baseline w/ alternate break size)
Demonstrate Mitigation Capability (Section 6.3)
Full DEGB of largest pipe
Realistic Analysis Assumptions
Credit for non-safety equipment and/or actions
Success Criteria Met?
Yes
Document GL Response
No
Refine Input using supplemental guidance
Refine Methods using supplemental guidance
Modify Design/Configuration
Identify Analysis Refinements and/ or design modifications (Sections 4 and 5)
DB Sump Evaluation (and DMC analysis, if Option B) (w/ one or more Refinements to Baseline)
Yes
No
Success Criteria Met?

Figure 1

Table 1
Typical Design Basis Conservatisms used in PWR ECCS Recirculation Analyses

	Key Design Basis Conservatism	Expected Behavior
Debris Generation		
1	For design basis ECCS performance calculations, the limiting break is controlled by a unique combination of break size and location that make it highly improbable.	The likelihood of a large rupture in PWR 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.
2	Break opening time is instantaneous.	The assumption of an instantaneous opening of a full double-ended rupture is physically impossible and 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 remain long enough to 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 (LBB) and is an accepted part of regulatory compliance with GDC 4 for most, if not all, PWRs.
3	A non-prototypic spherical zone of influence is used to maximize the affected volume surrounding the postulated break.	While dependent on postulated break characteristics, the zone of destruction around a break will generally be focused in a single direction, significantly limiting the "zone" of materials subjected to break forces.
4	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 encapsulated insulation is applied to SS encapsulated insulation; all insulation is presumed to have a limited 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.

Table 1
Typical Design Basis Conservatisms used in PWR ECCS Recirculation Analyses

	Key Design Basis Conservatism	**Expected Behavior**
5	The test that generated the highest percentage of fines was used as the basis for the fiber small fines fraction. This size distribution applies over the entire ZOI neglecting the reduction in small fines fraction with increasing distance from the break.	The debris size distribution of insulation debris caused by high energy pipe rupture will consist mostly of large pieces, with a small fraction of small fines due to jet impingement close to the break location. Most large pieces will not transport to the screen, hence the debris loads on the strainer will be significantly smaller than current analyses predict.
Debris Transport		
6	All fine 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 fines would likely be retained on walls and structures above the containment pool due to incomplete spray coverage and hold up on structures. Even in areas that are directly impacted by sprays, some amount of fines would agglomerate together and likely be left behind.
7	All fine debris is assumed to transport to the surface of the strainer. Flows that are sufficient to cause any movement of individual pieces of small and large debris are assumed to transport the debris to 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 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.
8	Credit for inactive pool regions of containment is artificially limited to 15%.	In a prototypical plant, most of the debris generated would wash down quickly. Substantially more than 15% of the fine debris would transport to the inactive sump regions where it could not affect sump performance.
9	Accepted guidance calls for conservatively high erosion percentages for non-transportable sizes of fiberglass insulation. Accepted values range from 40% to 90% erosion of small fiberglass pieces into individual transportable fibers.	Testing shows that fibers do not "erode" from fibrous insulation under the low flow conditions present in PWR containments. Loose fibers on the surface of small pieces will be pulled away if subjected to enough velocity and turbulence. In a prototypical plant, this type of debris would be transported along with other types of debris to low velocity areas on the pool floor (similar to a sand bar formation) where little or no loss of individual fibers could occur.

Table 1
Typical Design Basis Conservatisms used in PWR ECCS Recirculation Analyses

	Key Design Basis Conservatism	Expected Behavior
10	Prescribed guidance calls for uniform debris transport to 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. This results in significantly lower head loss across the strainers.
Chemical Effects		
11	NRC accepted chemical effects modeling (WCAP-16530) relies 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 one to two orders of magnitude lower that predicted by design basis models due to surface passivation and formation of surface films.
12	100% of chemical species of interest are assumed to precipitate. These precipitates are further assumed to be present at the beginning of the event when flow margins are at a minimum.	When solubility limits are taken into account, the predicted precipitation is reduced by 1-2 orders of magnitude. Further, precipitates will form during periods when flow margins are greater.
13	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 the large surface areas in containment and will not be readily transported to the strainer.
Debris Accumulation and Headloss		
14	During strainer thin bed testing, the full particulate load is introduced to the test tank/flume first, followed by fiber fines and finally small and large fiber pieces. This debris introduction sequence results in the highest strainer headloss, but is not prototypic.	During a DBA, particulate debris, fiber fines, and larger fibrous debris are expected to reach the strainer at the same time resulting in lower headloss across the debris bed.
15	During testing, 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. A significant portion of these fines will arrive after flow margin has increased to the point where additional strainer headloss can be readily accommodated.
16	During 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 surface is expected to be significantly lower that tested amounts. In addition the precipitate is expected to arrive gradually and resultant headloss would be compensated by increased headloss margins.

Table 1
Typical Design Basis Conservatisms used in PWR ECCS Recirculation Analyses

	Key Design Basis Conservatism	Expected Behavior
17	During testing, all fiber and particulate debris is collected on the strainer prior to addition of chemical precipitates.	The chemical precipitate coating on the strainer would be less uniform than that achieved during testing since some fiber and particulate debris would arrive along with the precipitates, producing a less uniform deposit. A less uniform coating would yield a lower strainer headloss.
18	All debris predicted to reach the strainer, including chemical precipitates, is assumed to contribute to debris bed development; no credit is taken for debris that reaches the strainer but does not contribute to strainer headloss because it passes through the strainer and settles somewhere else in the recirculation flow path.	Some debris reaching the strainer will pass through the strainer, collecting elsewhere in the recirculation flow path and therefore would not contribute to strainer headloss.
19	During headloss testing, repeated attempts are made to get debris that has 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 "mixing" 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.
20	During testing, metallic insulation debris is excluded from the tested debris bed in order to conservatively bound headloss.	Some of the smaller metallic insulation debris will transport to the strainer and disrupt formation of a uniform fiber/particulate debris bed. This results in lower strainer headloss.
21	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.	Under DBA conditions 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.
22	Higher-than-expected flow rates are conservatively used during strainer headloss testing.	Flow rates will generally be lower than as-tested flow rates and operator actions to further reduce flow would be expected following indications of significant strainer headloss.
23	Measured strainer headloss from testing is extrapolated to the full 30-day mission time.	Strainer headloss will reach a peak value and then decrease over time due to natural settling (sloughing) of the debris bed *or other changes in debris bed morphology*.

Table 1
Typical Design Basis Conservatisms used in PWR ECCS Recirculation Analyses

	Key Design Basis Conservatism	Expected Behavior
Downstream Effects		
24	Evaluations for in-vessel responses assume a worst case debris generation scenario where all debris is homogeneously distributed throughout the recirculation phase of the event. All material transported by boiling is assumed to deposit on the fuel. All bypassed fibrous material is assumed to deposit on the fuel. Deposits, once formed, are not allowed to be thinned by flow attrition or by dissolution.	Only some material will be transported to the core, less will accumulate on the rods themselves; fibrous debris will get caught in a debris bed and the debris will not be homogeneously distributed. Deposits, once formed, will be thinned by flow attrition or by dissolution. The resulting deposit thickness is expected to be much less than what is currently predicted by approved models (LOCADM).
25	During fuel assembly testing, uniform flows were used and lacked anticipated complex mixing patterns that would preclude the formation of a uniform debris bed. Debris constituents were introduced in a non-prototypic fashion (i.e., introduction of particulate debris followed by fibrous debris) to promote a high pressure drop. Additionally, all debris that bypasses the sump screens is assumed to reach the fuel assembly and is used in the fuel tests, allowing for no settling and no plating on the hot fuel rods despite LOCADM assumptions to the contrary.	The probability for the formation of a uniform debris bed is low; a non-uniform bed is more likely and less limiting, as only a few locations without blockages in the core are required to allow for coolant flow to remove heat from the fuel. The simultaneous arrival of fiber and particulate will also result in a lower pressure drop.
26	Fuel assembly testing ignored expected debris attrition mechanisms. Lack of consideration for filtration, settling, or boiling results in conservatively high pressure drops.	The debris-laden water, once passed through the core, will return to the sump. The debris will settle and/or be filtered out before it returns to the RCS. The simultaneous arrival of fiber and particulate will also result in a lower pressure drop. Boiling in the core will provide a more turbulent environment which will tend to remove debris from the spacer grids.
27	Fuel assembly testing was performed with quantities of debris greater than expected to reach the core.	Fuel assembly debris buildup will be considerably lower than seen in the tests with a low likelihood of extensive blockages at any one spacer grid. The flow rate will not remain constant – it will decrease which results in a lower pressure drop. Therefore, the pressure drop at the core inlet and spacer grids for a CL break will be considerably less than observed in the tests.