SAFETY EVALUATION BY
THE OFFICE OF NUCLEAR REACTOR REGULATION
RELATED TO NRC GENERIC LETTER 2004-02,
NUCLEAR ENERGY INSTITUTE
GUIDANCE REPORT
(PROPOSED DOCUMENT NUMBER NEI 04-07),
“PRESSURIZED WATER REACTOR
SUMP PERFORMANCE EVALUATION METHODOLOGY”

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FOREWORD

The Nuclear Energy Institute (NEI) submitted its report, “Pressurized Water Reactor Sump Performance Evaluation Methodology,” (proposed document number NEI 04-07) in May 2004 to the U.S. Nuclear Regulatory Commission (NRC or the staff) for review (NEI, 2004a). The objective of this safety evaluation (SE) is to document the staff’s review of methodology guidance for licensees of pressurized water reactors (PWRs). This SE relates to NRC Generic Letter (GL) 2004-02, “Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors,” issued September 13, 2004 (GL-04-02).

In the staff’s review of the NEI submission, it found that portions of the proposed guidance were acceptable as is; other portions needed additional justification and/or modification. Therefore, in an effort to expedite the resolution of Generic Safety Issue (GSI)-191, “Assessment of Debris Accumulation on PWR Sump Performance,” (issued in September 1996), the staff has identified conditions and limitations and required modifications, including alternative guidance to supplement those portions of the proposed guidance that the staff determined required additional justification and/or modification. The NEI submission, as approved in accordance with the staff safety evaluation, provides an acceptable overall guidance methodology for the plant-specific evaluation of emergency core cooling system (ECCS) or core spray system (CSS) sump performance following any postulated accident for which ECCS or CSS recirculation is required, with specific attention given to the potential for debris accumulation that could impede or prevent the ECCS or CSS from performing its intended safety functions.

EXECUTIVE SUMMARY

In May 2004, the Nuclear Energy Institute (NEI) submitted the report, “Pressurized Water Reactor Sump Performance Evaluation Methodology” (proposed document number NEI 04-07, (NEI, 2004a), referred to herein as the Guidance Report or GR), for review by the U.S. Nuclear Regulatory Commission (NRC or the staff). The NRC’s approval of this methodology guidance would allow licensees of pressurized water reactors (PWRs) to use the document to respond to the NRC Generic Letter (GL) 2004-02, “Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors” (GL-04-02), issued on September 13, 2004, as the cited NRC-approved methodology for evaluating plant-specific sump performance. The GL identifies inadequacies in previous approaches for modeling sump-screen debris blockage and related effects, such that the staff no longer considers many licensing-basis analyses acceptable for confirming compliance with the NRC regulations. The NEI submission offers guidance to all PWR licensees in response to those inadequacies, identified during the resolution of Generic Safety Issue (GSI)-191, “Assessment of Debris Accumulation on PWR Sump Performance,” issued in September 1996.

The NEI submission, as approved in accordance with the staff’s safety evaluation, provides an acceptable overall guidance methodology for the plant-specific evaluation of the emergency core cooling system (ECCS) or containment spray system (CSS) sump performance following all postulated accidents for which ECCS or CSS recirculation is required, with specific attention given to the potential for debris accumulation that could impede or prevent the ECCS or CSS from performing its intended safety functions.

The GR is divided into two primary parts, the baseline evaluation and the refinements sections. The baseline is intended by NEI to provide a conservative approach for utilities to perform a “baseline evaluation” of their PWR containment sump using a sample calculation for a consistent and simplified first-step in determining susceptibility to head loss. The refinements sections are intended to address, for those plants that do not “pass” the baseline evaluation, options for refinements to the baseline calculation that either lead to acceptable results, or identify hardware “fixes” to provide acceptable results. The NEI submission addresses the following major areas:

- pipe break characterization
- debris generation/zone-of-influence (ZOI)
- latent debris accumulation within containment
- debris transport to the sump screen(s)
- head loss as a result of debris accumulation
- analytical refinements to remove conservatism(s) from the evaluation
- physical refinements to plant
- alternate evaluation (realistic and risk-informed)
- sump structural analysis
- upstream effects of debris accumulation

- downstream effects of debris accumulation
- chemical precipitation effects of debris accumulation

The following is a brief summary of each major area of the staff's evaluation.

ES.1 PIPE BREAK CHARACTERIZATION

Analysis of the most challenging postulated accident with regard to sump performance during long-term core cooling involves selection of the most limiting pipe break size, location, and debris combination within containment. For a PWR, Section C, Regulatory Position 1.3.2.3 of Regulatory Guide (RG) 1.82, Revision 3, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," issued November 2003, specifies that a sufficient number of breaks in each high-pressure system that relies on recirculation should be considered to reasonably bound variations in debris generation by size, quantity, and type of debris (RG 1.82-3). RG 1.82, Revision 3, stipulates the following maximum set of break locations to be considered:

- breaks in the reactor coolant system (RCS) and, depending on the plant licensing basis, main steam and main feedwater lines with the largest amount of potential debris within the postulated Zone of Influence (ZOI)
- large breaks with the most variety of debris within the expected ZOI
- breaks in areas with the most direct path to the sump
- medium and large breaks with the largest potential particulate debris to insulation ratio by weight
- breaks that generate an amount of fibrous debris that, after transport to the sump screen, could form a uniform thin bed (i.e., usually 1/8 in. thick) that could subsequently filter sufficient particulate debris to create a relatively high head loss referred to as the "thin-bed effect".

The GR states that the objective of the break selection process is to identify the break size and location which results in debris generation that produces the maximum head loss across the sump screen. All phases of the accident scenario must be considered for each postulated break location, including debris generation, debris transport, and sump-screen head-loss calculations. The break selection process outlined in the GR identifies limiting break locations as those that result in the following effects:

- the maximum amount of debris that is transported to the sump screen
- the worst combination of debris mixes that are transported to the sump screen

The GR also provides the following guidance:

- Disregard break exclusion zones for this evaluation (pipe breaks must be postulated in pre-existing break exclusion zones).
- Exclude consideration of NRC Branch Technical Position (BTP) MEB 3-1, "Postulated Rupture Locations In Fluid System Piping Inside and Outside

Containment," (MEB 3-1) as a basis, because limiting conditions for ECCS sump concerns are not related to the pipe vulnerability issues addressed in MEB 3-1.

- For plants needing to consider main steam and feedwater line breaks, break locations should be consistent with the plant's current licensing basis.
- Consider locations that result in a unique debris source term (i.e., not multiple. identical locations).
- Consider locations with high concentrations of problematic insulation.
- Consider breaks that generate an amount of fibrous debris that could create a thin-bed effect.
- Do not consider small breaks less than 2 inches in diameter (for piping attached to the RCS).
- If a significant amount of fibrous debris is not generated, consider breaks that produce the greatest contribution of latent debris sources which may produce the limiting debris loading condition for sump screen blockage concerns.

The staff finds that the GR is consistent with NRC's positions, with the following two exceptions:

1. The GR does not provide guidance for those plants that can substantiate no thin-bed effect, which may impact head loss results and limiting break location.
2. For plants needing to evaluate secondary-side piping such as main steam and feedwater pipe breaks, break locations should be postulated in a manner consistent with the guidance in Section 3.3 of this SE.

To address these exceptions, the staff provided enhanced guidance in the appropriate sections of this SE. Additionally, Appendix VIII to this SE provides a description of a thin bed, including its formation and effects. The guidance provided in the GR, in accordance with the enhanced guidance offered in this SE, provides an acceptable overall approach.

ES.2 DEBRIS GENERATION/ZONE-OF-INFLUENCE

With the rupture of piping comes shock waves and jets of coolant that project from within the piping via the closed system pressure, until that pressure dissipates. Debris is generated as the shock waves and jets impact surrounding insulation, coatings, surfaces, and other materials within the zone. The volume of space affected by this impact, or zone-of-influence, is modeled to define and characterize the debris generated.

The ZOI recommended in GR Section 3.4 is a spherical boundary with the center of the sphere located at the break site. The use of a spherical ZOI is intended to encompass the effects of jet expansion resulting from impingement on structures and components, truncating the sphere wherever it intersects any structural boundary or large robust equipment. The GR recommends that ZOI sizing be determined using the American National Standards Institute/American Nuclear Society (ANSI/ANS) 58.2-1988 standard for a freely expanding jet (ANSI/ANS 58.2-1988). The baseline ZOI comprises the insulation type that generates the largest ZOI of all potentially affected insulation types located inside containment—(i.e., the insulation type with the lowest destruction pressure). The resulting ZOI will then be applied to all insulation types.

Coating debris generation, however, is treated separately. The GR indicates that coating debris is generated from postulated failure (destruction) of both design-basis accident (DBA)-qualified and unqualified coatings within the ZOI and from postulated failure of all unqualified coatings outside the ZOI. For coatings, the GR recommends a ZOI destruction pressure of 1000 pounds per square inch (psi), with a corresponding ZOI radius of 1 pipe diameter. The GR assumes that all coating debris will fail to a particulate size equivalent to the basic material constituent.

The GR describes the debris characteristics in terms of size distribution, size and shape, and density. The GR identifies two size distributions for material within the ZOI, small fines and large pieces. Small fines are defined as debris able to pass through the largest openings of the gratings, trash racks, and radiological fences, which are less than a nominal 4 inches. Debris that cannot pass through these barriers is classified as large pieces.

For sizing fibrous debris within the ZOI, most fiber is assumed to degrade to 60 percent small fines and 40 percent large pieces. Some fiber is considered to degrade to 100 percent small fines and no large pieces. Reflective metallic insulation (RMI) is assumed to degrade to 75 percent small fines and 25 percent large pieces. Most other debris types are considered to degrade to 100 percent small fines and no large pieces. Erosion is neglected based on the assumption that the small fines are already reduced to their basic constituents of individual particles and fibers. Jacketed large debris is also assumed not to erode.

The GR tabulated debris material densities and size distributions for select debris types. The GR lists properties of materials for which limited data are available as “best available.” For those materials for which no data are available, the GR assumes maximum destruction.

The GR assumes that coatings will fail as particulate. The amount of particulate is a function of coating properties, including the thickness and area. The GR indicates that when plant-specific data do not exist regarding the thickness of unqualified coatings, an equivalent thickness of 3 mils of inorganic zinc (IOZ) be used.

The staff has reviewed the use of a spherical model sized in accordance with the ANSI/ANS standard and finds this approach acceptable. The spherical geometry proposed encompasses a zone which considers multiple jet reflections at targets, offset between broken ends of a guillotine break, and pipe whip. The staff’s confirmatory analysis (see Appendix I to this SE) verifies the applicability of the ANSI/ANS standard for determining the size of this zone. The staff found the use of a ZOI model to be an acceptable approach for analyzing debris generation in accordance with RG 1.82, Revision 3 (The staff also used and approved this approach in the boiling-water reactor (BWR) sump performance SE). The GR recommendation to truncate the spherical ZOI when a robust barrier or large piece of equipment is encountered is acceptable to the staff. The refinement offered in the GR to apply spherical ZOIs that correspond to material-specific destruction pressures for each material that may be affected in the vicinity of a break, is also acceptable.

A light-water reactor (LWR) loss-of-coolant accident (LOCA) jet is a two-phase steam/water jet. The destruction pressures, cited in the GR and referenced from the Boiling Water Reactors Owners Group (BWROG) Utility Resolution Guide (URG), were determined using an air jet. Based on staff study of this difference and because of limited experimental evidence from two-phase jets, the BWROG destruction pressures could be too high and thus could underestimate debris quantities. The staff position in this SE is to lower the debris destruction pressure by 40 percent to account for two-phase jet effects (see Section 3.4.2.2 of this SE).

With regard to coatings, the staff agrees with the approach taken in the GR; however, the staff considers there to be insufficient technical justification to support a value of 1000 psi as a destruction pressure, with a corresponding ZOI of 1 pipe diameter. The staff position is that the licensees should use a coatings ZOI spherical equivalent determined by plant-specific analysis, based on experimental data that correlate to plant materials over the range of temperatures and pressures of concern, or 10D (10 pipe diameters.)

The staff concurs with the characterization of debris in GR Section 3.4.3. Confirmatory analyses provided in Appendix II to this SE verify the acceptability of the size distributions recommended in the GR. However, the staff position is that licensees apply insulation-specific debris size information when available.

For the characterization of coatings in Section 3.4.3.4, the staff position is that the alternative offered to the use of plant-specific data for the determination of coatings thicknesses should include plant-specific justification. The recommended equivalent inorganic zinc (IOZ) thickness of 3 mils may be nonconservative and unsubstantiated because, although the assumption that all “unqualified” coatings outside the ZOI fail is consistent with the position provided in NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants,” Section 6.1.2, “Protective Coatings Systems,” the staff is aware of numerous cases in which containment coatings, “qualified” and “unqualified”, are much thicker than the recommended 3 mil IOZ-equivalent thickness.

In addition, for those plants that can substantiate no formation of a fibrous thin bed, the assumptions and guidance provided in the GR for coatings may be nonconservative in that the particulate-sized debris assumed would simply pass through the screens and not cause a head-loss concern. Therefore, for any such plant, the staff position is that assumptions related to coatings characterization be realistically-conservative based upon the plant-specific susceptibilities and data identified by the licensee, or that a default area equivalent to the area of the sump-screen openings be used for coatings size.

ES.3 LATENT DEBRIS

Section 3.5 of the GR provides guidance for estimating the amount of latent debris as a contributing source to head loss across the ECCS sump screen. Generally, miscellaneous fiber, dust, and dirt are primary sources of this debris type. For all-RMI plants, latent debris sources may provide the primary contribution of fibrous debris toward formation of a thin bed.

The staff has reviewed the guidance provided for estimating the impact of latent debris and agrees that it is necessary to determine the types, quantities, and locations of latent debris. The staff also agrees that it is not appropriate for licensees to assume that their existing foreign material exclusion (FME) programs have entirely eliminated miscellaneous debris. Results from plant-specific walkdowns should be used to determine a realistic amount of latent debris in containment and to monitor cleanliness programs for consistency with committed estimates.

The staff considers the guidance provided in the GR for consideration of the effects of latent debris to be acceptable for (1) general considerations for latent debris, (2) estimates of some surface areas for evaluation of latent debris, and (3) some attributes associated with evaluation of debris buildup, quantity of miscellaneous debris, and defining debris characteristics. Section 3.5 of this SE provides alternate guidance for sampling techniques and analysis to allow licensees to more accurately determine the impact of latent debris on sump-screen performance. This revised approach is based on generic characterization of actual PWR debris samples. If desired, a licensee could pursue plant-specific characterization as a refinement.

ES.4 DEBRIS TRANSPORT

Section 3.6 describes debris transport which is separately specified for each of three containment types—highly-compartmentalized, mostly uncompartmentalized, and ice condenser containments. The staff's review of debris transport considers the transport of the two size distributions identified in ES.2 above, and discussed in Section 3.4.3 (i.e., small fines and large pieces).

The staff finds that the transport guidance for small fines of debris is acceptable. However, the guidance for the large pieces of debris is unacceptable because of the unrealistic assumption that large pieces of debris cannot be transported. Specifically, plants with configurations conducive to fast pool velocities will realistically transport some large pieces, therefore the staff position is that consideration of the transportability of large pieces of debris is necessary.

The staff also finds that the method recommended for determining the quantity of fine debris trapped in inactive pools based on the volume ratio of inactive pools to the total pools is unrealistic for plants with large inactive pools. Therefore the staff position is that licensees should limit the maximum fraction of fine debris being trapped in inactive pools to 15 percent to avoid nonconservative results.

ES.5 HEAD LOSS

Computation of head loss in the GR involves input of design characteristics and thermal-hydraulic conditions into a head loss correlation (NUREG/CR-6224). The approach is acceptable to the staff, with specific areas of additional guidance offered in Sections 3.7.2.2 and 3.7.2.3 of this SE. The licensees should ensure the validity of the NUREG/CR-6224 correlation for the application of specific types of insulation and the range of parameters using the guidance provided in Appendix V to this SE.

The following additional guidance on fibrous thin bed formation should be considered:

- use of the appropriate density in the determination of the quantity of debris needed to form a thin bed (i.e., the as-manufactured density)
- careful evaluation of the limiting porosity for the particular particulate or mixture of particulates in the debris bed
- consideration of uncertainties in specifying a 1/8-in. bed thickness criteria (e.g., the indication that calcium silicate can form a debris bed without supporting fibers)
- consideration of other uncertainties (e.g., uncertainties associated with mixing of constituents, or uncertainties associated with latent debris data collection)

Before using the NUREG/CR-6224 correlation that is recommended in the GR or any other head-loss correlation, licensees should ensure that the correlation is applicable for the type of insulation and the range of parameters. If the correlation has been validated for the type of insulation and the range of parameters, licensees may use it without further validation. If the correlation has not been validated for the type of insulations and the range of parameters, licensees should validate it using head- loss data from tests performed on the particular type of insulations.

ES.6 ANALYTICAL REFINEMENTS

Three analytical topics are identified in this section—i.e., debris generation, debris transport, and head loss. A fourth, break selection, is addressed in Section 4.2.1.

For debris generation, the GR recommends two refinements for insulation materials. First, the GR proposes use of debris-specific ZOIs versus use of the most conservative debris type applied to all. Second, the GR proposes use of two freely expanding jets emanating from each broken pipe section versus use of a spherical ZOI. The staff finds both debris generation refinements to be acceptable.

For debris transport, the analytical refinements section of the GR provides two methods for computing flow velocities in a sump pool, the network method and the computational fluid dynamics (CFD) method. The staff finds both methods to be acceptable for predicting sump pool flow velocities provided the models are properly applied. However, neither method adequately addressed the estimation of debris transport once sump pool hydraulic conditions were determined. The network method lacked any debris transport guidance. The CFD method included debris transport guidance, which did not address two key aspects of the evaluation, i.e., where and when the debris enters the sump pool and debris size distributions appropriate for sump pool debris transport. For this reason, the staff provided alternative methods.

For head loss, only refinements discussed in GR Section 3.7.2.3.2.3, “Thin Fibrous Beds,” are offered. This section addresses the need to consider fibrous thin-bed formation, and the alternative consideration of latent debris as the primary contributor to this thin bed for all-RMI plants.

ES.7 PHYSICAL REFINEMENTS TO PLANT

GR Section 5.0 provides guidance for refinements in the areas of debris source term, debris transport obstructions, and screen modifications.

The following areas for refinement are offered for the debris source term:

- housekeeping and foreign material exclusion (FME) programs
- change-out of insulation
- modification of existing insulation
- modification of other equipment or systems
- modification of or improve coatings program

The staff has reviewed these refinements and finds them to be acceptable. However, with regard to insulation change-out or modification, the staff emphasizes consideration of the minimum loadings required to form a thin bed. In addition, the statement that DBA-qualified coatings have very high destruction pressures has not been demonstrated (see Sections 3.4.2, and 4.2.2.2.3).

This section of the GR also discusses the potential use of floor obstructions to provide barriers to prevent debris transport to the sump. It mentions that barriers can be used either near the sump or closer to the debris source. Key considerations regarding the use of floor obstructions and barriers include; (1) that the barrier be located where flow velocities and turbulence are insufficient to lift debris over the barriers, and (2) that the barrier should cover the entire cross section of flow.

To credit debris transport obstructions for trapping debris, plant specific documentation should be available on site to demonstrate an appropriate correlation to the test results in terms of debris type and velocity limits.

The staff finds the screen modifications discussed in the GR to be acceptable; however, licensees are not limited to those identified.

ES.8 ALTERNATE EVALUATION

NEI has proposed an alternative evaluation approach which incorporates realistic and risk-informed elements to the PWR sump analysis. The following three steps are proposed for this alternative approach, or “Option B”:

- Define a “debris generation” LOCA break size to distinguish between customary and more realistic design-basis PWR sump analyses.
- Perform customary design-basis analyses for break sizes up through the debris generation break size identified above (i.e., Region I analyses).
- Perform analyses demonstrating long-term cooling and mitigative capability for break sizes larger than the debris generation break size up through the double-ended rupture of the largest RCS piping (i.e., Region II analyses).

The GR proposes realistic treatment of Region II break sizes based on the low probability of these larger breaks. The models, assumptions, and equipment availability for mitigation used for this analysis are proposed to be realistic and demonstrated as functionally reliable, and may not necessarily be safety related or single failure proof. Licensees would perform risk evaluations as a basis for plant modifications and credit taken for operator actions. Such analyses may require plant-specific exemption and/or license amendment requests.

In considering the risk-informing aspects of the resolution of GSI-191, the staff recognized that the potential exists for the containment sump to clog if the mitigation capability credited in the Region II analysis does not function properly. Based on the industry-proposed approach in the Region II analysis, which also uses the conservative large-break (LBLOCA) frequency reported in NUREG-1150 to calculate the target reliability of the mitigation capability, and using the related generic study information, the largest LBLOCA core damage frequency (CDF) would be 1.4x10-5/year. This indicates that at a minimum the risk associated with LBLOCAs will be reduced from the current condition by nearly an order of magnitude.

- The staff concludes that GR Section 6.0 provides an acceptable approach for evaluating PWR sump performance. Application of more realistic and risk-informed elements is technically justified based on the low likelihood of such breaks occurring.

ES.9 SUMP STRUCTURAL ANALYSIS

The staff provides information in this section to show that structural loads on a sump screen should be computed using the total pressure drop across the screen. The limiting conditions correspond to the break location and debris source term that induce the maximum total head loss at the sump screen after full consideration of transport and degradation mechanisms. This represents the minimum required performance criterion for judging recirculation-sump operability. In other words, the recirculation sump must be able to accommodate both the clean-screen head loss and the debris-induced head loss associated with the limiting break while providing adequate flow through both the ECCS injection pumps and the CSS pumps if needed. For some licensees, the minimum structural design criterion for the sump screen can depend on the plant’s net positive suction head (NPSH) margin. Revised plant-specific licensing bases may dictate the structural capacity of the sump screen for supporting water flow through a debris bed under recirculation velocities, depending on screen geometry (i.e., fully submerged versus partially submerged designs).

ES.10 UPSTREAM EFFECTS

The GR states that certain holdup or choke points exist which could reduce flow to and possibly cause blockage upstream of the sump. Such areas within containment are: (1) narrowing of hallways or passages, (2) gates or screens that restrict access to areas of containment, such as behind the bioshield or crane wall, and (3) the refueling canal drain.

The staff finds the guidance with respect to upstream blockage to be acceptable.

ES.11 DOWNSTREAM EFFECTS

This section provides guidance on the evaluation of entrained debris downstream of the sump causing downstream blockage. The three areas of concern identified are: (1) blockage of flowpaths in equipment, such as containment spray nozzles and tight-clearance valves, (2) wear and abrasion of surfaces, such as pump running surfaces, and heat exchanger tubes and orifices, and (3) blockage of flow clearances through fuel assemblies.

The staff finds that this section requires clarification and additional considerations and provides the following alternative guidance with regard to downstream blockage:

- Licensees should consider the potential for particles larger than the flow openings in a sump screen to deform and flow through or orient axially and flow through the screen, and determine what percentage of debris would likely pass through their sump screen and be available for blockage of piping, core spray nozzles, and instrument tubing at downstream locations.
- Licensees should consider the term of operating line-up (short or long), conditions of operation, and mission times.
- Licensees should consider wear and abrasion of pumps and rotating equipment, piping, spray nozzles, instrumentation tubing, and high-pressure safety injection (HPSI) throttle valves. The potential for wear to alter system flow distribution and/or form plating of slurry materials (in heat exchangers) should be included.
- An overall ECCS or CSS evaluation should be performed considering the potential for reduced pump/system capacity resulting from internal bypass leakage or through external leakage.
- Licensees should consider flow blockage associated with core grid supports, mixing vanes, and debris filters, and their effects on fuel rod temperature.

ES.12 CHEMICAL EFFECTS

GR Section 7.4 addresses how reaction products formed in a post-LOCA environment can contribute to blockage of the sump screens and increase the associated head loss across the screens. The GR also defers guidance for dealing with these effects until current testing is complete and the data have been appropriately evaluated.

The staff has considered the NEI response and finds that chemical effects should be addressed on a plant-specific basis. Initially, licensees should evaluate whether the current chemical test parameters are sufficiently bounding for their plant-specific conditions. If they are not, then licensees should justify the use of test results in their plant-specific evaluation. If chemical effects are observed during these tests, then licensees should evaluate the sump-screen head-loss consequences of this effect. A licensee who chooses to modify its sump screen before tests are complete should consider potential chemical effects to avoid additional screen modification should deleterious chemical effects be observed during testing.

GUIDANCE DEVELOPMENT BACKGROUND

The staff of the U.S. Nuclear Regulatory Commission (NRC or the staff) began working with the Nuclear Energy Institute (NEI) on the resolution of Generic Safety Issue (GSI)-191 in 1997 with the establishment of the PWR Industry Sump Performance Task Force. The staff also conducted a study on the susceptibility of pressurized-water reactors (PWRs) to emergency core cooling system (ECCS) sump blockage following a loss-of-coolant accident (LOCA). This study was entitled, “GSI-191: Parametric Evaluations for Pressurized Water Reactor Recirculation Sump Performance” (Rao, 2001), and was performed by Los Alamos National Laboratory (LANL) in support of the NRC’s GSI-191 technical assessment to determine if sump failure is a plausible concern for PWRs.

On July 26 and 27, 2001, the NRC held a public meeting with the industry and other stakeholders including NEI, the Westinghouse Owners Group, the Babcock and Wilcox Owners Group, and the Combustion Engineering Owners Group, on the preliminary findings of that study. This meeting was documented in a meeting summary dated August 14, 2001 (Mtg, 2001). The preliminary results of the study indicated that significant quantities of fibrous and particulate debris will be generated during various size LOCAs, and that a sufficient fraction of this debris may be transported to the sump screen and cause sump screen blockage. However, before determining what regulatory action was needed, the staff presented the results to the industry and interested stakeholders, to discuss the assumptions and calculations in the report. Since that time, the parametric report was approved and issued (NUREG/CR-6762), and the staff concluded that GSI-191 is a credible concern for the population of domestic PWRs and that detailed plant-specific evaluations are needed to determine the susceptibility of each U.S.-licensed PWR to ECCS sump blockage.

The staff has worked closely with NEI, providing feedback in the development of an acceptable approach to the resolution of GSI-191, through a series of public meetings held between July 2001 and October 2003, until the submission of NEI’s October 31, 2003, report entitled “PWR Containment Sump Evaluation Methodology” (NEI, 2003b). Following the public meeting on July 26 and 27, 2001, described above, which involved discussions of risk considerations, as well as the parametric evaluation results, a public meeting was held on March 28, 2002, which was described in a meeting summary dated April 16, 2002 (Mtg, 2002a). The staff presented its approach toward the resolution of GSI-191, as did the industry, making references to the revision of Regulatory Guide (RG) 1.82 “Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident,” the issuance of a generic letter, the update of NUREG-0800, “Standard Review Plan,” (SRP), chemical testing, data collection guidance, and evaluation guidance. The industry also committed to take the lead in resolving this issue.

By the next meeting on May 30, 2002, NEI had issued NEI 02-01, “Condition Assessment Guidelines: Debris Sources Inside PWR Containments,” dated April 19, 2002 (NEI, 2002a). The staff’s comments in response to NEI 02-01 identified minor concerns with a lack of firm direction in some areas of data collection; however, the staff considered that NEI 02-01 provided reasonable overall guidance. Attachment 3 to the meeting summary dated June 6, 2002, includes the staff’s conclusion, as well as status presentations from the staff, NEI, and the industry (Mtg, 2002b).

In the next two public meetings, held on July 2, 2002, and August 29, 2002, the staff discussed the schedule for the draft generic letter, the development of temporary instructions for NRC inspectors regarding GSI-191, concerns surrounding downstream effects, such as high-pressure safety injection (HPSI) throttle valve blockage, and presented fault tree modeling for ECCS injection. The NEI discussion focused on interim plant assessment templates and guidance on related compensatory measures, as well as its response to the staff's comments on NEI 02-01. Meeting summaries dated July 31, 2002 (Mtg, 2002c), and September 5, 2002 (Mtg, 2002d), respectively, document the discussions of both meetings.

The next two public meetings, held on October 24, 2002, and December 12, 2002, revolved around the NEI proposed ground rules for the sump evaluation guidance and discussion of head-loss behavior and leak before break (LBB) considerations for break selection, as well as the HPSI issue. The staff objected to the use of LBB as applied to break selection assumptions. NEI issued "NEI Draft Evaluation Methodology Ground Rules" on December 12, 2002 (NEI, 2002b). Meeting summaries dated October 31, 2002 (Mtg, 2002e), and December 31, 2002 (Mtg, 2002f), respectively, include the material presented during both meetings.

The staff, NEI, LANL, and interested stakeholders participated in discussions of GSI-191 issues and toured the University of New Mexico experimental facilities on March 5, 2003. The NRC presented the schedule for generic letter issuance, chemical testing status and expectations, its response to the NEI ground rules for sump evaluation guidance, and supporting data and research by LANL, including debris accumulation, ECCS vulnerability, and pool flow analysis. NEI presented material on the use of LBB for break selection, the use of a nodal network method as an alternative to computational fluid dynamics computer modeling for debris transport analysis, and the use of fracture mechanics for debris generation. The meeting summary, issued April 24, 2004, documented several individual presentations (Mtg, 2003a).

NEI requested a meeting on April 29, 2003, summarized in a meeting summary dated May 15, 2003 (Mtg, 2003b), where the technical basis for using LBB arguments for break selection was discussed at length. The staff recommended that NEI provide for staff consideration an official submission on its proposed approach to break selection. The staff presented the proposed bulletin in the meeting, which was titled "Potential Impact of Debris Blockage on Emergency Sump Recirculation at Pressurized-Water Reactors."

On June 30, 2003, the staff held a public meeting with NEI and interested stakeholders on the issuance of NRC Bulletin 2003-01, "Potential Impact of Debris Blockage on Emergency Recirculation during Design-Basis Accidents at Pressurized-Water Reactors," dated June 9, 2003 (NRCB, 2003). NEI had forwarded 73 industry questions and comments on the bulletin, to which the staff responded in a handout distributed at this meeting. The public also questioned the effect of the bulletin on the overall GSI-191 resolution schedule. All meeting material was attached to the meeting summary dated August 12, 2003 (Mtg, 2003c).

On July 1, 2003, the staff held a separate public meeting with NEI and industry representatives. NEI presented sections of the draft methodology to the staff. The staff discussed progress in four major regulatory areas: the issuance of RG 1.82 Revision 3, head-loss task report, debris characterization project, and chemical effects testing. The credibility of metal corrosion, precipitation of low-solubility lead, and significant head-loss effects from fiber debris beds were also addressed. The public raised the question of ranking the plants' susceptibility to sump blockage, to which the staff replied that no ranking was intended beyond the parametric study results for 69 cases which had already been issued. The associated meeting summary is dated August 11, 2003 (Mtg, 2003d).

The NRC participated in a public workshop on debris impact on ECCS recirculation held in Baltimore, Maryland, on July 30 and 31, 2003, at which the NRC and LANL presented material on sump evaluation methodology and the use of computer codes and volunteer plant studies in sump evaluation analyses. (See Wkshp, 2003 for documentation of the NRC presentations.

The staff held a public meeting with NEI and industry representatives on September 10, 2003, the results of which are documented in a meeting summary dated October 16, 2003 (Mtg, 2003e). The NRC staff expressed concern over chemical effects on sump-screen blockage based on testing. NEI and the industry also presented material on chemical effects. Considerable discussion centered on the formation of gelatinous material due to chemical effects.

On October 31, 2003, NEI submitted to the staff the "PWR Containment Sump Evaluation Methodology" (NEI, 2003b). The staff provided NEI a preliminary review of the October 31, 2003, submission, by letter dated February 9, 2004 (NRC, 2004a). The staff transmitted two requests for additional information (RAIs) by electronic mail to NEI on March 10, 2004, and June 28, 2004. The staff met with NEI and stakeholders in a public meeting on March 23 and 24, 2004, to discuss the draft submission and the March 10, 2004, RAIs. A meeting summary dated April 22, 2004 (Mtg, 2004a) describes the results of this meeting. NEI responded to the staff's RAIs by letters dated June 10, 2004 (NEI, 2004c), and July 8, 2004 (NEI, 2004d), respectively.

On April 19, 2004, NEI submitted to the staff a preliminary version of a baseline evaluation method (NEI, 2004b), found in Section 3.0 of the proposed guidance report (GR). On May 28, 2004, NEI submitted the final version of the "PWR Containment Sump Evaluation Methodology" (NEI, 2004a), including a revised Section 3.0 and a draft version of Section 6.0. On July 7, 2004, NEI provided the staff with a "Table of Refinements," via electronic mail, clarifying what refinements were being offered in the GR. On July 13, 2004, NEI submitted a final version of the risk-informed section, or Section 6.0 (NEI, 2004e), of the GR.

NEI submitted a total of three draft versions of the GR, which the staff reviewed, including a draft of key sections of the evaluation guidance submitted July 1, 2003 (NEI, 2003a); a first draft of the "PWR Containment Sump Evaluation Methodology," submitted October 31, 2003 (NEI, 2003b); and a preliminary version of the current baseline evaluation method, or Section 3.0, of the proposed GR, submitted April 19, 2004 (NEI, 2004b). NEI submitted the final GR to the NRC staff for review on May 28, 2004 (except Section 6.0, which was submitted to the staff on July 13, 2004), and is the subject of this safety evaluation. The final GR provides baseline guidance to utilities for evaluating plant-specific issues of pipe break selection, debris generation, latent debris, debris transport, sump-screen head loss, and ECCS pump net positive suction head. In addition, the GR provides supplemental guidance to be used by licensees to refine their analysis and evaluations. The GR baseline guidance does not provide detailed guidance for several important related issues, including long-term chemical effects and head-loss correlations for particular insulation materials (e.g., calcium silicate), nor does it provide guidance for evaluating the impact of debris passing through the screens and being ingested into the ECCS (downstream effects). The GR does note that licensees must consider these additional elements in the overall performance evaluation in their plant-specific analyses.

The process used between the industry and the staff involved (1) direct discussions between the industry and the staff on key issues, (2) the NRC staff's independent research in support of the GSI-191 resolution effort, and (3) the submission by NEI of three separate versions of the GR, which significantly contributed to the development of the technical basis for an acceptable methodology, which is described in this safety evaluation.

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Acronym List

ACRS	Advisory Committee on Reactor Safeguards
AJIT	air jet impact test
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
BWR	boiling water reactor
BWROG	Boiling Water Reactor Owners' Group
B&W	Babcock and Wilcox
CalSil	calcium silicate
CDF	core damage frequency
CFD	computational fluid dynamics
CP	corrosion products
CS	containment spray
CSS	containment spray system
DBA	design basis accident
DGBS	"debris generation" break size
DDTS	Drywell Debris Transport Study
DEGB	double-ended guillotine break
DPSC	Diamond Power Specialty Co.
ECC	emergency core cooling
ECCS	emergency core cooling system
GDC	General Design Criteria
GR	NEI PWR Sump Performance Evaluation Methodology guidance report
GSI	Generic Safety Issue
HELB	high-energy line break
HPSI	high-pressure safety injection
IEF	initiating event frequency
IOZ	inorganic zinc
LANL	Los Alamos National Laboratory
LBB	leak before break
LBLOCA	large break loss of coolant accident
LDFG	low density fiberglass
LERF	large early release frequency

LOCA	loss-of-coolant accident
NEI	Nuclear Energy Institute
NIST	National Institute for Standards and Technology
NPSH	net positive suction head
NRC	Nuclear Regulatory Commission
PE	Parametric Evaluation
PWR	pressurized water reactor
RAI	Request for Additional Information
RCS	Reactor Coolant System
RG	Regulatory Guide
RMI	reflective metal insulation
SEM	scanning electron microscope
SE	Safety Evaluation
SMC:FP	sump mitigation capability failure probability
SRP	Standard Review Plan
SS	stainless steel
TMI	Three Mile Island
TPI	Transco Products, Inc.
TR	target reliability
UNM	University of New Mexico
ZOI	zone of influence

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO NRC GENERIC LETTER 2004-02,

NUCLEAR ENERGY INSTITUTE

GUIDANCE REPORT (PROPOSED DOCUMENT NUMBER NEI 04-07)

“PRESSURIZED WATER REACTOR SUMP PERFORMANCE

EVALUATION METHODOLOGY”

1.0 INTRODUCTION

By letter dated May 28, 2004, the Nuclear Energy Institute (NEI) submitted a document entitled, “Pressurized Water Reactor Sump Performance Evaluation Methodology” (proposed document number NEI 04-07) (NEI, 2004a), to the U.S. Nuclear Regulatory Commission (NRC or the staff) for review. This document is herein referred to as the guidance report (GR). NRC approval of the GR would allow licensees of pressurized-water reactors (PWRs) to use the GR to respond to NRC Generic Letter (GL) 2004-02, “Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors” (GL-04-02), as the cited NRC-approved methodology for their evaluation of plant-specific sump performance. The GL identifies inadequacies in many of the current PWR licensing-basis analyses for modeling sump-screen debris blockage and related effects, such that the staff no longer considers those analyses acceptable for confirming compliance with NRC regulations. The NEI GR offers guidance to all PWR licensees in response to those inadequacies raised during the resolution of Generic Safety Issue (GSI)-191, “Assessment of Debris Accumulation on PWR Sump Performance,” which were documented in the generic letter.

The staff has completed its review of the GR and associated documentation, and this safety evaluation (SE) outlines the staff’s conclusions. In general, the staff found that portions of the GR are acceptable for use in conducting plant-specific analyses of emergency core cooling system (ECCS) sump-screen blockage and resultant ECCS and/or containment spray system (CSS) loss of net positive suction head (NPSH) for pumps required following a loss-of-coolant-accident (LOCA). However, the staff found that several portions of the GR are not acceptable because the proposed methods lack sufficient guidance, supporting data, or analysis to justify their technical bases. For each of these areas, the staff has provided a recommendation and/or alternative guidance to that offered in the GR. This SE addresses each section of the GR, discusses the staff’s evaluation of the proposed methodologies, and documents the basis for the staff’s conclusions.

This SE addresses each part of a plant-specific analysis of sump performance and is organized so that its discussions parallel the guidance discussions presented in the GR. The SE includes sections on each of the following topics:

- pipe break characterization (Section 3.3)
- debris generation/zone of influence (Section 3.4)
- latent debris (Section 3.5)
- debris transport (Section 3.6)
- head loss (Section 3.7)
- analytical refinements (Section 4.0)
- design and administrative control refinements (Section 5.0)
- debris source term refinements (Section 5.1)
- refinements by use of debris transport obstructions (Section 5.2)
- refinements via sump screen modifications (Section 5.3)
- risk-informed evaluation (Section 6.0)
- sump structural analysis (Section 7.1)
- upstream effects (Section 7.2)
- downstream effects (Section 7.3)
- chemical effects (Section 7.4)

1.1 BACKGROUND

In 1979, Unresolved Safety Issue (USI) A-43, “Containment Emergency Sump Performance,” was established as a result of evolving staff concerns related to the adequacy of PWR recirculation sump designs. After extensive research, the staff found that the design assumption of 50-percent sump blockage used by licensees was nonconservative under certain conditions, and published the technical findings in NUREG-0897, “Containment Emergency Sump Performance,” dated October 1985 (NUREG-0897). Although the staff’s regulatory analysis concerning USI A-43 did not support imposing new sump performance requirements, the staff issued GL 85-22, “Potential for Loss of Post-LOCA Recirculation Capability Due to Insulation Debris Blockage,” dated December 3, 1985 (GL 85-22). GL 85-22 documented the resolution of USI A-43, recommending that all reactor licensees replace the 50 percent blockage assumption with a comprehensive mechanistic assessment of plant-specific debris blockage potential for future modifications related to sump performance, such as thermal insulation change-outs. The staff also updated the NRC’s regulatory guidance, including Section 6.2.2 of NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants” (hereafter referred to as the Standard Review Plan or SRP) (NUREG-0800) and Regulatory Guide (RG) 1.82, “Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident” (RG 1.82), to reflect the USI A-43 technical findings documented in NUREG-0897.

Following the resolution of USI A-43 in 1985, several events challenged the staff's conclusion that no new requirements were necessary to prevent the clogging of ECCS strainers at operating boiling-water reactors (BWRs).

- On July 28, 1992, at Barseback Unit 2, a Swedish BWR, the spurious opening of a pilot-operated relief valve led to the plugging of two containment vessel spray system suction strainers with mineral wool and required operators to shut down the spray pumps and backflush the strainers.
- In 1993, at Perry Unit 1, ECCS strainers twice became plugged with debris. On January 16, 1993, ECCS strainers were plugged with suppression pool particulate matter, and on April 14, 1993, an ECCS strainer was plugged with glass fiber from ventilation filters that had fallen into the suppression pool. On both occasions, the affected ECCS strainers were deformed by excessive differential pressure created by the debris plugging.
- On September 11, 1995, at Limerick Unit 1, following a manual scram caused by a stuck-open safety/relief valve, operators observed fluctuating flow and pump motor current on the “A” loop of suppression pool cooling. The licensee later attributed these indications to a thin mat of fiber and sludge that had accumulated on the suction strainer.

In response to these ECCS suction strainer plugging events, the NRC issued several generic communications, including Bulletin 93-02, Supplement 1, “Debris Plugging of Emergency Core Cooling Suction Strainers,” dated February 18, 1994; Bulletin 95-02, “Unexpected Clogging of a Residual Heat Removal (RHR) Pump Strainer While Operating in Suppression Pool Cooling Mode,” dated October 17, 1995; and Bulletin 96-03, “Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling-Water Reactors,” dated May 6, 1996. Through these bulletins, the staff requested that BWR licensees implement appropriate procedural measures, maintenance practices, and plant modifications to minimize the potential for the clogging of ECCS suction strainers by debris accumulation following a LOCA. Bulletin 96-03, in particular, noted the experience-based finding that clogging by fibrous debris is not limited to fibrous insulation as a debris source. All BWR licensees adequately addressed these bulletins.

However, findings from research to resolve the BWR strainer clogging issue in the 1990s raised questions concerning the adequacy of PWR sump designs by confirming what the aforementioned BWR strainer clogging events had earlier indicated: (1) that the amount of debris generated by a high-energy line break (HELB) could be greater than estimated by the USI A-43 research program, (2) that the debris could be finer (and thus more easily transportable), and (3) that certain combinations of debris (e.g., fibrous material plus particulate material) could result in a substantially greater head loss than an equivalent amount of either type of debris alone. Therefore, in 1996, the staff identified GSI-191, to ensure that post accident debris blockage would not impede or prevent the operation of the ECCS and CSS in the recirculation mode at PWRs in the event of a LOCA or other HELB accidents for which sump recirculation is required. The staff began evaluating the potential vulnerability of PWRs and contracted Los Alamos National Laboratory (LANL) to evaluate the potential for debris to cause degraded PWR recirculating sump performance. In July 2001, preliminary parametric calculations were completed on PWR sump performance, which confirmed the potential for debris accumulation in a representative number of operating PWRs. A number of studies (e.g., NUREG/CR-6771, LA-UR-02-7562) have been performed to evaluate the potential for sump clogging and the concerns associated with GSI-191. Designing the containment sump so that it is not susceptible to clogging has been generically estimated in the above studies to reduce the risk associated with large-break LOCAs (LBLOCAs) by a factor of 45. Using the conservative NUREG-1150 LBLOCA frequency (i.e., 5x10-4/year) in the generic calculation results in a risk reduction from 1.6x10-4/year to 3.6x10-6/year. Using a current (more realistic) LBLOCA frequency (4x10-6/year) would result in a risk reduction from 1.2x10-6/year to 2.6x10-8/year.

On June 9, 2003, having completed its technical assessment of GSI-191 (summarized in the next section), the NRC issued Bulletin 2003-01, "Potential Impact of Debris Blockage on Emergency Recirculation During Design-Basis Accidents at Pressurized-Water Reactors," requesting an expedited response from PWR licensees regarding the status of their compliance with regulatory requirements concerning the ECCS and CSS recirculation functions. PWR licensees unable to assure regulatory compliance pending further analysis were asked to describe any interim compensatory measures that they had implemented, or would implement, to reduce risk until the analysis could be completed. All PWR licensees have since responded to Bulletin 2003-01.

In developing Bulletin 2003-01, the NRC staff recognized that it might be necessary for PWR licensees to undertake complex evaluations to determine whether regulatory compliance exists in light of the concerns identified in the bulletin, and that the methodology to perform such evaluations was not currently available. As a result, the NRC did not request such information in the bulletin, but PWR licensees were informed that the staff was preparing a generic letter that would request this information. On September 13, 2004, the staff issued GL 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors" (GL 04-02).

1.2 OVERVIEW

In the event of a HELB inside the containment of a PWR, energetic pressure waves and fluid jets would impinge upon materials in the vicinity of the break, such as thermal insulation, coatings, and concrete, causing them to become damaged and dislodged. Debris could also be generated through secondary mechanisms, such as severe post-accident temperature and humidity conditions, flooding of the lower containment, and the impact of containment spray droplets. In addition to debris generated by jet forces from the pipe rupture, debris can be created by the chemical reaction between the chemically reactive spray solutions used following a LOCA and the materials in containment. These reactions may result in additional debris, such as disbonded coatings and chemical precipitants, being generated. Through transport methods, such as entrainment in the steam/water flows issuing from the break and containment spray washdown, a fraction of the generated debris and foreign material in the containment would be transported to the pool of water formed on the containment floor. Subsequently, if the ECCS or CSS pumps were to take suction from the recirculation sump, the debris suspended in the containment pool would begin to accumulate on the sump screen or be transported through the associated system. The accumulation of this suspended debris on the sump screen could create a roughly uniform covering on the screen, referred to as a debris bed, which would tend to increase the head loss across the screen through a filtering action. If a sufficient amount of debris were to accumulate, the debris bed would reach a critical thickness at which the head loss across the debris bed would exceed the NPSH margin required to ensure the successful operation of the ECCS and CSS pumps in recirculation mode. A loss of NPSH margin for the ECCS or CSS pumps as a result of the accumulation of debris on the recirculation sump screen, referred to as sump clogging, could result in degraded pump performance and eventual pump failure. Debris could also plug or wear close tolerance components within the ECCS or CSS. The effect of this plugging or wear may cause a component to degrade to the point where it may be unable to perform its designated function (e.g., pump fluid, maintain system pressure, or pass and control system flow).

The primary objective of the NRC's technical assessment of GSI-191 was to assess the likelihood that the ECCS and CSS pumps at domestic PWRs would experience a debris-induced loss of NPSH margin during sump recirculation. The NRC's technical assessment culminated in a parametric study that mechanistically treated phenomena associated with debris blockage using analytical models of domestic PWRs generated with a combination of generic and plant-specific data. As documented in Volume 1 of NUREG/CR-6762, "GSI-191 Technical Assessment: Parametric Evaluations for Pressurized Water Reactor Recirculation Sump Performance," dated August 2002 (NUREG/CR-6762-1), the GSI-191 parametric study concludes that recirculation sump clogging is a credible concern for domestic PWRs. As a result of limitations with respect to plant-specific data and other modeling uncertainties, however, the parametric study does not definitively identify whether or not particular PWR plants are vulnerable to sump clogging when phenomena associated with debris blockage are modeled mechanistically.

The methodology employed by the GSI-191 parametric study is based upon the substantial body of test data and analyses documented in technical reports generated during the NRC's GSI-191 research program, as well as earlier technical reports generated by the NRC and the industry during the resolution of the BWR strainer clogging issue and USI A-43. The GSI-191 parametric study references the following pertinent technical reports, which cover debris generation, transport, accumulation, and head loss:

- NUREG/CR-6770, "GSI-191: Thermal-Hydraulic Response of PWR Reactor Coolant System and Containments to Selected Accident Sequences," dated August 2002
- NUREG/CR-6762, Volume 3, "GSI-191 Technical Assessment: Development of Debris Generation Quantities in Support of the Parametric Evaluation," dated August 2002
- NUREG/CR-6762, Volume 4, "GSI-191 Technical Assessment: Development of Debris Transport Fractions in Support of the Parametric Evaluation," dated August 2002
- NUREG/CR-6224, "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris," dated October 1995

In light of the new information identified during the efforts to resolve GSI-191, the NRC staff determined that the previous guidance used to develop current licensing-basis analyses did not adequately and completely model sump screen debris blockage and related effects. As a result, because of the deficiencies in the previous guidance, an analytical error could be introduced that would result in ECCS and CSS performance that does not conform to the existing applicable regulatory requirements outlined in GL 04-02. Therefore, the staff revised its guidance for determining the susceptibility of PWR recirculation sump screens to the adverse effects of debris blockage during design-basis accidents (DBAs) requiring recirculation operation of the ECCS or CSS (RG 1.82-3). The NRC staff determined that it was appropriate to request that addressees perform new, more realistic analyses and submit information to confirm their plant-specific compliance with NRC regulations and other existing regulatory requirements listed in GL-04-02 pertaining to post-accident debris blockage.

In addition to demonstrating the potential for debris to clog containment recirculation sumps, operational experience and the NRC's technical assessment of GSI-191 have also identified three integrally related modes by which post-accident debris blockage could adversely affect the sump screen's design function of intercepting debris that could impede or prevent the operation of the ECCS and CSS in recirculation mode.

First, as a result of the 50-percent blockage assumption, most PWR sump screens were designed assuming that relatively small structural loadings would result from the differential pressure associated with debris blockage. Consequently, PWR sump screens may not be capable of accommodating the increased structural loadings that would occur from mechanistically determined debris beds that cover essentially the entire screen surface. Inadequate structural reinforcement of a sump screen may result in its deformation, damage, or failure, which could allow large quantities of debris to be ingested into the ECCS and CSS piping, pumps, and other components, potentially leading to their clogging or failure. The ECCS strainer plugging and deformation events that occurred at Perry Unit 1 (further described in Information Notice [IN] 93-34, "Potential for Loss of Emergency Cooling Function Due to a Combination of Operational and Post-LOCA Debris in Containment," dated April 26, 1993, and licensee event report (LER) 50-440/93-011, "Excessive Strainer Differential Pressure Across the RHR Suction Strainer Could Have Compromised Long Term Cooling During Post LOCA Operation," submitted May 19, 1993,), demonstrate the credibility of this concern for screens and strainers that have not been designed with adequate reinforcement.

Second, in some PWR containments, the flowpaths by which containment spray or break flows return to the recirculation sump may include "choke points" where the flowpath becomes so constricted that it could become blocked with debris following a HELB. Examples of potential choke points are drains for pools, cavities, isolated containment compartments, and constricted drainage paths between physically separated containment elevations. Debris blockage at certain choke points could hold up substantial amounts of water required for adequate recirculation or cause the water to be diverted into containment volumes that do not drain to the recirculation sump. The holdup or diversion of water assumed to be available to support sump recirculation could result in an available NPSH for ECCS and CSS pumps that is lower than the analyzed value, thereby reducing assurance that recirculation would successfully function. A reduced available NPSH directly concerns sump screen design because the NPSH margin of the ECCS and CSS pumps must be conservatively calculated to determine correctly the required surface area of passive sump screens when mechanistically determined debris loadings are considered. Although the parametric study (NUREG/CR-6762-1) did not analyze in detail the potential for the holdup or diversion of recirculation sump inventory, the NRC's GSI-191 research identified this phenomenon as an important and potentially credible concern. A number of LERs associated with this concern have also been generated, which further confirms its credibility and potential significance:

- LER 50-369/90-012, “Loose Material Was Located in Upper Containment During Unit Operation Because of an Inappropriate Action,” McGuire Unit 1, submitted August 30, 1990
- LER 50-266/97-006, “Potential Refueling Cavity Drain Failure Could Affect Accident Mitigation,” Point Beach Unit 1, submitted February 19, 1997
- LER 50-455/97-001, “Unit 2 Containment Drain System Clogged Due to Debris,” Byron Unit 2, submitted April 17, 1997
- LER 50-269/97-010, “Inadequate Analysis of ECCS Sump Inventory Due to Inadequate Design Analysis,” Oconee Unit 1, submitted January 8, 1998
- LER 50-315/98-017, “Debris Recovered from Ice Condenser Represents Unanalyzed Condition,” D.C. Cook Unit 1, submitted July 1, 1998

Third, debris blockage at flow restrictions within the ECCS recirculation flowpath downstream of the sump screen is a potential concern for PWRs. Debris that is capable of passing through the recirculation sump screen may have the potential to become lodged at a downstream flow restriction, such as a high-pressure safety injection (HPSI) throttle valve or fuel assembly inlet debris screen. Debris blockage at such flow restrictions in the ECCS flowpath could impede or prevent the recirculation of coolant to the reactor core, thereby leading to inadequate core cooling. Similarly, debris blockage at flow restrictions in the CSS flowpath, such as a containment spray nozzle, could impede or prevent CSS recirculation, thereby leading to inadequate containment heat removal. Debris may also accumulate in close tolerance subcomponents of pumps and valves. The effect may either be to plug the subcomponent, thereby rendering the component unable to perform its function, or to wear critical close tolerance subcomponents to the point at which the component or system operation is degraded and unable to fully perform its function. Considering the recirculation sump screen’s design function of intercepting potentially harmful debris, it is essential that the screen openings are adequately sized and that the sump screen’s current configuration is free of gaps or breaches which could compromise the ECCS and CSS recirculation functions. It is also essential that system components are designed and evaluated to be able to operate with debris-laden fluid as necessary post-LOCA.

To assist in determining, on a plant-specific basis, whether compliance exists with Title 10, Section 40.46(b)(5), of the *Code of Federal Regulations* (10 CFR 50.46(b)(5)), licensees may use the guidance contained in RG 1.82, Revision 3, “Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident,” dated November 2003. RG 1.82, Revision 3, enhances the debris blockage evaluation guidance for PWRs provided in Revision 1 of the RG to better model sump-screen debris blockage and related effects. The NRC staff determined after the issuance of RG 1.82, Revision 2, that research for PWRs indicated that the guidance in this revision was not comprehensive enough to ensure adequate evaluation of a PWR plant’s susceptibility to the detrimental effects caused by debris accumulation on debris interceptors (e.g., trash racks and sump screens). RG 1.82, Revision 2, altered the debris blockage evaluation guidance found in Revision 1 of the guide following the evaluation of blockage events, such as the Barseback Unit 2 event mentioned above, but for BWRs only. RG1.82, Revision 1, replaced the 50-percent blockage assumption in Revision 0 of the guide with a comprehensive, mechanistic assessment of plant-specific debris blockage potential for future modifications related to sump performance, such as thermal insulation change-outs. This was in response to the findings of USI A-43.

The NEI GR expands on RG 1.82, Revision 3 (requirements for long-term cooling), using portions of NUREG/CR-6808 (knowledge-base report) and other NRC and industry-related documents. The NEI research contributions are (1) in the area of alternate break size, including options for risk informing the analysis as it relates to the initial postulated break size, and (2) on the behavior of protective coatings (a potential debris type) under high-pressure, two-phase jet impact.

In support of the GSI-191 resolution effort, the staff also conducted research, for a plant-specific sump performance analysis based on sample plant data. Although the work was not published, some of it was completed and simply not documented. Therefore, the staff has provided results from specific aspects of this research to supplement areas in the GR that lack supporting data and experimentation as a basis for alternative guidance. Appendices III and VI to this SE provide details of such cases.

2.0 REGULATORY EVALUATION

This section details the regulatory requirements, associated guidance, and precedent upon which the staff based its review of the GR submitted by NEI to be used for the evaluation of PWR sump recirculation performance.

In accordance with 10 CFR50.46(b)(5), licensees of domestic nuclear power plants are required to provide long-term cooling of the reactor core. Specifically, this regulation provides that “after any calculated successful initial operation of the ECCS,” the “calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.” For this evaluation of PWR recirculation performance, the staff considers this extended time to be 30 days, and requires cooling by recirculation of coolant using the ECCS sump, where coolant is accumulated for this purpose. However, if debris collects and clogs the sump screen or other components or pathways that prevent adequate suction for the ECCS or CSS pumps, then compliance with this regulation may be in question.

RG 1.82, Revision 3, provides guidance for determining compliance with 10 CFR 50.46(b)(5). Section 6.22, “Containment Heat Removal Systems,” of the SRP includes the staff’s review guidance for evaluating licensee compliance with 10 CFR 50.46(b)(5) Additionally, SRP Section 6.1.1, “Engineered Safety Features Materials,” provides the review process for thermal insulation and coating systems, which impact long-term cooling evaluation; SRP 9.2.5, “Ultimate Heat Sink,” provides review guidance from which the extended time for recirculation performance is derived; and SRP 6.1.2, “Protective Coating Systems (Paints),” provides review guidance for coating systems, a debris type evaluated in the sump analysis.

For PWRs licensed to the General Design Criteria (GDC) listed in Appendix A to 10 CFR 50; GDC 35 “Emergency Core Cooling” specifies additional ECCS requirements, GDC 38 “Containment Heat Removal” specifies heat removal systems requirements, and GDC 41 “Containment Atmosphere Cleanup” provides requirements for ensuring a clean containment atmosphere. Many PWR licensees credit a CSS, at least in part, with performing the safety functions to satisfy these requirements. PWRs that are not licensed to the GDC may credit a CSS to satisfy similar, plant-specific licensing-basis requirements. In addition, PWR licensees may credit a CSS with reducing the accident source term to meet the limits of 10 CFR 100 or 10 CFR 50.67.

Technical specifications pertain to the ECCS and CSS insofar as they require the operability of these systems for the mitigation of certain DBAs. The final safety analysis report also documents other plant-specific licensing commitments concerning the ECCS and CSS.

The staff considered the NRC’s August 28, 1998, SE on the “Utility Resolution Guidance (URG) for ECCS Suction Strainer Blockage (NEDO-32686-A)” (URG SE) used to resolve the related strainer blockage issue for BWRs in its evaluation of the GR. This approach helped to assure consistency and efficiency. In some areas, departures from the GR and the URG SE were warranted because of differences in the design features of BWRs and PWRs, as well as later information obtained through regulatory research.

The staff considered the Commission’s staff requirements memorandum (SRM) from A.L. Vietti-Cook to L.A. Reyes, SECY-04-0037, “Issues Related to Proposed Rulemaking to Risk-Inform Requirements Related to Large Break Loss-of-Coolant-Accident (LOCA) Break Size and Plans for Rulemaking on LOCA with Coincident Loss-of-Offsite-Power,” dated July 1, 2004 (SECY-04-0037) and RG 1.174, “An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis,” dated July 1998 (RG 1.174), in the review of industry-proposed alternatives, and in the realistic and risk-informed options with regard to break size selection and mitigative equipment requirements.

3.0 BASELINE EVALUATION

Section 3 of the GR provides an evaluation methodology referred to as a baseline set of methods that help identify the dominant design factors for a given plant. The baseline evaluation methodology is intended to provide an approach that includes sufficient conservatism to allow the use of simpler analytical methods.

3.1 INTRODUCTION

Section 3.1 of the GR describes the purpose of the baseline and presents background information regarding general accident scenarios of concern and accident phenomena. This section also notes the limitations of the evaluation method. It makes reference to supplemental guidance for refinements, and data collection to support base evaluations.

Key introductory points include the following:

1. This section states, “If a plant uses this method and guidance to determine that sufficient head-loss margin exists for proper long-term Emergency Core Cooling (ECC) and Containment Spray (CS) function, no additional evaluation for head loss is required.”
2. The baseline evaluation method only addresses the phenomena and issues up to and including head loss across the sump screen. Insufficient information presently exists to evaluate the effects of chemical reaction products on head loss across a sump screen and the associated debris bed. In addition, the baseline methodology does not include the evaluation of holdup of flow by debris upstream of the sump screen, the structural integrity of the sump screen, or the effects resulting from debris passing through the sump screen and being ingested into the ECCS or CSS.
3. The baseline evaluation guidance provides a conservative approach for evaluating the generation and transport of debris and the resulting head loss across the sump screen. If a plant determines that the results of the baseline approach are not acceptable, or additional design margin is desirable, the refinement guidance provided in subsequent sections may be used to further evaluate the post-accident performance of the ECC sump.

Staff Evaluation of GR Section 3.1: The baseline guidance acknowledges that the chemical reaction product effects on head loss, downstream effects, and upstream effects are not fully considered in the baseline evaluation methodology. However, the guidance does not make it explicitly clear that the plant must still address these issues, even if the licensee successfully applied the baseline method to the plant. Therefore, the staff position is that licensees address these effects in accordance with the staff positions specified in Section 7.0 of this SE.

The staff questions the GR statement that the baseline provides a conservative approach. Aspects of the baseline guidance have been identified that are clearly not conservative, while other aspects are conservative. The subject aspects are identified at the appropriate locations in this SE. Acceptance of the baseline evaluation requires that the baseline approach results in an evaluation that, overall, is realistically conservative.

The staff has sponsored research to confirm whether or not specific aspects of the guidance are truly conservative, as stated by the guidance. Results of this research are included in Appendices I, II, IV, and V, to this SE; and are referenced appropriately in the pertinent sections of this document. Section 3.8 of this SE documents the staff's evaluation of assumptions for which conservatism is in question, and provides alternative guidance toward ensuring an overall realistic conservatism for the baseline.

3.2 METHOD OVERVIEW

Section 3.2 of the GR presents the five major areas of the baseline guidance as break selection, debris generation, latent debris, debris transport, and head loss.

3.3 BREAK SELECTION

This section of the GR presents considerations and guidance for selecting an appropriate postulated break size and location for use in the baseline analysis. The stated objective of the selection process is to identify the break conditions that present the greatest challenge to post-accident sump performance.

The staff review resulted in two exceptions to the proposed GR guidance for break selection. These two exceptions involved the treatment of secondary-side breaks and the guidance for plants that can substantiate that no thin bed develops. A discussion of the evaluation of secondary-side breaks is included in this section of the SE. Other sections of this SE discuss guidance for thin-bed considerations, including those on debris generation, latent debris, transport, and head loss. Additionally, Appendix VIII to this SE provides a description of a thin bed, including its formation and effects.

3.3.1 Introduction

The GR describes break selection as a two-step process involving selection of (1) the size of the break and (2) the location of the break.

Staff Evaluation of GR Section 3.3.1 The staff notes that double-ended guillotine breaks (DEGBs) need to be assumed for the baseline analysis of primary system piping (GR Section 3.3.3), so the size of the break is then determined by the diameter of the pipe. Other break-size criteria may be adopted for postulated breaks in secondary piping, depending on assumptions in the plant licensing basis.

The GR states that the objective of the break selection process is to identify the break size and location which results in debris generation that is determined to produce the maximum head loss across the sump screen. The staff finds this objective to be acceptable. Because the assessment will address several complex phenomena for each break location, the location of the most challenging break cannot be identified with confidence until a number of postulated break locations have been evaluated.

3.3.2 Discussion

As stated in the GR, the criterion used to define the most challenging break conditions is the estimated head loss across the sump screen. The break location that maximizes estimated head loss is referred to in the GR as the "limiting break location." All phases of the accident scenario must be considered for each postulated break location, including debris generation, debris transport, and sump-screen head loss calculations. The outcome of head-loss predictions from each candidate break location should be performed systematically and should be self-contained.

Two attributes of break selection which are emphasized in the GR that can contribute to head loss are (1) the maximum amount of debris transported to the screen and (2) the worst combination of debris mixes that are transported to the screen. The GR emphasizes the proper metric for comparison, head-loss effect upon arrival at the screen. The GR requires that break locations be surveyed to provide for both items 1 and 2, above, because under given circumstances, either could represent the limiting break. For example, relatively small quantities of fiber, in combination with LOCA-generated or latent-debris particulate, can induce head losses which exceed the effects of much larger debris beds. RG 1.82, Revision 3 itemizes additional features of a break that may dominate effects on the screen, but these two GR criteria encompass quantity, type, transport, and mixed composition as key issues.

3.3.3 Postulated Break Size

Staff Evaluation of GR Section 3.3.3 The NRC agrees that DEGBs with full piping separation and offset should be used for baseline evaluation of LOCA debris generation for breaks assumed to occur in primary system piping (reactor coolant system (RCS) main loop piping and attached auxiliary piping). For plants that require recirculation to maintain long-term cooling after secondary-system pipe ruptures, either DEGB conditions may be assumed, or conditions consistent with the plant's licensing basis for breaks may be used to characterize the break size (typically, a spectrum of break sizes is evaluated, up through a double ended rupture). The staff finds that the GR guidance with respect to break size is acceptable because this approach provides for large volumes of debris and the worst combinations of debris.

3.3.4 Identifying Break Locations

Staff Evaluation of GR Section 3.3.4 The NRC agrees that, in accordance with 10 CFR 50.46, all RCS piping and connected piping, must be considered in the evaluation of locations to identify the limiting break. As stated in the GR, some plant designs require eventual coolant recirculation from the sump for pipe ruptures other than a LOCA. If recirculation is required under the plant's licensing-basis to mitigate these events, then breaks must be examined in this piping, as well. Any actuation of the recirculation pumps implies an initiating event that should be examined for potential debris generation, regardless of whether the recirculation supplies containment spray or safety injection systems.

3.3.4.1 General Guidance

The staff position is provided for each of the following seven principles of break selection guidance offered in the GR.

1. The GR states that break exclusion zones must be disregarded for this evaluation. The staff finds this to be acceptable because all piping locations should be considered. The GR also states that for main steam and feedwater line breaks, licensees should evaluate the licensing basis and include potential break locations in the evaluation, if necessary. The staff finds this to be

acceptable. However, the staff position is that if secondary breaches (i.e., main steam and feedwater line breaks), rely on sump recirculation, as described in the plant licensing basis, breaks should be postulated in these systems at locations chosen in a manner consistent with the remaining guidance in this section.

2. The GR states that application of NRC Branch Technical Position (BTP) MEB 3-1 is not appropriate for determining potential LOCA break locations. The staff finds this to be acceptable (see Section 4.2.1 of this SE for a more detailed discussion of the staff position).

3. The GR states that for plants for which secondary-system breaks (i.e., main steam and feedwater line breaks) rely on sump recirculation as described in the licensing basis, postulated break locations should be consistent with the plant's current licensing basis. The staff finds this position to be unacceptable. The staff position is that secondary-side break locations should be postulated in a manner consistent with the remaining guidance in this section. The reason supporting this position is that inclusion of secondary-break scenarios in the licensing basis acknowledges the possible need for recirculation, but the break locations evaluated in the licensing basis may not have been defined specific to sump performance and could not have anticipated the range of concerns identified in the course of resolving GSI-191. Although secondary side breaks are not analyzed in accordance with the requirements of 10 CFR 50.46 or to demonstrate compliance with these requirements, the staff's position is that licensees relying on the ECCS sumps to mitigate the consequences of secondary-side breaks (e.g., for EEQ purposes) should identify and evaluate the limiting break locations to ensure acceptable sump performance.

4. The GR recommends that pipe breaks be postulated at locations that result in unique debris source terms to avoid multiple locations with identical composition and quantity of debris. The staff considers that in order to assess the potential head loss on the sump screen, the break location must also be judged based on the degree of transport that is expected. Licensees may analyze the first few break locations in full detail, quantifying all phases of the accident sequence. A licensee may then evaluate additional breaks by comparing debris composition, debris quantity, and debris transport potential. This approach will avoid some duplication of effort and will permit a systematic survey of break locations.

5. The GR states that licensees must postulate pipe breaks that affect locations containing high concentrations of problematic insulation (microporous insulation, calcium silicate, fire barrier material, etc.). The staff finds this position to be acceptable. Additionally, in keeping with the objective of identifying limiting break conditions, zones of problematic insulation might be affected by smaller breaks in their vicinity or by larger breaks that encompass them. Both possibilities should be considered because the overall composition of the debris arriving at the screen may be different.

6. As discussed above, the initial quantity and composition of the debris source are important attributes of break selection, but potential transport must also be considered. The GR states that "pipe breaks shall be postulated with the goal of creating the largest quantity of debris and/or the worst-case combination of debris types at the sump screen." The staff agrees that these conditions should

be evaluated. The GR correctly notes that the largest quantity at the screen may not produce the highest head loss. Additional discussion of screen head loss analysis found in Section 3.7 of the SE may help guide the selection of break locations that could create adverse conditions at the sump screen.

7. The GR proposes that piping less than 2 inches in diameter need not be considered in order to identify the limiting break conditions. The staff finds this to be acceptable. While it may be possible for a 2-in. break to challenge NPSH margins for some existing screens, larger breaks postulated with minimal transport would pose an identical challenge. Larger breaks with higher transport potential will certainly bound the maximum on-screen debris permitted by a 2-in. break. Eliminating 2-in. diameter breaks from the baseline greatly simplifies the systematic survey.

3.3.4.2 Piping Runs to Consider

The staff agrees that breaks, ruptures and leaks other than a LOCA will be considered in this analysis, if these scenarios eventually require recirculation for any purpose and if they are part of the plant licensing basis.

The staff's position is that all broken lines, regardless of piping system, that (1) are incorporated in the licensing basis, (2) are capable of generating debris, and (3) lead to a recirculation demand on the sumps should be considered. This position is not meant to imply that breaks must be fully analyzed in every length of every system. Many postulated locations will be eliminated by comparison with other collocated break possibilities of their respective debris volume, composition, and transport potential. However all piping in containment should be considered, regardless of its location within containment because breaks in secondary systems may also be of interest if the above criteria for consideration are satisfied (e.g., main steam and feedwater piping).

The level of detail pursued in the application of breaks in alternative piping systems depends largely on assumptions made in other steps of the accident analysis. For example, if assumptions made in the transport and head-loss analyses both require the assessment of thin bed formation, then break selection can focus on (1) particulate sources that may contribute to the thin-bed, and (2) maximum debris quantities that may dominate the debris bed. An example of a case in which detailed examination of an alternative system might be required is a high-energy line with debris generation potential that is either insulated with or that might affect problematic or diverse insulation types in locations outside the range of larger pipe breaks. Locations of this type might be found in upper containment near component cooling lines close to the pressurizer, for example. Scenarios of this type could be conservatively analyzed using bounding jet parameters relevant to the primary system piping or a new jet calculation could be performed specific to the conditions of the line in question. The actuation of spray for breaks postulated in alternative systems is also a key consideration in their assessment as potentially limiting conditions because containment spray will enhance transport to the recirculation pool and to the sump screen. This discussion is intended to recognize that there may be candidate break locations outside of the larger break zone of influence (ZOI). Conversely, if such locations are already considered within larger postulated breaks with a large ZOI, then detailed examination may not be required.

The explicit assumption of thin-bed formation, regardless of break size or location, offers a significant simplification for break selection because more focus can be placed on the larger piping systems that envelop more spatial volume. Breaks outside of the crane wall may require more detailed examination for pipe size, pipe pressure, nearby insulation types, and transport potential.

3.3.4.3 Other Considerations for Selecting Break Locations

The GR presents three additional considerations for selecting break. The staff's position regarding each respective consideration is discussed below.

1. The staff finds that the GR correctly emphasizes proper consideration of relative locations between the postulated break location and the affected containment material targets. Additionally, the staff notes that a good understanding of spatial volume obtained from the ZOI discussion in Section 3.4.2 of this SE and related calculations will assist in determining the level of detail needed for the break location survey.
2. The second consideration focuses on the potential for the formation of a thin fiber layer on the screen that filters particulates very efficiently, the so-called thin-bed effect. In general, state-of-the art debris transport methods are not sufficiently advanced to preclude the formation of a thin bed when fibrous insulation is damaged within any ZOI. The degree of vulnerability to this effect is specific to the sump screen in question. This GR consideration for break selection sets a marginal value for debris generation that might already be bounded by larger breaks with minimal transport. The staff agrees that the thin-bed effect should be evaluated. Additionally, the staff's position is that smaller breaks affecting unique combinations of insulation not encompassed by larger breaks should still be examined for potential thin-bed formation. When computing the volume of fibrous debris needed to form a 1/8-inch thick uniform layer on a given sump screen, the dry-bed, or as-manufactured, density should be used, and only the wetted screen area relevant to the break in question should be credited.
3. The GR offers an additional consideration that recognizes the importance of latent debris inventory as a potentially limiting debris source for plants with little or no fibrous insulation. The staff agrees with this consideration, and refers to Section 3.5 of this SE for a more complete discussion of latent debris characterization. The staff notes that plants with non-fiber insulation can use an appropriate dry-bed density for latent fiber and a wetted screen area to establish a plant cleanliness criterion for their foreign material exclusion (FME) programs.

3.3.4.4 Selecting the Initial Break Locations

The staff finds that the guidance offered in the GR for initial break location selection is acceptable and notes that spatial perspectives gained from implementation of the ZOI models will be helpful at directing the break-location survey further. In general, the survey should first consider larger breaks with more complex debris composition and proceed down to smaller breaks with more unique debris compositions that have not yet been captured in the survey. The degree of transport, which can be affected by the use of containment spray, should be considered during the comparison of potential break locations. Starting with this initial break location and moving to other large breaks that envelop any previously identified debris-source concerns will quickly build a set of comparative source-term and transport factors that can be used to judge other locations and classes of postulated breaks without as much detailed quantification. Comparative rationale that disqualifies a candidate location from designation as a limiting break condition should be documented to illustrate the systematic and comprehensive scope of the break-selection survey.

3.3.5 Evaluation of Break Consequences

Staff Evaluation of GR Section 3.3.5 The staff finds that the GR emphasizes the proper metric of comparison between break locations (i.e., head loss across the sump screen as a result of generation, transport, and accumulation of debris on the sump screen). Break locations cannot be eliminated from consideration based on any single attribute alone. The staff agrees that all breaks should be evaluated in the context of the complete accident sequence and the potential effect on sump-screen head loss. Nevertheless, many comparisons will be found that are useful. For example, all large break locations within a compartment may be found to have similar transport characteristics and spatial volume, so only one or two locations within the compartment are needed to bound the variation in debris composition.

3.3.5.1 Purpose of Break Consequence Evaluation

Once the limiting break condition(s) has been identified, the corresponding head loss will be compared to the required NPSH either as a measure of vulnerability to sump blockage or as a design criterion for sump-screen modifications. The staff finds that the GR provides an acceptable and concise summary in this section of the steps involved with evaluating each candidate break location against the criterion of maximum sump-screen head loss.

3.3.5.2 Selection of Intervals for Additional Break Locations

This section of the GR describes a systematic approach to break selection along individual piping runs that starts at an initial location along a pipe, generally a terminal end, and steps along in equal increments (3-ft increments), placing breaks at each sequential location. The staff position is that break intervals can be relaxed to 5-ft increments along the pipe in question and notes that the concept of equal increments is only a reminder to be systematic and thorough. Earlier work reported by NRC contractors using automated analysis tools to evaluate higher spatial resolution (1 to 3 ft increments) was motivated by a risk assessment approach that required an accurate sampling of piping lengths and break sizes to represent the proportional contribution to the overall frequency of sump screen failure. For the purpose of identifying limiting break conditions, a more discrete approach driven by the comparison of debris source term and transport potential can be effective at placing postulated breaks. The key difference between many breaks (especially large breaks) will not be the exact location along the pipe, but rather the envelope of containment material targets that is affected.

The staff agrees that as the plant-specific analysis develops, many break locations along a pipe will be determined by inspection of potential debris inventory, similarity of transport paths, and piping physical characteristics compared to a smaller number of fully quantified break scenarios.

As discussed previously, the staff does not accept the GR position regarding the treatment of secondary-break locations. The staff position is that if secondary-break scenarios involve a recirculation-sump demand, and if these scenarios are part of the plant licensing basis, the same considerations for break location must be applied as discussed in this section for LOCA events in primary piping. The reason supporting this position is that inclusion of secondary-break scenarios in the licensing basis acknowledges the possible need for recirculation, but the break locations evaluated in the licensing basis may not have been defined specific to sump performance and could not have anticipated the range of concerns identified in the course of resolving GSI-191. Although secondary-side breaks are not analyzed in accordance with the requirements of 10 CFR 50.46 or to demonstrate compliance with these requirements, the staff's position is that licensees relying on the ECCS sumps to mitigate the consequences of secondary-side breaks (e.g., for EEQ purposes) should identify and evaluate the limiting break locations to ensure acceptable sump performance.

The staff accepts the GR-stated position regarding breaks in attached piping beyond isolation points, provided there is no possible need for recirculation should a break occur in these sections. The decision whether to include piping segments beyond the isolation points should consider possible failure of the isolation valves in a manner consistent with the licensing basis.

3.4 DEBRIS GENERATION

3.4.1 Introduction

This section of the GR discusses the process of determining, for each postulated pipe break location, the zone within which the break jet forces will be sufficient to damage materials and create debris, the amount of debris generated by the break jet forces and the need to determine the characteristics of the debris.

3.4.2 Zone of Influence

The GR in Section 3.4.2 recommends a spherical boundary for the ZOI with the center of the sphere located at the break site. The ZOI is defined as the volume about the break in which the fluid escaping from the break has sufficient energy to generate debris from insulation, coatings, and other materials within the zone. The use of a spherical ZOI is intended to encompass the effects of jet expansion resulting from impingement on structures and components.

Staff Evaluation of GR Section 3.4.2 The recommended spherical ZOI is a key feature of the baseline evaluation and any alternatives other than spherical or alternatives specifically reviewed and approved by the staff for use within the baseline as described in Section 6.0 of this SE will not be considered valid for the baseline. Section 4.2.2 of this SE addresses the staff's evaluation of refinements to the spherical ZOI.

The spherical zone is a practical convenience that accounts for multiple jet reflections and mutual interference of jets from opposing sides of a guillotine break, as well as pipe whip. It is important to note that when the spherical volume is computed using an acceptable approximation for unimpeded free-jet expansion, the actual energy loss involved in multiple reflections is conservatively neglected to maximize the size of the

ZOI. The staff concurs with the use of a spherical ZOI as a practical approximation for jet impingement damage zones.

3.4.2.1 Recommended Size of Zone of Influence

The GR recommends using the ANSI/ANS 58.2-1988 standard to determine the radius of the spherical ZOI that represents the effects of the jet originating from a postulated pipe break. Appendices B, C, and D of the ANSI/ANS standard provide guidance necessary to determine the geometry of a freely expanding jet for jets originating from a variety of reservoir conditions, including subcooled conditions. This section of the GR reviews the key steps used in the ANSI/ANS 58.2-1988 procedure to determine the size of the ZOI.

Section 3.4.2.1 of the GR also specifically addresses the break jet pressures that will result in coating debris generation within the ZOI.

Table 3-1 of the GR contains the recommended destruction pressures for typical protective coatings and for several types of insulation.

Staff Evaluation of GR Section 3.4.2.1 The staff agrees that the ANSI/ANS 58.2-1988 standard (cited as Reference 3 in the GR) provides a suitable basis for computing spatial volumes inside a damage zone defined by a jet impingement pressure isobar. Appendices in the standard do provide a set of equations that can be evaluated for this purpose, but the presentation is somewhat confusing, and the physical limitations of the model are not discussed thoroughly. For these reasons, Appendix I to this SE adds guidance on the proper evaluation and interpretation of results from the ANSI model.

The GR outlines the following six steps for performing ZOI calculations using the ANSI jet model:

1. The mass flux from the postulated break was determined using the Henry-Fauske model, as recommended in Appendix B to the standard, for subcooled water blowdown through nozzles, based on a homogeneous, none-equilibrium flow process. No irreversible losses were considered.
2. The initial and steady-state thrust forces were calculated based on the guidance in Appendix B to the standard, with reservoir conditions postulated.
3. The jet outer boundary and regions were mapped using the guidance in Section 1.1 of Appendix C, to the standard for a circumferential break with full separation.
4. A spectrum of isobars was mapped using the guidance in Appendix D to the standard.
5. The volume encompassed by the various isobars was calculated using a trapezoidal approximation to the integral with results doubled to represent a DEGB.
6. The radius of an equivalent sphere was calculated to encompass the same volume as twice the volume of a freely expanding jet.

The staff finds these steps acceptable for generic implementation of the model and conversion of isobar volumes to a volume-equivalent spherical radius. However, this SE provides the following observations which concern the implementation details of this method that should be considered when using the model. Appendix I to this SE further explains these details:

1. Plots of metrics related to the Henry-Fauske mass flux presented in the standard do not extend to the desired state point, so it is not clear exactly how the GR evaluated the mass flux. Licensees using this technique should refer to confirmatory Appendix I to this SE for guidance.
2. It should be noted that neglect of irreversible losses refers to internal pipe and pipe component friction losses between the upstream reservoir and the location of the break.
3. Only the steady-state thrust coefficient should be used in this calculation as a conservative bound.
4. Insulation damage pressures, such as the 10 psi cited for Nukon fiberglass, can only be interpreted with a full understanding of the test conditions under which they were experimentally measured. The computed jet conditions will not match the experimental test conditions; therefore, care should be taken to assure that equivalent damage effects are considered. Finally, it should be noted that the GR exercised the model for a spectrum of pressure isobar values because different materials have different resistances to damage from jet impingement.

Regarding the three conditions offered for jet expansion calculations, the staff agrees that DEGB configurations with circular geometries, and full separation and offset between the broken ends, provides the maximum debris generation volume. However, as further discussed in Appendix I to this SE, the choice of fluid reservoir conditions is not justified as bounding for the baseline evaluation, and the reported thermodynamic properties do not match the stated conditions. Using automated National Institute for Standards and Technology (NIST)/American Society of Mechanical Engineers (ASME) steam tables (NIS96), the stagnation enthalpy and degree of subcooling for the stated conditions of 2250 psia and 540°F are 534.9 Btu/lbm and 112.7°F, respectively. Appendix I to this SE confirms that these conditions bound nominal conditions for a hot-leg break, and offers some guidance for licensees to estimate the effects of minor system pressure increases without the need for reevaluating the model.

The staff agrees with the GR's choice of ambient containment pressure versus crediting containment backpressure. The staff considers this choice important because ZOI volumes are strongly driven by the system stagnation pressure, which is highest when the containment is at ambient conditions. The maximum debris generation would occur instantaneously within this ZOI. Furthermore, the use of atmospheric pressure may not be conservative for subatmospheric containment designs that would permit the discharge of a slightly higher mass flux across a break. However, the effect is judged to be small and is compensated by jet-pressure equations in the standard that do neglect ambient pressure in containment. See Appendix I to this SE for a discussion of mass flux calculations and the dependence of ANSI correlations for thrust coefficient on the choice of psia.

The staff finds that the citation of 10-diameter limits for jet damage recommended in NUREG/CR-2913 (WEI83) for structural loadings on equipment and components is not applicable to the present concern regarding insulation damage. The criteria for onset of damage and the implications of structural damage versus debris generation are not directly related. Furthermore, any comparison of conservatism between methods should consider the range of damage pressures for various insulation types. Therefore, the 10-diameter limit for jet damage may only be used for structural loading and for coatings as described below.

Protective Coatings Destruction

The potential debris term generated by failed coatings can be a significant contributor to the total containment sump debris term for some plants. The GR assumes the following LOCA effects on coatings:

- all coatings in the ZOI will fail
- all “qualified” (DBA-qualified or acceptable) coatings outside the ZOI will remain intact
- all “unqualified” coatings will fail

The GR also assumes that coating failure will generate debris in the form of fine particulate which is equivalent in size to the basic material constituents. This is descriptive of the size of the average zinc particle in inorganic zinc (IOZ) coatings or the pigment used in epoxy coatings, which is approximately a 10µm (in diameter) spherical particle in both cases. The GR states that because there is a lack of experimental data regarding coating debris size values, a debris size distribution of 100 percent small fines (10µm IOZ equivalent) is adopted for all coatings inside the ZOI. For coatings outside the ZOI, the GR states that all indeterminate and “DBA-unqualified” and “unacceptable” coatings should be treated as a single coating category which produces debris of the same characteristic, independent of the type of coating. As such, the coating debris size within the ZOI is applicable to all “unqualified”, indeterminate, and “unacceptable” coatings that fail outside the ZOI, as well.

Outside the ZOI, the GR assumes that all “qualified” coatings remain intact and do not contribute to the debris term. Although the GR assumes that all “unqualified” coatings will fail and break down into 10µm particles, it also indicates that plant-specific data should be used to estimate the area and thickness of the “unqualified” coating to determine the amount of debris generated.

The GR indicates that “the ZOI for DBA-qualified coatings or coatings determined to be ‘Acceptable,’ applied to PWR containment surfaces, which results from fluid impingement from the break jet, has not been clearly defined.” However, two key pieces of evidence are offered in the GR to support the argument that “DBA–qualified” and “acceptable” coatings are resistant to direct jet impingement, (1) DBA qualification tests subject samples to elevated temperatures with no apparent loss of structural integrity or performance degradation, and (2) water jet pressures in excess of 2250 psia are commonly required to efficiently remove coatings in industrial applications.

This GR-assumed destruction pressure is tied to experience for removing coatings by the commercial water blast industry and industry waterjet testing detailed in Appendix A to the GR. This testing was performed using a 3500 psig positive displacement pump, hose, and nozzle attachment (high-pressure washer) at two temperatures, approximately 80 °F and 150 °F, to investigate coating degradation under jet impingement conditions. The test apparatus was used at various distances from substrates coated with “qualified” coatings. The testing indicated that coating debris generated in the ZOI would fail as the result of erosion and would generate debris sized roughly equivalent to the coating pigment size. Both IOZ and epoxy were tested. The testing also indicated that coating degradation was influenced by temperature.

Staff Evaluation of Protective Coatings Destruction The staff finds the spherical modeling of the ZOI to be consistent with the approach approved in Section 3.4.2 of this SE, and therefore an acceptable approach for application to coatings. The staff finds that the following assumptions should be applied with regard to coating debris destruction subjected to a LOCA jet:

- “Qualified” coatings outside the ZOI are assumed to remain intact and will not contribute to the sump debris load during a postulated event.
- All “unqualified” coatings outside the ZOI are assumed to fail and act as a potential contributor to the debris load during a postulated event.
- All coatings, regardless of qualification are assumed to fail within the LOCA jet ZOI. The baseline guidance does not provide sufficient technical justification to support use of a 1000 psig coating destruction pressure and corresponding ZOI equivalent to 1 pipe diameter. The staff position is that licensees should use a coatings ZOI spherical equivalent determined by plant specific analysis, or 10D. The specified ZOI of 10D is based upon the previous staff position used for BWR sump analysis (even though there may be differences between the spherical ZOI geometry proposed in this SE and the geometry that may have been used at some BWRs). Any plant specific analysis should incorporate at a minimum the temperature and pressure effects of the jet on plant coating systems in the ZOI. Such an analysis should be based on experimental data over the range of pressures and temperatures of concern using coating samples that can be correlated to coatings found at the plant. The analysis should also seek to accurately estimate the amount of coating on a plant specific basis within the ZOI. If a realistically conservative approach is taken, the basis and justification for why the method is realistically conservative should be provided.

The staff agrees that it is conservative to treat coating debris as highly transportable particulates in the range of 10 to 50 μm in diameter, based on plant susceptibility to thin bed formation at the sump screen. However, for those plants that can substantiate no formation of a thin bed at the sump, this assumption may be non-conservative with regard to sump blockage because fine particulates would pass through the sump screen and generate no blockage concerns. Therefore, for those plants that are susceptible to thin bed formation at the sump screen, use of the basic material constituent (i.e., 10 μm sphere) to size coating debris is acceptable. However, for those plants that can substantiate no formation of a thin bed at which particulate debris can collect, the staff finds that coating debris should be sized based on plant-specific analyses for debris generated from within the ZOI and from outside the ZOI. Such an analysis should conservatively assess the coating debris generated with appropriate justification for the assumed particulate size or debris size distribution. Degraded “qualified” coatings that have not been remediated should be treated as unqualified coatings. Finally, testing regarding jet interaction and coating debris formation could provide insight into coating debris formation and help remove some of the potential conservatism associated with treating coatings debris as highly transportable particulate. If coatings, when tested at corresponding LOCA jet pressures and temperatures, are found to fail by means other than erosion, or the erosion is limited, the majority of debris may be larger, less transportable, or pose less of a concern for head loss.

The staff agrees with the assumption that “qualified” coatings outside the ZOI remain intact during a postulated event and will not contribute to the ECCS sump debris load, because it is based on qualified coatings meeting established quality criteria and acceptance testing and is consistent with the position outlined in Section 6.1.2, “Protective Coating Systems,” of the Standard Review Plan. The assumption is also based on the coatings being in good condition at the initiation of the postulated LOCA. However, operating experience indicates “qualified” coatings require periodic maintenance throughout the coating service life, and operating experience has identified cases in which “qualified” coatings have exhibited significant degradation during the coatings’ normal service life. Therefore, the staff position is that a periodic coating condition assessment be identified, described, and implemented during routine outages, to assure that “qualified” coatings remain capable of performing in a manner consistent with assumptions used to evaluate sump debris loads. Further, the staff has concluded that “qualified” coatings which have degraded, but which have not yet been remediated, should be considered to fail during a postulated accident and will potentially contribute to the debris load. The staff finds that the estimated quantity of debris from degraded qualified coatings (if any) should be based on plant-specific data and should follow the guidance for debris resulting from unqualified coatings.

The staff agrees with the assumption that all “unqualified” coatings outside the ZOI fail, based on the position outlined in SRP Section 6.1.2.

The staff agrees with the assumption that all coatings, regardless of type and qualification will fail within the ZOI because it conservatively addresses the LOCA jet interaction with all coatings (“unqualified” coatings are assumed to fail regardless of location) in this zone; however, the staff believes there is insufficient technical justification for the assumption of a 1000 psig destruction pressure and corresponding spherical ZOI with a radius equivalent to 1 pipe diameter.

Although Appendix A to the GR provides useful test data illustrating the erosion effects of high-pressure water-jets on coating systems, no test data are offered that combine both the effects of mechanical insult and elevated temperature in the same test, and no data appear to be available on the effects of very rapid thermal transients on coating performance. Specifically, the initial conditions of the LOCA jet established in the baseline methodology are 540 °F and 2250 psig, while industry testing referenced in Appendix A to the GR was performed at approximately 3500 psig and 150 °F. Although the initial LOCA jet pressure is expected to be lower than the industry test pressure used (approximately 3500 psig) and waterjet pressure data, the initial LOCA jet temperature expected is significantly higher than the industry test temperatures used (150 °F). The NEI baseline methodology provided no correlation or extrapolation illustrating how the elevated test pressure accounts for the reduced test temperature to produce a similar damage mechanism and degree of damage as the combined temperature and pressure from a LOCA jet. Thus, to the test results do not adequately establish the coating ZOI, and the staff finds the results of the water jet testing to be inconclusive in this regard.

Additional information offered in Appendix I to this SE presents spatial contours of estimated jet impingement temperature for a reference cold-leg break condition. Temperature zones exceeding 300°F are observed to extend out to 10 pipe diameters from the break, and exceed 220°F for most of the jet envelope. Given the small thickness of the paint and the differences in heat conduction between the layer and the substrate, it is presumed that the coating would reach the impingement temperature almost instantly when directly hit by the break jet. Thermal shock may affect bonding with the substrate, induce expansion cracking in the coating layer, and change its tensile properties. All of these potential effects increase the vulnerability of paint to jet impingement. The occurrence of very rapid thermal transients in combination with the mechanical insult of water-laden jet impact is a unique environment that should be subject to experimental study.

The NRC staff acknowledges that the five reasons given to defend the selection of 1000 psig as a destruction pressure for DBA-qualified or acceptable coatings are factual, while the GR arguments do not address important phenomenology of the accident environment. It is premature to accept the proposed value of 1000 psig as either appropriate or conservative. Individual licensees should provide data to support the robustness of their DBA-qualified and acceptable coatings system for use in the baseline analysis. Spatial contours of jet impingement temperature, such as that offered in Appendix I to this SE, may be useful in judging the cost-benefit of alternative test conditions.

Because (1) the temperature effect may be influenced by the coating system (i.e., IOZ alone, IOZ topcoated with epoxy, or multiple coats of epoxy), (2) epoxy and IOZ each would be expected to have a different temperature response, and (3) no testing replicating the effects of LOCA jet pressures and temperatures on coatings (epoxy, IOZ, qualified, or unqualified coatings) have been performed or referenced; the staff position is that either a coating spherical ZOI of 10D be used, or a ZOI be determined by plant-specific analysis. If an analysis is performed, it should incorporate, at a minimum, the combined temperature and pressure effects of the jet on potential coating systems in the ZOI. Such an analysis should be based on experimental data over the range of pressures and temperatures of concern using coating samples that can be correlated to plant materials. The analysis should also seek to accurately estimate the amount of coating on a plant-specific basis within the ZOI. If a bounding approach is taken, it is the staff's position that the basis and justification why the method is conservatively bounding must be provided. The staff believes that a comprehensive test program investigating the effects of direct impingement of a LOCA jet (accounting for jet pressure and temperature) on coating degradation should be performed to have a sound basis for the destruction pressure and size of the coating ZOI.

3.4.2.2 Selecting a Zone of Influence

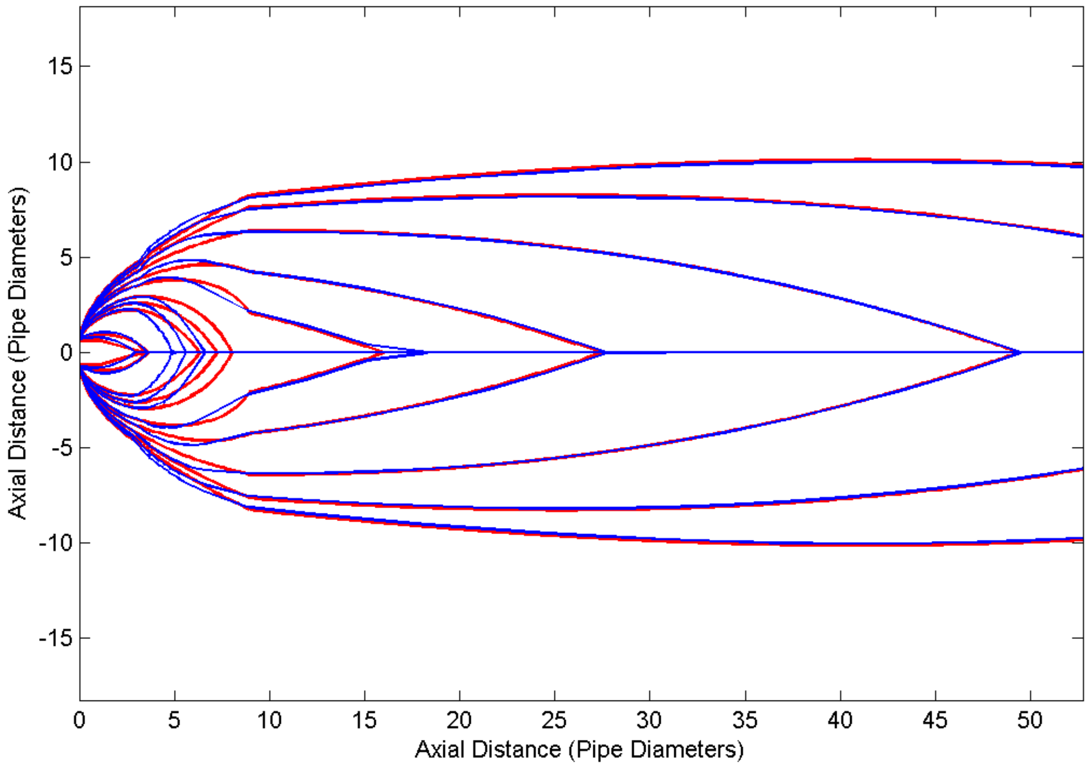
Section 3.4.2.2 of the GR recommends that for the baseline calculation, the ZOI for a break be selected based on the potentially affected insulation inside containment with the minimum destruction pressure. This ZOI is then applied to all insulation types.

Staff Evaluation of GR Section 3.4.2.2 The staff accepts the baseline approach of selecting ZOI size based on the potentially affected insulation type in containment with the lowest destruction pressure, provided that (1) there are no other materials in containment more fragile than insulation that might pose a debris generation potential, and that (2) defensible damage pressures are available or can be ascertained conservatively with engineering judgment, for all insulation types, coatings and other materials of concern. The implication of the assumption that the presence of a single vulnerable material is that all candidate debris materials should be presumed damaged to the same level. Credit for the individual response of well-characterized insulation types can be given under the refinement offered in Section 4 of the GR.

GR Table 3-1 can be used to match experimentally determined damage pressures with "calculated" values of volume-equivalent spherical ZOI radii. Presumably, the calculations were performed in the manner described in Appendix D to the GR, but no cross reference or explanation is offered. Appendix D cites an evaluation of the ANSI/ANS 58.2-1988 standard that was used to generate spatial jet-pressure contours, but the GR offers no insights for interpreting the resulting pressures with respect to material damage.

In order to confirm that the ANSI jet model was implemented properly, the model was independently programmed and the results compared with the isobar map tabulated in Table D-1 of the GR. This comparison is shown in Figure 3-1 in which the blue contour lines represent the GR evaluation of a break at 2250 psia and 540°F and the red contour lines represent a reference cold-leg break at 2250 psia and 530°F. Appendix I to this SE provides further explanation of the independent calculation and additional guidance on interpreting the results of the ANSI jet model.

Good agreement is seen between the calculations for downrange behavior (Zone 3), but discrepancies exist in Zones 1 and 2. It appears that contour termination points on the centerline are not accurate and that the quadratic behavior of the Zone 2 isobar equations is not implemented correctly. These differences will have a negligible effect on volume integrals for jet pressures less than 20 psig, but may become more of a concern for higher pressures near the break. To quantify the magnitude of the difference, Table 3-1 below presents a comparison of ZOI radii computed from both methods. In particular, the GR approach may not have preserved the system stagnation pressure throughout the volume of the liquid core region, as specified by the standard. However, the GR recommended values essentially bound both sets of calculated values.



Outside to Inside Contour Values (psig)

4, 6, 10, 17, 24, 40, 50, 64, 150, 190

Figure 3-1. Comparison of GR Isobar Map (Blue) with Isobars from Independently Evaluated ANSI Jet Model (Red)

Table 3-1 Comparison of Computed Spherical ZOI Radii from Independent Evaluations of the ANSI Jet Model

Impingement Pressure (psig)	ZOI Radius/Break Diameter		
	Guidance Report Recommendation	Calculated Value	SE Appendix I
1000	1.0	0.24	0.89[a]
333	1.0	0.55	0.90
190	1.3	1.11	1.05
150	1.6	1.51	1.46
40	3.8	3.73	4.00
24	5.5	5.45	5.40
17	7.8	7.72	7.49
10	12.1	12.07	11.92
6	17	16.97	16.95
4	21.6	21.53	21.60

[a] The core volume at stagnation pressure P0 gives a minimum possible ZOI radius of 0.88 diameters.

The larger question of what damage pressure to recommend for each material type requires an understanding of both the limits of the jet model and the knowledge base of existing experimental data.

First, as discussed in Appendix I to this SE, the jet model predicts impingement pressures in the longitudinal (downstream) direction only and may underestimate the radial extent of isobars in Zones 1 and 2 when considering the impingement pressure that would develop on the face of a target perpendicular to the local flow velocity.

Second, the ANSI model appears to be unbounded in the downstream direction. This means that for very small impingement pressures, the isobar volume will grow unrealistically large. These two limitations compensate to some extent when volume-equivalent spherical radii are computed; because the jet envelope provides a rigid constraint to radial growth of the contours, unbounded downstream growth will eventually dominate.

Unreasonable growth of low-pressure isobars can be illustrated by comparing the spherical radius plot in Figure I-26 (Appendix I) to Figure 3-3 in the parametric evaluation (PE) supplement (NUREG/CR-6762-3). The PE study plots a function of spherical ZOI radii that was determined by the Boiling Water Reactor Owners Group (BWROG) using the NPARC computational fluid dynamics (CFD) model for BWR blowdown conditions. Despite the differences in thermodynamic state point, the differences in qualitative behavior for target pressures less than 20 psig is evident; the ANSI trend appears to be diverging, while the BWROG correlation appears to approach a finite maximum at zero pressure. The NRC reviewed the BWROG calculations and found the NPARC code to be a more capable method of modeling steam jets than the ANSI model.

The staff notes that a comparison using a CFD model for PWR break conditions was not performed for either the GR or this safety evaluation. Caution should be used in comparing calculated and experimentally determined pressures to ensure that the computed parameter of the field matches the measured parameter as closely as possible. For example, while it is trivial to fractionate a computed pressure into static and dynamic components over any incident angle, it may be difficult to obtain high-fidelity measurements under equivalent conditions and diagnostic orientations.

Third, the correlation between any prediction of jet pressure and an experimental observation of damage pressure depends on how the measurements were taken, how the debris was characterized, and what the thermodynamic conditions of the test actually were. Data from the references cited in Table 3-1 of the GR are dominated by tests conducted for resolving the strainer blockage issue for BWRs using high-pressure air as a working fluid. Therefore, much of the test data are not directly applicable to PWR or BWR blowdown conditions in which jets consist of steam and water mixtures. Without directly applicable data and/or high-fidelity predictive models, this surrogate information can only be applied with appropriate caution. The NRC was concerned about potential differences in debris generation between air surrogates and two-phase jets, and therefore initiated a joint test program with Ontario Power Generation (OPG). Testing of low-density fiberglass ended prematurely after only one test, and the concerns were not fully resolved, but Volume 3 of the PE report (NUREG/CR-6762-3 and Reference 7 of the GR document the available results. GR Table 3-1 cites, but does not discuss, these data in reference to damage pressures for calcium silicate. Therefore, there is a very limited set of data to evaluate the effects of two-phase jets on low-density fiberglass.

Destruction pressure is the threshold pressure for the onset of damage. This is normally determined by experimentally measuring the differential pressure on the face of a target. One recurring problem with defining damage pressure is inconsistency in the degree of damage that is correlated to the pressure value. Two obvious choices exist. The first option is to define the minimum pressure (threshold) at which jacketing is breached in any way. Issues regarding contribution to potential screen blockage are then handled with a complete description of the debris size distribution from fines to partially intact cassettes and blankets. The second option is to presume a debris size that is suspected to contribute to the blockage potential and to report the damage pressure as the point at which significant quantities of this debris size are generated. The second option will have higher values of damage pressure than the first, and the debris size distribution will be skewed towards smaller, and therefore more transportable, pieces, if the two options are to give equivalent results in a vulnerability assessment. The second method also requires more a priori subjective judgment. Table 3-1 of the GR reports damage-pressure values based on the second approach. The single fiberglass test performed by OPG resulted in conversion of approximately 50 percent of the insulation volume into debris of sufficiently small size to be a concern. It is assumed that this test meets, by a significant margin, the criteria for significant quantity implicit in the second damage-pressure definition.

The OPG test for fiberglass was conducted at a distance of 10D on the centerline downstream of a heated vessel of water at 1450 psia. Comparisons with more extensive OPG data for calcium silicate suggested that the lower threshold for fiberglass damage in two-phase jets might be as low as 4 psig (NUREG/CR-6762-3). The actual range can only be determined by bracketing with two tests at differing distance the transition from significant damage to negligible damage. While it is true that the insulation products tested by OPG were not identical to those tested in the BWROG air jet tests, substantially different debris characteristics were observed.

In the absence of more complete test data, it is prudent to attribute the observed effects to the differences in the jet medium (i.e. the difference between air used in the BWROG tests and the two-phase steam/water mixture used by OPG). Several plausible physical mechanisms may contribute to enhanced debris generation in two-phase jets, including penetration and erosion from impingement of entrained droplets, increased shear forces within the jet caused by radial velocity components of the expanding fluid, and higher local velocities because of the lower density of water vapor compared to air. To judge the potential contributions of these effects without more extensive data would be speculative, as would be any counter arguments offered to refute their importance. The GR has already acknowledged the potential for material degradation by erosion in relation to coatings damage. Although offered there as an ostensible conservatism, the same phenomenon should be considered for all material types.

Based on the OPG test results, an argument could be made for reducing damage pressures determined through air-jet testing by a factor of 2 or more. In fact, the PE study recommended this approach by reducing the damage pressure for fiberglass from 10 psig to 4 psig. A corresponding spherical ZOI radius was then recommended based, not on the ANSI model for PWR break conditions, but rather on the BWROG correlation for BWR break conditions that were similar to the OPG test. The corresponding radius was reported to be 12-D for an incident pressure of 4 psig, while the ANSI model predicted a 21.6D radius for nominal PWR break conditions at the same impingement pressure. Hence, there appears to be an inconsistency in the PE report because no compensation was made for increased ZOI volume induced by the higher initial pressure of a PWR break.

Given the uncertainties discussed above regarding (1) interpretations and applicability of the ANSI jet model and its performance compared to CFD correlations for very low impingement pressures, (2) the dissimilarity of insulation types, jacketing and target orientation used in the OPG test compared to U.S. PWRs, and (3) the practical definition of damage pressure and its empirical correlation to the degree of insult, it would be speculative to assess the full damage-pressure reduction derived in the PE report. Therefore, based on the 50 percent destruction of fiberglass observed in the only publicly accessible two-phase debris generation test for this insulation type, comparison with OPG data on greater than 40 percent reduction in damage pressure for calcium-silicate insulation, and on the similarity of this degree of damage to the definitions used in Table 3-1 of the GR, the NRC staff position is that damage pressures for all material types characterized with air jet testing should be reduced by 40 percent to account for potentially enhanced debris generation in a two-phase PWR jet.

Of course, specific materials may respond differently (if at all) to the effects of a two-phase jet, but this reduction in damage pressure provides adequate recognition of the issue and could focus some attention on the remediation or mitigation of high-debris volume accident scenarios. When available, the reduced damage pressure thresholds should be replaced with material-specific test data, so the GR recommendation of 24 psig for the damage pressure of calcium silicate is appropriate, based on the findings of the OPG study. Table 3-2 lists the revised destruction pressures and the corresponding ZOI diameters computed as described in Appendix I to this SE for the reference cold-leg break.

Table 3-2 Revised Damage Pressures and Corresponding Volume-Equivalent Spherical ZOI Radii

Insulation Types	Destruction Pressure (psig)	ZOI Radius/ Break Diameter
Protective Coatings (epoxy and epoxy-phenolic paints)	TBD[1]	NA[2]
Protective Coatings (untopcoated inorganic zinc)	TBD[1]	NA[2]
Transco RMI Darchem DARMET	114	2.0
Jacketed Nukon with Sure-Hold® bands Mirror® with Sure-Hold® bands	90	2.4
K-wool	24	5.4
Cal-Sil (Al. cladding, SS bands)	24	5.45
Temp-Mat with stainless steel wire retainer	10.2	11.7
Unjacketed Nukon, Jacketed Nukon with standard bands Knaupf ET Panel	6	17.0
Koolphen-K	3.6	22.9
Min-K Mirror® with standard bands	2.4	28.6

[1] To be determined by experiment.

[2] Not available for evaluation at this time.

Formal debris generation studies have confirmed that insulation products having outer casings, jackets, or other similar mechanical barriers resistant to jet impingement yield smaller quantities of debris than do less robust materials. Various studies have also demonstrated dependence between the orientation of the jacketing seam relative to the jet and the amount of debris generation. This suggests that the integrity of the jacket during impingement is an important feature for minimizing debris generation. Russell reports, for example, that double jacketing an insulation product with a second overcladding of stainless steel having a rotated, opposing seam was very effective at minimizing the distance from the jet to the onset of damage (OPG, 2001). As mentioned in Appendix I to this SE, any improvement in the mechanical resistance of the insulation product will help to avoid inflated ZOI volumes predicted by the ANSI jet model for very low damage pressures.

As noted above, the ANSI/ANS jet model has been proposed in the GR and found acceptable by the staff for the purpose of estimating potential damage volumes associated with empirically measured damage pressures. Various attributes and interpretations of the ANSI jet model are presented in Appendix I to this SE. Among those observations is the explanation of potentially exaggerated conservatism for very low damage pressures. While this is conservative, it may be detrimental for the identification and design of practical mitigation strategies. The staff notes that the use of robust insulation materials is one possible approach for avoiding excess conservatism. Another approach, which can be accomplished concurrently with the testing of specific insulation products, is to properly instrument jet tests for the purpose of refining the ANSI model for the specific application of debris generation. Particular emphasis should be placed on the measurement of impingement pressures on small targets placed both perpendicular to the jet centerline and at radial locations parallel to the jet centerline. A test program such as this would be most effective when combined with concurrent insights gained from models including ANSI-58.2-1988 and CFD.

In a letter dated October 18, 2004, the Advisory Committee on Reactor Safeguards (ACRS) provided its view on the draft SE. Regarding the ANSI/ANS 1988 standard, the ACRS noted several inconsistencies and errors in the models described in the standard. These included no definition of "impingement pressure;" assumed flow patterns which do not correspond to observed and computed patterns for supersonic jets; inconsistent conditions in a free jet compared with a jet impinging on a large target; an unrealistic representation of the physics and inappropriate one-dimensional approximations for an "asymptotic plane;" and that the density at this fictional "asymptotic plane" is evaluated as if the fluid were at rest, whereas in reality it is flowing at a high Mach number. The staff agrees with the ACRS comment on the ANSI/ANS model and observes that additional model inaccuracies, such as unrealistically large isobars calculated for lower stagnation pressures, are noted in Appendix I.

Notwithstanding these technical points, the staff considers the standard acceptable for use in determining the ZOI to be used for modeling debris generation during design basis accidents. This determination is based in large part on the method which is used to approximate the debris generation resulting from postulated breaks. To account for jet reflections, shadowing effects, directionally changing discharge from a whipping pipe, and the difficulty of assessing all potential orientations of breaks, the GR proposes using a spherical volume equivalent to a volume determined using the ANSI/ANS model using the demonstrated destruction pressure of debris sources. This volume translation conservatively ignores the energy that would be lost in multiple reflections and in the generation of debris.

The precision that could be gained by the development of a more accurate method to determine the characteristics of a freely expanding jet is more than offset by conservatism in using an equivalent volume approach for determining ZOI. This is because in reality, damage does not occur throughout a volume but rather on a surface. Although reflection of jets will occur, and can even result in pressure pulses above stagnation pressure in front of particular targets, energy will also be lost in generating debris and redirection of the jets. The staff's position is that the overall approach to determining ZOI is sufficiently conservative (by conserving the volume of a freely expanding jet to isobars of demonstrated destruction pressure) to allow use of the ANSI/ANS standard for determining ZOI. However, the staff remains open to licensee use of alternatives which more accurately model two-phase jets. Such models could be used to significantly reduce the ZOI for low-damage pressure debris sources such as NUKON insulation.

3.4.2.3 The Zone of Influence and Robust Barriers

Section 3.4.2.3 of the GR recommends truncating the spherical ZOI whenever the ZOI intersects a robust barrier such as walls, or components, such as supports, pressurizers, steam generators, reactor coolant pumps or jet shields. Such barriers will terminate further expansion of the ZOI. The area in the shadow of the component or structure will be free from damage. The baseline assumes there is sufficient conservatism in drawing the sphere that it is not reasonable that a jet reflected off of a wall or structure would extend further than the unrestrained sphere.

Staff Evaluation of GR Section 3.4.2.3 Conceptually, the volume integral under a computed jet expansion isobar represents the potential for material degradation at pressures equal to the isobar value and higher. Multiple reflections and deflections of a LOCA jet within a confined space would dissipate energy, so conservation of the jet volume under an impingement pressure isobar provides an upper bound on the integral volume of the spatial damage zone, regardless of the shape it is mapped into either by the local geometry of obstacles or by convention for the purpose of analysis. Spherical zones were originally conceived as an adequate approximation for opposing jets from each side of a guillotine break in the congested piping environment of a BWR containment structure. Spherical zones also provide significant convenience for mapping onto piping layouts.

The only conservatism inherent to the ZOI mapping within containment is the conservation of damage potential computed as the volume under a relevant damage-pressure isobar. The degree of conservatism depends on the piping and equipment congestion in the vicinity of the break. More deflections and redirections lead to greater local deposition of energy, and hence, to greater conservatism in the preservation of damage volume, which maximizes the size of the ZOI by assuming no interference with jet development. It is difficult to quantify the degree of conservatism introduced by ignoring jet reflections, but for BWR break conditions, CFD calculations were performed in a spatial domain with contrived obstacles and flow paths to demonstrate rapid dissipation of the potential damage volume. Similar examples have not been offered in the GR to quantify the conservatism that would rationalize the truncation of spherical ZOI. Relevant attributes of this calculation would include representative spatial complexity and scale relative to the damage volume for PWR break conditions.

PWR containment structures often have structural paths that are designed to direct the principal expansion flow. These features include the ice columns in ice condenser plants and steam generator compartments in large dry plants that are vented to upper containment domes with spray deluge systems. Given the potentially large damage volumes that may be predicted from the previous section, it seems reasonable that these spherical ZOI will be redirected along the designed flowpaths for many break scenarios.

The potential benefits of shadowing by equipment and components are also difficult to quantify. Undoubtedly, shadowing is a relevant effect for impingement on a large steam generator from one side in a relatively unconfined location, but within a doghouse enclosure, flows may accelerate completely around the generator causing damage on all sides. Shadowing effects cannot be approximated by strict geometric obstruction angles. The GR provides limited guidance on the practical implementation of the proposed method.

For the baseline analysis, the NRC staff position is that licensees should center the spherical ZOI at the location of the break. Where the sphere extends beyond robust barriers, such as walls, or encompasses large components, such as tanks and steam generators, the extended volume can be truncated. This truncation should be conservatively determined with a goal of +0/–25 percent accuracy, and only large obstructions should be considered. The shadow surfaces of components should be included in this analysis and not truncated, as debris generation tests clearly demonstrate damage to shadowed surfaces of components.

3.4.2.4 Simplifying the Determination of the Zone of Influence

GR Section 3.4.2.4 offers a conservative simplification for the determination of the ZOI. Given the complexity of the analysis as a whole, it may be desirable to make conservative assumptions with the goal of simplifying the analysis. For example, for some breaks it may be only slightly more conservative and much simpler to assume that an entire subcompartment (but not outside the subcompartment) becomes the ZOI.

Staff Evaluation of GR Section 3.4.2.4 The staff concurs that simplifications may be desirable. As a point of practical guidance, it may be useful to precalculate the free volume of subcompartments and rooms that could host a break location or be affected by an adjacent break location. This will facilitate cumulative volume estimates for the total affected zone.

The staff finds the example simplification acceptable; provided the simplification procedure properly justifies that significant jet destruction cannot occur beyond the assumed boundaries of the affected compartments.

3.4.2.5 Evaluating Debris Generation within the Zone of Influence

Section 3.4.2.5 of the GR provides a general statement regarding the assessments of debris within the ZOI and refers to GR Section 3.4.3. It notes that plant-specific information on the type, location, and amount of debris sources within containment is needed. This information is obtained from plant drawings and the results of condition assessment walkdowns.

Staff Evaluation of GR Section 3.4.2.5 The staff finds the general statement in GR Section 3.4.2.5 to be acceptable. To further clarify, the staff suggests that once the spatial region of the ZOI has been determined, the next step is to calculate the volume of insulation, the surface area of coatings (both qualified and unqualified), and the amounts of any other potentially frangible debris sources within that ZOI. Guidance provided in other sections determines how this insulation is distributed by size and character into debris.

3.4.2.6 Sample Calculation

GR Section 3.4.2.6 provides a sample calculation. The sample postulates the break of a 10-inch diameter pipe attached to the RCS. The break occurs at the base of a steam generator. Two types of insulation materials are specified (Nukon and reflective metallic insulation (RMI)), and the quantities of each in the affected zone are given. A ZOI radius is determined based on the pertinent ZOI/break diameter values given in Table 3-1 of the GR. All of the insulation material within the affected zone is assumed to be damaged and becomes debris. The sample also calculates the surface area of coatings estimated to be destructed by the break jet forces.

Staff Evaluation of GR Section 3.4.2.6 Separation of the containment into inventory zones appears to be a very effective aide in moving through the break selection and ZOI mapping processes in a systematic way. Alternative segmentation schemes (or useful subdivisions), other than the uniform grid shown in Figure 3-1 of the GR, might be based on structural barriers or groupings of diverse, but collocated, insulation types. In step 4 of the calculation, the volume of the evaluation zone and the estimated surface area of coatings (both qualified and unqualified) are not provided, even though this step should represent all available information about the potential impacts of a break in the postulated location.

The sample calculation is inconsistent with the baseline methodology discussed above because it implies that the potentially affected insulation type with the minimum destruction pressure can be selected from within an accounting region in the vicinity of the break, rather than from the entire containment inventory, as specified in Section 3.4.2.2. For example, if Min-K were present in an adjacent evaluation zone (or anywhere else in containment), the ZOI radius would have to be larger to account for the lower damage pressure of this particular insulation type. The ZOI may easily overlap several evaluation zones for large breaks.

If NUKON^{TM} is the most fragile insulation in containment, then the example is consistent through step 5 except that, using the revised damage pressures presented in Table 3-2 above for two-phase jet impingement, the ZOI radius would be 17 pipe diameters, the ZOI radius would be 14.1 ft, and the ZOI spherical volume would be 11,742 ft^3. The debris inventory should include all potential debris generation materials within this zone.

Step 6 appears to invoke the simplification of assuming 100 percent inventory within the zone. The decision to make this simplification might be assisted by comparing the ratio of the ZOI volume to the volume of the evaluation zone. It is further reinforced by considering the relative volume of the ZOI obstructed by the steam generator and major piping. When this additional volume is added back to account for flow divergence, the ZOI occupies an even larger proportion of the evaluation zone.

For strict compliance with the baseline methodology, step 6 should also include all of the coatings within the evaluation zone as debris, both qualified and unqualified. Instead, step 7 illustrates an example of a proposed refinement presented in Section 4 of the GR for which a ZOI specific to a material type is computed to account for the possible higher resistance of coatings to jet impact. Under this refinement, a separate ZOI radius can be computed for each potentially affected debris source. It is likely that many licensees will choose this refinement rather than accept the conservatism of applying, at all break locations, damage zones defined by the most vulnerable material in containment.

Because acceptable damage pressures for coatings have not been developed, the staff does not agree with step 7 of the calculation. However, once a ZOI has been established, the total area (or equivalent mass) of qualified paint within the spherical zone should be added to the initial debris inventory. There is no basis for the assumption of a coating area equal to the surface area of the ZOI except to satisfy the intent of conservatism for very small damage zones. This assumption of a minimum coating contribution is not necessary if no paint is present within the potential ZOI that is eventually defined by a coatings damage pressure.

3.4.3 Quantification of Debris Characteristics

3.4.3.1 Definition

Section 3.4.3.1 of the GR defines debris characteristics as post-accident size distribution of material, material size and shape, and material densities. The input information needed to determine debris characteristics is also noted.

3.4.3.2 Discussion

GR Section 3.4.3.2 provides a discussion of the debris size distributions that have been used in various studies and specifies the distribution recommended for the baseline evaluation. The GR adopts a two-size distribution for material inside the ZOI of a postulated break. These two size groups are small fines and large pieces. Small fines are defined as any material that could transport through gratings, trash racks, or radiological protection fences by blowdown, containment sprays, or post accident pool flows. Furthermore, small fines are assumed to be the basic constituent of the material for fibrous blankets and coatings (i.e., individual fibers and pigments, respectively). The GR assumes the largest openings of the gratings, trash racks, or radiological protection fences to be less than a nominal 4 inches (less than 20 square inches total open area). The GR classifies the remaining material that cannot pass through gratings, trash racks, and radiological fences as large pieces.

Section 3.4.3.2 of the GR also discusses the erosion and potential disintegration of some debris materials by post-DBA environment water flows. Because the small fines were already classified as reduced down to the basic constituent, further erosion of the small fines does not apply (e.g., for fibrous and coating debris). For fibrous insulation material, the large pieces are assumed to be jacketed or canvassed. According to NUREG/CR-6369, jacketed pieces are not subjected to further erosion. In addition, for material outside the ZOI, all insulation material that is jacketed is assumed not to undergo erosion or disintegration by containment spray or break flow.

The discussion noted the NUKON™ debris size distribution from the test as the insulation that had the most data points and that produced the smallest fines. This distribution was then adapted as the bounding value of fines production for unjacketed fibrous blankets. The GR references the OPG testing (OPG, 2001) for a low-density fiberglass, which indicated that 52 percent of the debris was in the category defined as small fines.

The GR assumes that if a material has a higher destruction pressure than NUKON™, then it signifies that the material has a higher resistance to damage, hence the size distribution would be larger than a more fragile material indicated by a lower destruction pressure. Therefore, it is conservative to adopt the NUKON™ blanket size distribution for material with a higher destruction pressure.

Staff Evaluation of GR Section 3.4.3.2 The categories in any size distribution must correlate to the transport model assumptions. The recommended two-category size distribution (i.e., small fines and larger pieces) adapted by the NEI baseline for material inside the ZOI of a postulated break is suitable to the baseline transport assumptions, which are based on the transport of either the basic constituent (e.g. individual fibers) or large pieces. The division between the two categories of a nominal 4-in. size is adequate in that it agrees well with debris generation testing data. The two-category size distribution, however, is likely to become highly problematic for debris transport refinements that more realistically treat the transport processes. For example, a transport model designed to treat small fibrous debris that transport along the pool floor rather than as suspended fibers will require the small fines in the NEI baseline to be further subdivided into suspended fines and small pieces. The staff finds the two-category size distribution suitable to the baseline; but the use of this size distribution should be reevaluated when debris transport refinements are proposed, such as those discussed in Section 4 of the GR.

The baseline approach contains the assumption that all large pieces of fibrous insulation material would be jacketed or canvassed and therefore would not be subject to further erosion resulting from water flows. Although this assumption is inconsistent with debris generation data acquired through NRC-sponsored tests, the staff position is that the overall impact of this nonconservatism on the results of the analysis is relatively minor in terms of the acceptance of the baseline guidance, and therefore acceptable. This is based on GR assumptions which include a large fraction of small debris (60 percent), all of which is assumed to be small fines. These are unrealistically conservative assumptions which substantiate the minor importance of addressing degradation of large debris. Further, it is agreed that for material outside the ZOI, all insulation material that is jacketed will not undergo significant erosion or disintegration by containment spray or break flow.

The NEI baseline guidance for determining a conservative fraction for the small fines based on one insulation type (i.e., NUKON™), is not realistic even though the 60 percent determination is adequate. The GR indicates that the debris generation test with the most destruction for the determination is the low-density fiberglass test conducted by OPG and documented in NUREG/CR-6808, which indicated 52 percent of the debris was in the category defined as small fines, which is in close agreement with the GR assumption of 60 percent. During the debris generation for the drywell debris transport tests documented in NUREG/CR-6369, Transco™ fiberglass blankets (similar to NUKON™ blankets) were located at a distance in front of the air jet nozzle so that the blankets were routinely completely or nearly completely destroyed (seepage 3-20 in NUREG/CR-6369). Therefore, it must be concluded that fiberglass blankets will be essentially totally destructed into small fines given sufficient jet pressures (approximately 17 psi for Transco™). However, because this testing was based on a small distance between the nozzle and the insulation target, a realistic determination of the fraction of the insulation in a spherical ZOI that would be destructed to small fines requires integration over the sphere based on damage versus pressure and a mapping of the test jets into the spherical ZOI. Analyses documented in Appendix II to this SE confirmed the adequacy of the recommendation of 60 percent for the fraction of small fines debris generation for NUKON™ fiberglass insulation. Further, this analysis confirmed the 60 percent number for Transco™ and Knauf insulations, which are similar to NUKON™ (all low-density fiberglass insulations). The Appendix II analyses also illustrate the correct process to determine the debris size recommendation.

The baseline guidance assumes it is conservative to adopt the NUKON™ blanket size distribution for other materials with a higher destruction pressure than NUKON™. This assumption has been supported, but not conclusively assured, by the debris generation confirmatory analyses documented in Appendix II to this SE. This assumption should only be applied if insulation-specific debris size information is not available.

In addition, although the GR provides damage pressures for a number of insulation products, this list reflects only those products that have received some type of prior testing. The list is not comprehensive either in trade name or by mechanical insulation type. Acceptable default assumptions regarding material damage have been discussed, but product-specific testing can be performed to avoid unnecessary conservatism. Test data should be used to quantify the performance of mitigation strategies, such as double cladding, double banding, or other redesigned insulation-application methods.

3.4.3.3 Size Distribution

Section 3.4.3.3 of the GR provides the recommended size distributions (i.e., percentages that are small fines versus large pieces) for fibrous materials in a ZOI, reflective metallic insulation (RMI) in a ZOI, other material in ZOI, and material outside the ZOI. Table 3-3 summarizes these recommendations.

Table 3-3 NEI Recommended Debris Size Distributions

Material	Percentage Small Fines	Percentage Large Pieces
Fibrous Materials in a ZOI		
NUKON™ Fiber Blankets	60	40
Transco™ Fiber Blankets	60	40
Knaupf	60	40
Temp-Mat	60	40
K-Wool	60	40
Min-K	100	0
Generic Low-Density Fiberglass	100	0
Generic High-Density Fiberglass	100	0
Generic Mineral Wool	100	0
Reflective Metallic Insulation in a ZOI		
All Types	75	25
Other Material in a ZOI		
Calcium Silicate	100	0
Microtherm	100	0
Koolphen	100	0
Fire Barrier	100	0
Lead Wool	100	0
Coatings	100	0
Material outside a ZOI		
Covered Undamaged Insulation	0	0
Fire Barrier (Covered)	0	0
Fire Barrier (Uncovered)	100	0
Lead Wool (Covered)	0	0
Unjacketed Insulation	100	0
“Qualified” Coatings	0	0
“Unqualified” Coatings	100	0

Staff Evaluation of GR Section 3.4.3.3: The baseline recommendations can be grouped as follows:

- Materials for which adequate debris generation data exists to evaluate the debris size distribution, i.e., NUKON™ fiberglass and DPSC Mirror™ RMI insulations.
- Materials deemed to have a size distribution no finer than the materials for which debris generation data is available.

- Materials for which the debris generation is not known well enough to conservatively estimate debris size distributions, therefore maximum destruction is assumed.
- Materials outside the ZOI that are not expected to form debris due to qualification of or lack of protective coverings.

For section 3.4.3.3 of the GR, the staff finds the following:

1. Analyses documented in Appendix II confirmed the adequacy of the recommendation of 60% for the fraction of small fines debris generation for NUKON™ fiberglass insulation. Further, this analysis confirmed the 60% number for Transco and Knauf insulations, which are similar to NUKON™. The small fine generation fraction of 60% is a realistic value that is only slightly conservative.
2. The GR assumes it is conservative to adopt the NUKON™ blanket size distribution for other materials with a higher destruction pressure than NUKON™. This NEI assumption has been supported but not conclusively assured by debris generation confirmatory analyses documented in Appendix II. This assumption should only be applied if insulation-specific debris size information is not available.
3. The staff agrees with the assumption of 100% of the materials becoming small fines for materials for which the debris generation is not known well enough to conservatively estimate debris size distributions. However, for those plants that can substantiate no formation of a thin bed at the sump, this assumption would be nonconservative with regard to sump blockage because fine particulates would pass through the sump screen and generate no blockage concerns. Therefore, for those plants that can substantiate no formation of a thin bed at the sump at which particulate debris can collect, the staff finds that debris generated should be assumed to be sized with realistic conservatism based on the plant-specific environment and susceptibilities identified for that facility, with appropriate justification for the sizing used.
4. The staff agrees that covered insulations and fire barrier material outside the ZOI will not form significant debris, provided the covering is substantial enough to remain intact and to stop significant water from passing through the insulating materials. For example, an exception would be a vinyl covering of fibrous or particulate material that might melt at post-LOCA containment temperatures, and thus would not protect the materials inside from the effects of water erosion.

3.4.3.4 Calculate Quantities of Each Size Distribution

Section 3.4.3.4 of the GR provides guidance for estimating the quantities of debris for each material and each size distribution category. For materials located within the ZOI, other than coatings, the volumes of materials are simply multiplied by the respective size distribution fractions for either small fines debris or large piece debris to obtain the debris volumes of small fines and large pieces, respectively.

Staff Evaluation of GR Section 3.4.3.4 The staff agrees that for materials other than coatings, it is appropriate to multiply the volumes of the ZOI by the appropriate debris size distribution fractions to determine the volumes of debris.

Protective Coatings Quantification

The ZOI for protective coatings is based on the coating destruction pressure assumed in the GR. The same approach used to map the ZOI for other debris types (described in GR Section 3.4.2) is also used to map the ZOI for coatings, specifically, modeling the ZOI as a spherical volume resulting from the freely expanding LOCA jet that will be exposed to pressures greater than or equal to the assumed destruction pressure. Depending on the break location, coated components may or may not exist within this sphere. Where plant-specific data do not exist regarding the amount of coating within the ZOI, the GR assumes that coated components equivalent to the surface area of the sphere will exist within this volume and will fail, generating fine particulate debris. The amount of coating debris is a function of the coating thickness, as well as the surface area. If plant-specific coating thicknesses are not available, then the GR provides guidance on assuming a coating thickness in the ZOI that consists of 3 mils of IOZ primer plus 6 mils of epoxy topcoat.

Staff Evaluation for Protective Coatings Quantification The staff finds that the quantity of coating debris that will be generated as a result of a LOCA jet should be based on the following:

- For plants that can substantiate the formation of a thin bed, use of the basic material constituent (10 µm sphere) to size coating debris is acceptable.
- For those plants that can substantiate that the formation of a thin bed which can collect particulate debris will not occur, the staff finds that coating debris should be sized based on plant specific analyses for debris generated from within the ZOI and from outside the ZOI, or that a default area equivalent to the area of the sump-screen openings, be used for coatings size. If analyzed, then such an analysis should conservatively assess the coating debris generated with appropriate justification for the assumed particulate size or debris size distribution. Degraded “qualified” coatings that have not been remediated should be treated as “unqualified” coatings. Finally, testing regarding jet interaction and coating debris formation could provide insight into coating debris formation and help remove some of the potential conservatism associated with treating coatings debris as highly transportable particulate. If coatings, when tested at corresponding LOCA jet pressures and temperatures, fail by means other than erosion or the erosion is limited, the majority of debris may be larger, less transportable, or pose less of a concern for head loss.

The GR stipulates that all “unqualified” coatings outside the ZOI are assumed to fail. This assumption is consistent with the position provided in Section 6.1.2 of the Standard Review Plan. The amount of debris will be a function of the area of “unqualified” coating and the coating thickness as described in the GR, but the staff recommends that plant-specific values regarding the “unqualified” coating properties and thickness be used. The GR recommendation to use 3 mils of IOZ as a default thickness for “unqualified” coatings outside of the ZOI was based on the fact that 3 mils of IOZ, being 4.5 to 5 times denser than epoxy, epoxy phenolic, or alkyd coatings, would yield approximately the same mass as 13.5 to 15 mils of epoxy coating film. This concept of an "IOZ-equivalent" coatings quantity can lead to inaccurate results in the calculation of the amount of debris generated because the GR does no clearly explain that the mass of coatings debris estimated in this way must then be combined with the actual coating density (not the density of IOZ) to accurately determine the amount of particulate that may impact sump-screen head loss.

Further, the staff is aware of numerous instances in which containment coatings, "qualified" and "unqualified", are much thicker than the assumed equivalent thickness of 13.5 to 15 mils, so the assumed equivalent thickness may not be conservative. The staff concludes that the GR alternative is not acceptable without plant-specific justification and recommends that plant-specific evaluation of the plant's "unqualified" coatings be performed to determine conservative coating properties and thicknesses. The staff recognizes that the amount of "unqualified" coating in a plant may vary as a result of changes in plant equipment and modifications which could affect the sump-debris load. Therefore, the staff recommends that licensees periodically assess the amount of "unqualified" coating identified and used in the sump analysis to ensure the quantity remains bounding, and if nonconservative changes in the amount of "unqualified" coating occur, that the impact of this change be evaluated.

Staff Conclusions Regarding GR Section 3.4.3.4 The staff concludes that the baseline alternatives to plant-specific data for the determination of the coatings thickness may not be conservative and are not acceptable without plant-specific justification. The staff further concludes that each plant should perform a plant-specific evaluation of its respective coatings to determine realistically conservative coating thicknesses. The staff drew this conclusion despite the perceived conservatism of the recommendations of assuming all the unqualified coatings in containment fail and all coating debris forms a fine, 10 μm particulate. It is considered reasonable for each plant to assess its respective coating thicknesses, as well as the soundness of its coatings, rather than assume a default recommendation which may not be conservative.

3.4.3.5 Sample Calculation

Section 3.4.3.5 of the GR provides a sample calculation for estimating the quantities of debris from the ZOI by size category and for the "DBA-unqualified" coatings outside the ZOI.

Staff Evaluation of GR Section 3.4.3.5 The staff found the sample calculation presented in this section of the GR to be adequate in concept and practice, but numerically inconsistent with revised guidance explained in this SE, particularly in its treatment of coatings debris. First, the size distribution of fine and large pieces for both fiberglass and RMI insulation should be reviewed for consistency with the recommendations found in Section 3.4.3 of this SE. Second, the estimate of coating debris from within the ZOI should be based on plant-specific characterization of coating thickness and a defensible ZOI radius. Finally, the estimate of coating debris from outside the ZOI should also be based on a plant-specific characterization of unqualified coating thickness and total inventory, rather than the suggested default thickness.

3.4.3.6 Debris Characteristics for Use in Debris Transport and Head Loss

GR Section 3.4.3.6 provides Tables 3-2 and 3-3, which present selected debris characteristics for a variety of materials, specifically material densities and characteristic sizes. The baseline guidance declared the characteristic sizes to be the most conservative values that can be associated with debris transport and head loss. The tables include data for fibrous, cellular, RMI, and particulate (granular) insulation materials. It is noted that the manufacturer should be contacted to obtain information for materials not listed.

Staff Evaluation of GR Section 3.4.3.6 The staff notes the following concerns regarding the use of the data in GR Tables 3-2 and 3-3:

1. The range of variation for several data entries is substantial (e.g., the as-fabricated density for Kaowool ranges from 3 to 12 lb/ft^3). The reason for such wide variation was not provided, but is likely caused by the variability in the manufacture of that insulation. Further, the specification of such a wide range is not specific enough for head-loss predictions because using 3 lb/ft^3 versus 12 lb/ft^3 for an as-manufactured density could easily make a drastic difference in the prediction. For example, it would take 4 times the volume of insulation to form a uniform 1/8-in. thick layer if the density were 12 rather than 3. It is important that each plant locate data specific to its installed insulation.
2. An inconsistency exists in the guidance regarding the particulate size for coatings debris outside the ZOI. GR Table 3-3 lists the characteristic size for epoxy and epoxy phenolic coating chips (outside the ZOI) as 25 µm. However, the discussion on page 3-25 of the GR appears to recommend a 10 µm particulate size for all unqualified coatings. It is the staff's understanding that the intent of the baseline guidance was to recommend the 10 µm size for the coating particulate; therefore, acceptance of the baseline is based on the 10 µm recommendation.
3. Table 3-2 recommends a range of 5 to 12 lb/ft^3 for as-fabricated densities for Microtherm. However, GR Reference 13 provides several ranges (i.e., 8 to 25 lb/ft^3, 12.5 to 22 lb/ft^3, and 15 to 22 lb/ft^3), none of which match the range recommended in the GR. Therefore, the value used for Microtherm should be confirmed by the licensee before its application.
4. The data tables provide a characteristic size to represent the material in head-loss calculations, rather than the specific surface area required when using a correlation such as the NUREG/CR-6224 head loss correlation. In the discussion of head loss in Section 3.7 of the GR, the characteristic size is used to estimate the specific surface area from simple geometric formulas. The staff is concerned with the method of converting characteristic dimensions into specific surface area because it has been demonstrated that the method shown in GR Section 3.7 is not reliable. This concern is particularly important when estimating a specific surface area for a particulate with a distribution of particle sizes for which the tendency of using the mean of the size distribution is incorrect and leads to an underestimate of the specific surface area that, in turn, can lead to an underestimate of the head loss. The staff evaluation in Section 3.7 of this SE further discusses this issue. Confirmatory research presented in Appendix V of this SE was performed and illustrates the application of simple geometric equations (e.g., 4/d for fibers and 6/d for particles).

Staff Conclusions Regarding GR Section 3.4.3.6 The staff concludes that acceptance of this section depends upon each plant-specific evaluation properly determining that the parameters selected for the analysis adequately reflect the insulation types actually used in that containment, and that the specific surface area used in the head loss calculation is properly determined.

The staff did not independently verify all the data contained in GR Tables 3-2 and 3-3, however, the values presented agree with analyst perceptions for these materials.

Failed Coatings

The GR assumes that all failed coatings generate debris sizes equivalent to the coatings' basic constituent or pigment sizes which the methodology identifies as 10μm. The GR chose this value because experimental evidence was lacking regarding coating debris size generation during a postulated event. The industry pressure wash testing detailed in Appendix A to the GR provided some insight that coatings within the ZOI will likely fail by erosion resulting in debris sized in the range of 10μm–50μm spheres. The testing also provided insight that the "qualified" epoxy and "qualified" IOZ coatings that were tested would not fail as chips or sheets during simulated jet-impingement testing. Coatings outside the ZOI that fail are also assumed to generate debris in sizes equivalent to their basic constituents or pigment sizes. This debris is on the order of 10μm spheres.

Staff Conclusions Regarding Failed Coatings: For plants that substantiate a thin bed, use of the basic material constituent (10 μm sphere) to size coating debris is acceptable.

For those plants that can substantiate no formation of a thin bed that can collect particulate debris, the staff finds that coating debris should be sized based on plant-specific analyses for debris generated from within the ZOI and from outside the ZOI, or that a default area equivalent to the area of the sump screen openings should be used. Such an analysis should conservatively assess the coating debris generated with appropriate justification for the assumed particulate size or debris size distribution. Degraded, "qualified" coatings that have not been remediated should be treated as "unqualified" coatings.

Finally, testing of jet impingement on coatings could provide insight into how coating debris is formed and could help remove some of the potential conservatism associated with treating coatings debris as highly transportable particulates. If coatings, when tested at corresponding LOCA jet pressures and temperatures, are found to fail by means other than erosion, or the erosion is limited, the majority of debris may be larger, less transportable, or pose less of a concern for head loss.

3.5 LATENT DEBRIS

3.5.1 Discussion

Section 3.5.1 of the GR discusses general considerations for latent debris in terms of its potential impact on sump-screen blockage, as well as some variables that should be addressed on a plant-specific basis. The GR outlines the following five generic activities needed to quantify and characterize latent debris inside containment: (1) Estimate horizontal and vertical surface area; (2) Evaluate resident debris buildup; (3) Define debris characteristics; (4) Determine fractional surface area susceptible to debris buildup; and (5) Calculate total quantity and composition of debris—provide a working outline of the process.

Staff Evaluation of GR Section 3.5.1 The staff finds the GR guidance with respect to general considerations for latent debris to be acceptable. The staff agrees with the position in the GR that latent debris present in containment during operation may contribute to head loss across the ECCS sump screens, and that it is necessary to determine the types, quantities and locations of latent debris. The staff also agrees that it is not appropriate for licensees to claim that their existing FME programs have entirely eliminated miscellaneous latent debris. Results from plant-specific walkdowns should be used to determine a realistic amount of dust and dirt in containment and to monitor cleanliness metrics that may be deemed necessary following the overall sump-screen blockage vulnerability assessment.

For more detailed analysis, the staff believes that when characterizing the resident debris buildup, it would be useful to partition the inventory not only by vertical and horizontal location, but also by relationship to spray impingement and washing by containment-spray drainage.

3.5.2 Baseline Approach

The introduction provided in this section of the GR provides practical insights into the level of importance that latent debris may take in the overall vulnerability assessment and helps licensees to judge the level of effort needed to characterize their plants. In this section, NEI acknowledges that latent debris should be considered as an input to sump-screen head loss, and recommends the use of conservative strategies rather than evaluating the effects of latent debris to a high level of detail.

Staff Evaluation of GR Section 3.5.2: The staff finds the GR guidance with respect to the introduction of the baseline approach for consideration of latent debris to be acceptable. For plants that expect to have fibrous insulation debris generated in the ZOI, the additional contribution to head loss from the latent fiber component may be small by comparison, and reasonable approximations of inventory will suffice. However, for predominantly RMI plants, the latent fiber component represents the dominant potential for thin-bed formation across the screen. In any case, accurate fiber inventories can provide valuable insight for critical decisions regarding sump-screen vulnerability.

3.5.2.1 Estimate Horizontal and Vertical Surface Area inside Containment

This section of the GR provides a general outline of steps required to estimate the horizontal and vertical surface areas in containment. The bulleted list of items that should be included in the surface area calculation (floor area, walls, cable trays, major ductwork, control rod drive mechanism coolers, tops of reactor coolant pumps, and equipment, such as valve operators, air handlers, etc.) provides a starting point for licensees to consider for major inputs. The five steps provided for surface-area calculations (flat surface considerations, round surface area considerations, vertical surface area considerations, thorough calculation of surface areas in containment, and use of estimated dimensions when exact dimensions are unavailable) are informative.

Staff Evaluation of GR Section 3.5.2.1: The staff finds the GR guidance for estimating surface areas within containment to be acceptable with the provisions outlined below for specific sections/attributes.

The staff agrees that the quantity of ambient dust and dirt collected on vertical surfaces by settling from the air is small compared to that collected on horizontal surfaces in the absence of factors that promote adhesion to those vertical surfaces. Any special factors that might promote adhesion to vertical surfaces should be noted and examined more carefully for dust accumulation. A list of potential adhesive factors includes oil leaks, moisture- or condensate-laden surfaces, residue from previously sprayed oils or solutions, and detergent films. Dust that accumulates on vertical surfaces is very small and should be assumed to be 100 percent transportable, if affected by water during a LOCA.

Other surfaces that should be considered for inclusion in plant-specific inventory estimates include steam generators; pressurizers and pressurizer relief tanks; cooling fans; other large equipment; structural supports, such as I-beams and seismic restraint collars; access gratings and steps; and piping. In general, the area inventory refers to external surfaces that can be affected by spray wash down. Internal compartments and cabinets with known loadings of dust and debris which are not typical of most surface conditions after containment closeout should be examined carefully for water infiltration and potential flushing. Areas of this type include inlet-air filter housings and confined crawl spaces that are accessed infrequently.

The guidance provided in the GR for surface-area calculations treats the contribution of vertical surfaces in an inconsistent manner. In general, the staff agrees that practical simplifications can be made to make estimating surface area easier; however, the 10 percent factor proposed for general vertical surfaces does not provide complete guidance for debris estimation. The method the staff finds acceptable is discussed in Section 3.5.2.2.1. Vertical surfaces that are subject to enhanced dust and debris accumulation should be added to the latent debris load estimation separately as part of the resident debris buildup evaluation explained in GR Section 3.5.2.2. This section also provides additional guidance for considerations to be included in containment surveys for latent debris loading.

The staff agrees that the containment dome does not need to be considered from the point of view of dust accumulation. However, the dome may be a contributor of degraded coatings that are dislodged during vapor expansion and should be addressed as such in the determination of the coatings debris source term.

The staff agrees with step 2 in the GR regarding the treatment of round surfaces, but notes that piping surfaces should be considered. Steps 4 and 5 also provide some practical recommendations that are acceptable.

3.5.2.2 Evaluate Resident Debris Buildup

Section 3.5.2.2 of the GR provides a high-level discussion of general practices needed to evaluate latent debris buildup in containment. The GR cites recent sampling of surfaces inside the containment at a number of plants, and recommends that surveys of the containment be performed to determine the quantity of latent debris. As this information is not available in the public domain to allow confirmation of consistency in sampling methods and reporting practices, any statement of expected maximum dust inventory should be considered speculative. The GR references NEI 02-01 to provide guidance for conduct of these containment surveys and evaluation of the presence of foreign material found. The GR also suggests that the degree of rigor for containment survey and surface swiping be applied in inverse proportion to the attention given to foreign material exclusion under normal operations.

Staff Evaluation of GR Section 3.5.2.2 The staff finds the GR guidance with respect to the practices for overall evaluation of latent debris to be acceptable, provided the provisions outlined below are incorporated into the site-specific surveys for latent debris in containment. These surveys will produce opportunities to maximize credit for plant cleanliness, and identify areas of higher than expected debris loadings.

In its present form, the baseline guidance requires detailed calculations of both horizontal and vertical surface areas and physical surveys of dust accumulation on horizontal surfaces (see GR Section 3.5.2.2.1). To improve consistency in the treatment of vertical surfaces, the staff provides the following two acceptable alternative options for baseline analysis based on the best available information documented by the industry:

Option 1. Adopt a default vertical-surface debris inventory of 30 pounds to be characterized by the smallest size fraction found in the horizontal surface inventory, and document a simplified, but realistic calculation of vertical surface area. Consideration should still be given to the unique deposition areas discussed above and the results should be added to the default vertical debris inventory. This value is approximately 5 times (established by using a 2-standard deviation expansion from the mean of the reported sample data set to achieve a 95 percent coverage of the expected data curve and, then doubling the result for conservatism) higher than the vertical inventory reported in Appendix B to the GR for concrete walls and the containment liner and should be sufficiently high to bound variations in surface area, plant cleanliness and the additional vertical areas represented by piping and equipment.

Option 2. Conduct swipes for three categories (a, b, c) of vertical surfaces in the manner illustrated in Appendix B to the GR. It should be noted that repeated wiping with a lint-free cloth (Masolin) under manual pressure or high-efficiency particulate air (HEPA)-filtered vacuuming with mild brush agitation of the surface are both effective methods for collecting the full spectrum of particle sizes found on surfaces. Both methods provide collection media that can be weighed before and after collection to determine the mass of debris in the sample (see Appendix VII to this SE). Concrete walls (a), the liner (b), and vertical piping/equipment (c) should each be sampled at a minimum of three locations selected and documented by a simple rationale to represent typical variations in expected dust loadings within containment. For example, walls near the equipment hatch might represent maxima, and the upper containment liner might represent minima. A simplified, but realistic, calculation of vertical surface area for each category of surface that is sampled should be documented and the average of the three (or more) measurements should be used to determine the mass present on vertical surfaces of each surface category. The three subtotals are then added to the inventory estimate obtained from any unique deposition areas (as identified below). If recently cleaned surfaces are used to establish the minima for a surface category, a documented cleanliness plan should be referenced that describes the frequency of this cleaning treatment. This option represents a minimal increase in effort over that required in the

GR, specifically the collection of vertical-surface swipes, and yet allows maximum credit for individual variations in plant cleanliness.

To ensure a comprehensive evaluation of containment debris, the following items should be considered as part of the containment survey. Phenomena that can enhance dust collection on both vertical and horizontal surfaces include temperature gradients (thermophoresis) and static electrical charge (electrophoresis). The vertical surfaces of cooling fins, heat exchangers, and warm electrical panels may attract higher concentrations of dust than painted concrete structures. Hanging lamp shades inside containment are a common location for enhanced dust collection caused by the thermal gradient. Static charge may accumulate on any surface exposed regularly to air flow. Dielectric materials, such as plastics and exposed cable jackets, may be principle candidates for inspection. For some plants, these effects and locations may be minor contributors to the total dust inventory and can be dismissed with proper examination. However, these issues should be considered and their disposition documented.

For the purposes of latent debris characterization, surveys taken after every second outage should be sufficient. Exceptions to this schedule warrant surveys after any invasive or extended maintenance such as steam generator replacement.

3.5.2.2.1 Evaluate the Resident Debris Buildup on Surfaces

This section of the GR focuses on the measurement of dust and dirt found on horizontal surfaces of containment. The GR presents the following four steps for this purpose:—(1) Divide the containment into areas based on robust barriers; (2) Determine representative surfaces for each section of containment; (3) Survey the representative surfaces in each section to measure debris quantity; and (4) Calculate the thickness of the debris layer—and describe the process. Of these, Steps 1 and 2 offer practical and thorough guidance for performing a systematic survey. The primary method for determining latent debris inventory suggested in Steps 3 and 4 of the GR is direct measurement of debris thickness.

Staff Evaluation of GR Section 3.5.2.2.1 The staff finds the GR guidance to be acceptable with respect to division of containment areas (Step 1) and determination of representative surfaces (Step 2). However, the staff found the methods identified for measuring and evaluating the buildup of debris on surfaces to be unacceptable. The staff considers the recommendation in the GR for direct measurement of dust thickness to be impractical. This SE offers a revised approach for the assessment that is based on generic characterization of actual PWR debris samples. This revised approach also addresses the question of particulate-to-fiber ratio as it relates to the thin-bed effect. If desired, a limited plant-specific characterization can also be pursued as a refinement using this guidance.

Attempting to directly measure latent debris thickness is not recommended because (1) masses can be measured much more accurately than thickness, (2) comparison of dirt layers to reference thickness standards is subjective and prone to error because of heterogeneous small objects that may reside on the surface and because of non-uniform dust thickness across a surface like piping, and (3) in situ estimates of thickness do not characterize size distributions, particulate-to-fiber mass ratios, or densities that are needed to define hydraulic head-loss properties. These problems can be avoided by measuring total masses within a known surface area and then partitioning the fiber and particulate mass fractions either by physical measurement or by generic assumptions described in the next section of this SE.

Statistical sample mass collection is an acceptable method for quantifying latent debris inventories. This approach will not pose an undue burden if planned in advance and incorporated with other survey activities. A list of unique debris sample locations should be developed starting with the previous discussion in Section 3.5.2.1 that can be checked for each evaluation zone that is defined in containment. For convenient cross reference, these evaluation zones should be defined to coincide with the break zones discussed in Section 3.4. For later input in debris transport assessment, the potential for exposure to water from either direct containment-spray, containment-spray drainage, or recirculation-pool immersion should be noted for the surfaces in each evaluation zone. Other areas that should be included in the survey include annular compartments outside of the bioshield and the reactor cavity, if the area participates in circulatory flow with the sump pool during recirculation. Using the practical guidance offered in GR Section 3.4.2.2.1, item 2, for selecting typically loaded surfaces within each inventory evaluation zone, several classes of horizontal surfaces should be defined to represent places where latent debris is found (e.g., high- and low-traffic floor areas, tops of equipment, floor near curbing, cable trays, etc.). At least three samples should be taken from each category as they appear throughout containment, and the results should be treated in the same manner described for vertical surfaces.

The goal of defining debris characteristics is satisfied by collecting swipe or vacuum-filter samples that can be weighed before and after collection to determine the total mass of debris within a measured area. It is important that the collection method adequately captures the full range of particulate sizes from very small (less than 10 μm) up to the large miscellaneous chips and pieces, and all fibers in the sample region. Both HEPA-filtered vacuuming with light-brush agitation of the surface and repeated swiping under manual pressure with a Masolin cloth were found to be effective collection methods for fine particulates and fiber. Vacuuming is considered more efficient for collecting larger grains and miscellaneous objects. Scraping with a metal blade or sweeping with a bristle-type brush will not adequately collect the full range of debris (DIN04).

3.5.2.2.2 Evaluate the Quantity of Other Miscellaneous Debris

Section 3.5.2.2.2 of the GR provides general guidance for the considerations to be used in identifying and evaluating potential sources of miscellaneous debris in containment. The GR refers to and endorses the use of NEI 02-01 to provide guidance for performance of containment surveys. A list of three items, equipment tags, tape, and stickers or placards affixed by adhesives, is used to provide guidance for these specific sources of latent debris.

Staff Evaluation of GR Section 3.5.2.2.2 The staff finds the GR guidance acceptable with respect to methods to identify and evaluate miscellaneous debris, provided the guidance is supplemented with the additional direction identified below. The staff agrees that surveys of containment for the presence of miscellaneous debris should be performed and that miscellaneous debris types should be assessed for potential contributions to sump-screen head loss. In addition to the three categories of miscellaneous debris discussed in the GR, the quantity, characteristics, and location of any failed qualified coatings should also be noted in the survey. This issue may be addressed elsewhere in the GR, but it warrants emphasis in this section as well.

- Without specific data to cite regarding the behavior of miscellaneous debris types, the phrases “available for transport” and “transportable debris” should be interpreted as “complete transport to the screen” for fines and particulate debris under the conditions of interaction with water. Larger, miscellaneous debris types must be evaluated on a case-by-case basis for susceptibility to transport as outlined in GR Section 3.6. If data on disintegration and transport become available, they should be documented and used as an acceptable refinement to quantify an assumption of partial degradation or partial transport. If applicable, refinements should include a plausible timeline or necessary operating condition for failure. For example, if adhesives are shown to fail after hours in containment, large or heavy stickers and signs may become detached, but still may not be transportable in low-velocity recirculation conditions. Similarly, delayed failure of adhesives on upper levels of containment may not lead to debris being transported if containment sprays are no longer operating. Proper consideration should be given to the location of these items and the logic of the rationale that is used. For example, slow softening of adhesive in a high-humidity environment is much different than erosion by spray-water cascade or break-jet impingement. The following additional guidance is offered on the evaluation of the GR-listed categories of latent debris.

- Equipment tags. The GR guidance provided on the post-LOCA status of paper tags is ambiguous. There is an implied assumption that complete tags arriving at the screen will induce more head loss than shredded or dissolved paper fiber contributing to a mixed-debris bed. Regardless of their physical condition, tags can only contribute to head loss if they are transportable. Robust lanyards and attachment methods should prevent most equipment tags that exist outside the ZOI from becoming detached (equipment tags within the ZOI shall be assumed to become detached). The size and weight of detached equipment tags and broken lanyards should be evaluated against the criteria in GR Section 3.6 to determine if they should be considered transportable debris. For all equipment tags that are found to be potentially transportable, it is necessary to determine the number and location of tags by type for contribution to screen-head loss. If transportability or the capability of tags to remain intact cannot be determined, it should be assumed that they remain intact and are transported to the sump screen, to preserve conservatism. In other applications, an average mean packing ratio of 0.75 (a 50% overlap of the items stacked on top of each other) has been assumed for larger, flat objects (paint peels), and has been considered reasonably conservative. Consequently, the wetted sump-screen flow area should be reduced by an area equivalent to 75% of the total of the original single-sided surface area of the tags. If there is information that indicates the tags will not remain intact, the staff recommends that the equivalent mass of the tags be treated as latent fiber.

- Tape. The GR mentions some specific applications of tape and recommends that all tape be assumed to fail as transportable debris. The staff agrees that the size, weight, and composition of tape that would interact with water should be evaluated for transportability, as discussed in GR Section 3.6, to determine the realistic amount that would arrive on the sump screen. As stated in the GR for equipment tags, all failed tape that is determined to be transportable should be assumed to arrive on the screen intact and to obstruct an area equivalent to 75% of the total of the original single-sided surface area, unless there is evidence that the tapes will not remain intact. If there is evidence that the tapes will not remain intact (e.g., prior in-service disintegration), then the equivalent mass of the tape should be assumed to be transported to the screen in the form of latent fiber.

- Stickers or placards affixed by adhesives. The staff agrees with the position in the GR that adhesives may fail in post accident conditions. Under the present guidance offered in the GR, all items attached by adhesives should be assumed to fail and be evaluated for transport to the sump screen as outlined in GR Section 3.6. The staff considers this an acceptable position. Where evidence is available that these items will degrade, the equivalent mass of the items in question should be assumed to be transported to the sump screen in the form of latent fiber. Otherwise, the wetted flow area of the sump screen should be reduced by 75% of the total of the original single-sided area of the items in question.

3.5.2.3 Define Debris Characteristics

This section of the GR notes that two generic methods can be applied for defining debris characteristics, Method 1 analysis of samples, or Method 2 assume composition and properties based on conservative values. NEI indicates that Method 2 (assume conservative values for debris composition properties) is preferable, and provides parameter values for fiber density, particle density, and particle diameter. The GR notes that for this option to be used, an appropriate fiber/particulate mix for the plant being evaluated should be employed. The GR goes on to describe some of the difficulties and challenges associated with Method 1.

Staff Evaluation of GR Section 3.5.2.3 The staff finds the GR guidance to be acceptable with respect to defining debris characteristics, provided the method used is supplemented with the additional details outlined below.

It should be noted that conservatism with respect to head-loss potential includes both the aspects of transportability and the hydraulic properties of the material in a mixed-debris bed. The four GR bullets provided in this section for evaluating debris characteristics will be addressed in a parallel format that discusses the Method 1 and Method 2 approaches to each topic concurrently. Both methods first require that adequate surface samples be taken to characterize variability in the plant, and that total masses in containment be estimated by multiplying the empirically determined concentration for each type of collection area (g/ft^2) by the corresponding surface areas before summing to obtain the total inventory. Since the GR indicates that Method 2 is preferred, it will be addressed first for each bullet provided.

First GR Bullet – Use an appropriate fiber/particulate mix for the plant being evaluated.

> Method 2 – Assume that fiber contributes 15 percent of the mass of the total estimated inventory. If abnormal qualified coating conditions indicate a dominant presence of paint chips compared to normal dust and dirt at a particular sampling location, that location should be characterized by measurement under Method 1 (See Appendix VII to this SE concerning latent debris for more specific information.)

Method 1 – Characterize the fiber-to-particulate mass ratio in the plant by wet rinsing and manual separation of the fibers from the particulates followed by drying and weighing to obtain mass ratios for samples taken. If this option is chosen, HEPA filtration is recommended as the preferred collection method because of easier separation of the debris from the filter.

Second GR Bullet – Fiber density

- It is conservative to assume that all fiber exposed to water is transported to the screen (unless special circumstances are noted, as discussed earlier), but material buoyancy is not the primary contributing factor and a density equal to that of water should not be assigned.

Method 2 – Assume that latent fiber material has a mean density of 1.5 g/cm^3.

Method 1 – Immerse dry fiber samples of known mass in a graduated cylinder with a known quantity of water. Cover with plastic film to prevent evaporation and let stand for several days or heat gently to remove trapped air. Measure new volume of contents and determine fiber material density by displacement.

Third GR Bullet – Particle density

- It is appropriate to assume that latent particulates are primarily geophysical in origin being composed of soil, sand, and dust (i.e., “dirt”).

Method 2- Assume latent particulate material has a nominal density of 2.7 g/cm^3.

Method 1 – Measure the particulate density by water displacement as described above for fiber.

Fourth GR Bullet – Particle Diameter

- The principal use of particle diameter is to estimate the hydraulic properties of the debris, such as the specific surface area. This information can also affect judgments regarding transportability and retention in a fibrous debris bed.

Method 2 – The GR provides the guidance to assume all particulate mass is composed of 10-μm diameter grains. The staff considers this assumption to be acceptable, but this approach is very conservative, especially when much of the mass may be composed of small paint chips, hardware, and visible sand grains. However, this assumption offers the convenience of consistency with baseline assumptions applied to failed coatings as mentioned in the GR. A more refined set of assumptions that would also be considered acceptable are as follows:

- Assume that typical mixtures of latent particulate debris have a specific surface area of 106,000 ft^{-1}, as defined for use in the NUREG/CR-6224 head-loss correlation.

- Assume that 22 percent of the particulate mass determined from the raw samples above the recirculation-pool flood level is non-transportable.
- Under conditions of low sump-screen flow (i.e., less than 0.2 ft/s) and estimated particle-to-fiber mass ratios less than 3, assume that 7.5 percent of the latent particulate debris penetrates the sump screen and is not permanently deposited in the bed to contribute to head loss.

  Method 1 – Dry sieve particulates into size fractions down to 75 μm and characterize the mass distribution as a function of diameter. Assume that the fraction less than 2 mm is not transportable. Assume that 25 percent of the 75 μm diameter mass fraction can penetrate the debris bed. Use scanning electron microscopy (SEM) on subsamples of the 75-μm fraction to determine statistically the fraction of particles below a 10-μm diameter. Compare measured size distributions to literature reported determinations of latent debris size distribution and adjust the Method 2 specific surface area by ratios of estimated masses in each size bin.

The following two additional factors not mentioned in the GR are :

- The dry-bed accumulated density of latent fibers is needed for head-loss calculations. For fiberglass, this density is typically reported as the as-manufactured density, but there is no equivalent definition for latent fiber.

  Method 2 – Assume the dry-bed bulk density for latent fiber is equal to that of fiberglass insulation (2.4 lbm/ft^3=38.4 kg/m^3).

  Method 1 – Using the dry-fiber component obtained from the Method 1 measurement of fiber-to-particulate mass ratios, separate fibers and small flocks from a sample of known mass and drop them successively through several inches of air into a graduated container. Measure the volume after a bed has been formed by random settling and compute the bulk density of this configuration.

- The fiber-specific surface area is also needed for head-loss calculations to compute the contributions to head loss of latent fiber in a mixed debris bed.

  Method 2 – Assume the head-loss properties of latent fiber are the same as reported in NUREG/CR-6224 for commercial fiberglass. Latent fiber will either be dominated by fiberglass present from the break location or it will form the substrate of a thin-bed particulate filter and be dominated by the particulate bed forming on top of the fiber. In either case, the exact properties of the latent fiber are dominated by another debris type, so the error associated with the assumption should be small.

  Method 1 – Measure the hydraulic properties of latent fiber by inference using iterative comparisons of head-loss data and model predictions using the NUREG/CR-6224 head-loss correlation.

The staff agrees with all of the cautionary notes provided in the GR regarding the difficulties of debris characterization, except for the presumptive judgment of extreme expense and little benefit. While cost/benefit is an important practical consideration, the NRC never discourages well-documented testing to obtain site-specific information. For some of the simpler steps of the analysis, it may be an immediate benefit to characterize plant conditions more completely than the default assumptions permit. Improved particulate-to-fiber mass ratios, for example, may offer an immediate potential benefit because of the key role latent fiber plays in the assessment of vulnerability for thin-bed formation in a predominantly RMI-insulated plant.

3.5.2.4 Determine Fraction of Surface Area Susceptible to Debris Accumulation

The guidance in this section of the GR is again offered in the form of a baseline approach. The GR offers the two following options for guidance, (1) assume that 100% of the surface area is susceptible to debris accumulation, and (2) perform an evaluation that consists of estimating fractional surface areas susceptible to debris accumulation on a case-by-case basis. The intent of the guidance in this section is to offer credit for cleanliness programs exercised in certain parts of containment. The GR provides a basic approach for reducing the area considered susceptible to debris accumulation through (1) a calculation of the total surface area, (2) a calculation of the surface area considered to be clean using conservative assumptions, and (3) a calculation of the ratio of potentially dirty area to total area.

Staff Evaluation of GR Section 3.5.2.4: The staff finds the GR guidance acceptable with respect to fractional surface area susceptible to debris accumulation, with the provisions outlined below:

To implement the baseline approach, the GR intended for a measurement to be made of dust thickness on a representative surface within each inventory evaluation zone and that this thickness would be multiplied by the total relevant area in the zone to obtain the volume of debris. This approach is not considered reliable because of the difficulty and subjectivity of measuring a debris thickness, as discussed in Section 3.5.2.2.1.

Either approach presented in this section of the GR for establishing a fractional surface area for debris accumulation is acceptable to the staff with the following caveat--if areas are excluded from the surface inventory, documented cleaning procedures should be in place that are exercised before each restart. If periodic cleaning occurs less frequently, the sampling method outlined earlier in this SE is recommended to determine the minimum dust loading in those areas of a surface type that have been previously cleaned.

An issue similar to accumulation susceptibility that may lead to a credit for reduced latent inventory is transport susceptibility. As recommended earlier in this SE, potential exposure to water should be assessed for each inventory evaluation zone. It is expected that most surfaces will be exposed to either direct spray, spray accumulation flow, or immersion in the recirculation pool but some isolated areas may exist for which little or no water transport can occur (interior cabinets, elevated crawl spaces, locked rooms, etc). For these types of areas where latent debris is known or expected to exist, justification for exemptions from considering the total latent-debris inventory can be documented on a case-by-case basis.

3.5.2.5 Calculate Total Quantity and Composition of Debris

The GR provides four basic steps for calculating the total quantity of latent debris: (1) perform calculations as previously outlined on an area-by-area basis; (2) compute the total quantity of debris using the area/debris thickness method outlined in the GR; (3) include other types of debris from containment survey data as outlined previously in the GR; and (4) categorize and catalog the results for consideration in debris transport evaluation.

Staff evaluation of GR Section 3.5.2.5: The staff finds the general steps identified with respect to the total process acceptable, provided that methods outlined earlier in this SE are used in place of those specific items previously identified for computation of quantity of debris and debris density.

This SE has alluded to the process for integrating survey findings over all surface types several times. Given the revised approach to measurement of debris build up recommended by the staff, the total quantity of debris for each inventory evaluation zone and each surface type will be found by multiplying debris concentration (lbm/ft^2) by the respective areas to obtain the total number of pounds in containment. Proper evaluation of debris for transportability has been discussed previously in other sections of this SE pertaining to evaluation of debris types. Most importantly, the calculation must separate the fiber and particulate components of the debris aggregate. These fractions behave differently during transport, contribute separately to head loss, and introduce separate considerations regarding sump-screen vulnerability.

3.5.3 Sample Calculation

The sample calculation presented in this section of the GR illustrates the concept and systematic process involved with defining categories of surfaces that reside within a given inventory evaluation zone, calculating areas, and summing debris inventories. The following sections offer minor points of clarification.

3.5.3.1 Calculate Horizontal Surface Area

This section of the GR illustrates the appropriate level of simplification for computing structural surface areas in containment.

Staff Evaluation of GR Section 3.5.3.1: The staff finds the sample calculations provided to be acceptable for implementing concepts for determining the horizontal surface areas in containment. The following clarifications are added for licensees to consider when performing these calculations.

Step 4 of the calculation discusses the calculation of additional horizontal surface areas contributed by equipment, piping, cable trays, etc. Where these items are large and obstruct floor areas computed in previous steps, the projected area of the item is effectively included twice. The duplicate area can either be subtracted from the inventory or cited as a conservatism to account for the complexity of the object in question, whichever is most appropriate.

The treatment given to the recirculation sump cover as a projected area accounted for in the floor-area calculation is appropriate.

3.5.3.2 Calculate Quantity of Debris

The example calculation in the GR is consistent with guidance given in previous sections, assuming that a debris-layer thickness can be measured and that in situ densities can be determined; total latent-debris mass is then computed accordingly.

Staff Evaluation of GR Section 3.5.3.2: The staff finds the GR guidance with respect to the total calculation of the quantity of debris to be unacceptable. The problems associated with direct measurement of debris thickness have been explained. If inventory analysis options involving sampling are pursued, it might be practical to conduct calculations like the example provided in this section of the GR.

3.6 DEBRIS TRANSPORT

3.6.1 Definition

Section 3.6 provides guidance for estimating debris that is transported from debris sources to the sump screen. The four major transport modes considered in the GR are blowdown, spray washdown, pool fill-up, and pool recirculation flow.

3.6.2 Discussion

Section 3.6.2 of this GR presents a generic transport logic tree used subsequently in the transport recommendations. In addition, the GR defines the following three containment-type categorizations:

1. Highly compartmentalized containments are defined as those containments that have distinct robust structures and compartments totally surrounding the major components of the RCS. For a main steamline break in a highly compartmentalized containment, the mostly uncompartmentalized containment values should be used.
2. Mostly uncompartmentalized containments are defined as those containments that have partial robust structures surrounding the steam generators.
3. Ice condenser containments are defined as all seven ice condenser plants, which lack lower containment compartmentalization.

Staff Evaluation of GR Section 3.6.2 The staff considers the simple generic debris transport chart shown in GR Figure 3-2 to be acceptable for a schematic representation of the GR baseline debris transport evaluation methodology. However, the distinction between the highly compartmentalized and mostly uncompartmentalized containments has not been clearly defined. Therefore, if the containment category in a plant-specific analysis is not certain, then the evaluation should assume the category which predicts the greater debris accumulation on the sump screens. Section 3.8. of the GR discusses the acceptance of the baseline guidance as a package.

3.6.3 Debris Transport

The introduction to GR Section 3.6.3 introduces the NEI baseline concept for estimating debris trapped in inactive pool volumes which are defined as volumes located below the containment bottom floor (e.g., the cavity under the reactor vessel) that are not affected by drains from the upper part of the containment that may cause them to participate in the active volumes. All volumes at the containment bottom floor elevation are assumed to participate in the recirculation flowpath from the containment sprays and break flow to the sump. The baseline model assumed no preferential direction for water to flow to the sump. Further, the baseline guidance assumes that all debris in the containment bottom floor is uniformly distributed throughout the entire volume of water in containment. This guidance then assumes that the debris transported to the inactive sumps is strictly based on the ratio of the volume of the inactive sumps to the total water volume in containment at the start of recirculation. The baseline guidance states that this assumption is conservative because it ignores the preferential sweeping of the debris on the containment floor to the inactive sumps by the thin sheets of high-velocity water. It was further noted that all small fine debris in active pools on the containment floor is transported to the sump during recirculation.

GR Sections 3.6.3.1, 3.6.3.2, and 3.6.3.3 which address the highly compartmentalized, the mostly uncompartmentalized, and the ice condenser containments, respectively, primarily contain compartmental specific debris transport assumptions. Table 3-4 summarizes these assumptions for the small fines debris generated within the ZOI. The baseline guidance recommends that all debris generated outside the ZOI be treated as small fines debris that is subsequently transported to the sump screens (i.e., 100 percent washdown transport, 100 percent sump pool recirculation transport, and no transport into the inactive pools). The baseline guidance recommends the assumption that all of the large piece debris deposits onto the containment bottom floor where it stays.

Table 3-4. Summary of Debris Transport Assumptions for Small Fines Debris from ZOI

Transport Assumption	Fibrous Debris	RMI Debris	Other Debris
Highly Compartmentalized Containments			
Fraction of Debris Generated	0.6	0.75	1
Fraction of Debris Generated That Transports into Upward Levels by Blowdown	0.25	0.25	0.25
Fraction of Debris Generated That Transports Directly to Sump Pool Floor by Blowdown	0.75	0.75	0.75
Fraction of Debris Generated That Blows into Upper Levels and Washes Down into Sump Pool	1	0	1
Fraction of Debris Generated That Enters into Inactive Sump Pools	Volume Ratio	Volume Ratio	Volume Ratio
Fraction of Debris that Enters Sump Pool That Transports to Sump Screens	1	1	1
Mostly Uncompartmentalized Containments			
Fraction of Debris Generated	0.6	0.75	1
Fraction of Debris Generated That Transports into Upward Levels by Blowdown	0*	0	0
Fraction of Debris Generated That Transports Directly to Sump Pool Floor by Blowdown	1*	1	1
Fraction of Debris Generated That Blows into Upper Levels and Washes Down into Sump Pool	1	0	1
Fraction of Debris Generated That Enters into Inactive Sump Pools	Volume Ratio	Volume Ratio	Volume Ratio
Fraction of Debris that Enters Sump Pool That Transports to Sump Screens	1	1	1
Ice Condenser Containments			
Fraction of Debris Generated	0.6	0.75	1
Fraction of Debris Generated That Transports into Upward Levels by Blowdown	0.1**	0.1**	0.1
Fraction of Debris Generated That Transports Directly to Sump Pool Floor by Blowdown	0.9	0.9	0.9
Fraction of Debris Generated That Blows into Upper Levels and Washes Down into Sump Pool	1	0	1
Fraction of Debris Generated That Enters into Inactive Sump Pools	Volume Ratio	Volume Ratio	Volume Ratio
Fraction of Debris that Enters Sump Pool That Transports to Sump Screens	1	1	1

*Because this value was not actually specified in the baseline guidance (Section 3.6.3.2, fibrous blowdown transport), the table value was assumed to be the same as the stated RMI value.

** Guidance assumes 100% ejected upwards of which 90% returns via ice melt to containment floor.

Staff Evaluation of GR Section 3.6.3 The staff based its evaluation of this section on confirmatory research documented in Appendices IV and VI to this SE and the base of debris transport knowledge documented in NUREG/CR-6808.

Table 3-5 includes the baseline recommendations for the fractions of the debris generated that are transported into upward levels by blowdown, which were 0.25, 0, and 0.1 for highly compartmentalized, mostly uncompartmentalized, and ice condenser containments, respectively. These fractions are conservative. In the detailed analysis performed for the volunteer plant, which was assumed to have a highly compartmentalized containment, the fractions were 0.92 and 0.44 for small fines fibrous and small RMI debris, respectively, as compared to the 0.25 fraction recommended for the baseline analysis (see Appendix VI to this SE). For mostly uncompartmentalized containments, the GR recommends no debris be transported to the upper containment. For ice condenser containments, the GR recommends a value of 0.1, which is conservative because these containments are designed to divert a significantly higher fraction of blowdown flow towards the ice condensers.

The inactive pool debris entrapment model does not represent the realities of debris transport. In the detailed volunteer plant debris blowdown/washdown transport analysis (see Appendix VI to this SE), a majority of the small fines debris was determined to be transported upwards in the containment, where it deposited onto any number of surfaces. Only a few percent of the small fines would likely deposit directly onto the containment bottom floor where the debris would be subjected to pool formation flows into the inactive volumes. In the volunteer plant, the openings into the bottom sump-level floor consisted of two personnel access doorways, which are small compared to the large area that opens directly to the containment dome. The large opening was designed for pressure relief from HELB events in the steam generator compartments housing most of the RCS. A significant time delay would most certainly exist between the blowdown period and the time when major portions of the small fines would be transported down to the sump pool by the containment spray drainage. Therefore, the inactive pools would most likely fill (within the first few minutes) before a large portion of the debris could wash to the sump pool, hence the assumed volume ratio is nonconservative.

The baseline guidance assumes that the debris transported to the inactive sumps is strictly based on the ratio of the volume of the inactive sumps to the total water volume in containment at the start of recirculation. The baseline guidance states that this assumption is conservative because the debris transport methodology ignored the preferential sweeping of the debris on the containment floor to the inactive sumps by the thin sheets of high-velocity water. This basis does not reflect realistic debris transport.

Observations made during the integrated tank tests (NUREG/CR-6773) show debris being directionally driven by the sheeting-flow wave front. Such transport could drive debris across the tank bottom (either away from or to the sump), unless the debris became otherwise trapped along the transport path. With this type of sheeting-flow transport of fine debris, a sharp direction change, such as at an entrance into a hallway leading to the reactor cavity, could easily result in the debris being swept past such an entrance because it was unable to alter direction with flow into the doorway. Because it is difficult to determine how sheeting flow would actually transport debris, the amount of conservatism achieved by ignoring the preferential transport of debris to the inactive volumes is difficult to quantify.

The baseline assumption that all debris in the containment bottom floor is uniformly distributed throughout the entire volume of water in containment also does not reflect reality, certainly not in the general sense of all PWRs. The volunteer plant's detailed analysis of a line break within a steam generator compartment indicated that more of the blowdown-deposited debris on the bottom floor was likely retained within the affected steam generator compartment than was transported outside the compartment. Hence, a substantial concentration of debris would initially be located in the affected steam generator compartment. Although the washdown debris would enter the sump pool at multiple locations with the containment spray drainage, the entry points would place the debris directly into the sump pool flow-stream, rather than into inactive pools or inactive or quieter portions of the sump pool.

The inactive pool debris entrapment model can predict an unrealistically high fraction of debris moving into inactive pools for some plants. Therefore, the licensees should limit the fraction of debris moving into inactive pools to a maximum of 15 percent of the source, unless shown otherwise by analysis as described in Appendix IV of this SE.

Table 3-4 shows that the only distinguishing feature among the highly compartmentalized, mostly uncompartmentalized, and ice condenser containments relative to the debris transport assumptions is the fraction of the debris assumed to deposit directly onto the containment bottom floor as a result of blowdown debris transport. For fibrous debris transport, however, this fraction becomes irrelevant because all the debris transported upwards is conservatively assumed to wash back down to the sump pool, whereas the washdown debris is treated in the same manner as the blowdown floor deposited debris. In summary, for small fines fibrous debris transport (all three containment categories); the overall transport fraction to the sump screens is 1 minus the fraction assumed to enter the inactive pools (based on a water volume ratio). The 100 percent washdown assumption for fibrous (and other) debris is conservative.

For small fines RMI debris transport, the fraction assumed ejected upwards (25 percent) is subsequently assumed to remain in the upper containment areas. In reality, some portion of the small fines RMI debris deposited in the upper reaches of the containment during blowdown would wash back down to the sump pool; therefore, this baseline assumption is non-conservative in isolation. However, based on the confirmatory debris transport research summarized in Appendices IV and VI to this SE, this nonconservative transport assumption, in conjunction with the relatively high fractions of small fines blowdown assumed to be deposited on the bottom floor (0.75, 1.0, or 0.9), represents a conservative estimate of small fines RMI debris placed in the sump pool.

The baseline assumption that the recirculation phase pool transport is 100 percent for small fines is conservative and removes a need to address the effects of the variety of pool geometries and flow velocities associated with the differences among the PWR containments. However, the baseline assumption of zero sump pool transport of the large piece debris is nonconservative for the plants with relatively fast pool velocities that are capable of moving large debris. The implication of this assumption is that absolutely no large piece debris would accumulate on the sump screens. Based on experimental results from testing performed at the University of New Mexico (UNM), the volunteer plant pool model demonstrated that large pieces will degrade and fibers will come out of the large flocks and be transported to the screen (NUREG/CR-6773). As stated in Appendix IV to this SE, the characteristic transport velocities must be compared to typical debris transport velocities to determine whether or not the baseline method should be modified to include the transport of large debris. Characteristic transport velocities can be sufficiently estimated using recirculation flow rates and nominal sump dimensions to determine if a potential exists for substantial portions of the large debris to be transported. If substantial transport of large debris is reasonably possible, and if such transport can alter the outcome of the NPSH margin evaluation, then analytical refinements are needed that evaluate large debris transport.

The baseline guidance recommends a conservative assumption that all debris generated outside the ZOI will consist of small fines debris that subsequently is transported to the sump screens (i.e., 100 percent washdown transport, 100 percent sump pool recirculation transport, and no transport into the inactive pools). This assumption removes a need to address the variability and uncertainties caused by a lack of data on the generation and transport of debris outside the ZOI, especially when considering the differences among the PWR containments.

Staff Conclusions Regarding GR Section 3.6.3: The staff concludes that two of the transport assumptions given in the baseline guidance are non-conservative. These assumptions are (1) that the quantity of fine debris trapped in inactive pools, especially debris washed down from the upper levels of the containment, can be estimated simply by the ratio of the inactive pool volume to the total water volume, and (2) the large piece debris will not transport in the sump pool. To avoid predicting unrealistic results when using these assumptions, the licensees should (1) limit the fraction of debris moving into inactive pools to a maximum of 15 percent of the source, unless shown otherwise by analysis, and (2) evaluate large debris transport if characteristic transport velocities show that substantial transport of large debris is possible.

The baseline assumption that all debris in the containment bottom floor is uniformly distributed throughout the entire volume of water in containment is also not conservative. This assumption was made in the baseline guidance to justify the inactive pool volume ratio, but otherwise does not directly affect the acceptance of the baseline guidance resulting from the 100 percent recirculation pool transport assumption. However, should a plant subsequently perform a pool transport refinement, then this assumption would not apply and alternative approaches, such as those detailed in Appendix III to this SE should be considered.

3.6.4 Calculate Transport Factors

Section 3.6.4 of the GR provides a sample transport calculation. For the sample calculation, it was assumed that the containment was highly compartmentalized, with an inactive pool fraction of 30 percent, and that the ZOI insulation debris included NUKON™ and RMI debris. The unquantified logic chart shown in GR Figure 3-2 was applied to both the NUKON™ and RMI debris in accordance with the guidance outlined in GR Section 3.6.3. GR Figures 3-3 and 3-4 depict quantified transport logic trees for NUKONTM and RMI debris.

Applying the chart to NUKON™ debris, the size distribution is 60 percent small fines and 40 percent large pieces that were assumed not to be transportable. Two transport pathways delivered small fines debris to the sump (1) 75% of the debris was assumed directly deposited to the sump pool floor, and (2) the remaining 25 percent of the debris deposited in the upper containment, but subsequently washed down to the sump pool after 30 percent of each case was sequestered in inactive pools. Therefore, 42 percent of the total NUKON™ debris was assumed to reach the sump with the remaining 58 percent assumed either trapped in the inactive pools (18 percent) or as large pieces (40 percent). Applying the chart to RMI debris, the size distribution is 75 percent small pieces and 25 percent large pieces that were assumed not to transport. Only one transport pathway delivered debris to the sump, resulting in 75 percent of the debris assumed to be directly deposited to the sump pool floor. The 18.75 percent of the RMI assumed deposited in the upper containment was thought to remain, and 30 percent of the small pieces were assumed to reach the lower containment (56 percent was assumed trapped in the inactive pools). Therefore, 39 percent of the total (or 53 percent of the small pieces) RMI debris was assumed to reach the sump. No large debris was transported to the sump. The sample calculation acknowledges 100 percent transport of coatings debris, from both within and outside the ZOI, and all debris material outside the ZOI, including latent debris. A list of all debris by type and size is provided and available for the subsequent sample head-loss calculations.

<u>Staff Evaluation of GR Section 3.6.4</u>: The sample problem is consistent with the baseline methodology discussed above and the specified transport assumptions.

3.7 HEAD LOSS

3.7.1 Introduction and Scope

Section 3.7.1 of the GR consists of an introduction to the head-loss guidance.

3.7.2 Inputs for Head-Loss Evaluation

3.7.2.1 Sump-Screen Design

Section 3.7.2.1 of the GR briefly describes several aspects of sump-screen design pertinent to estimating the head loss across the sump screen. The aspects described include screen construction, screen orientation, screen mesh size, applicable screen area, flat screen versus alternate geometries, such as stacked-disc strainers (circumscribed area versus actual screen area), and clean strainer head-loss estimation.

<u>Staff Evaluation of GR Section 3.7.2.1</u>: The staff finds the general guidance in this section acceptable because it is consistent with general engineering practice.

3.7.2.2 Thermal-Hydraulic Conditions

3.7.2.2.1 Recirculation Pool Water Level

Section 3.7.2.2.1 of the GR recommends using the minimum water level of the recirculation pool in estimating the head loss across the debris bed accumulated on the screen. The minimum water level will yield the smallest surface area for the water flow through the screens that are partially submerged, as well as the lowest available NPSH to the ECCS pumps.

<u>Staff Evaluation of GR Section 3.7.2.2.1:</u> The staff determined that the recommendation of using the minimum water level in the pool is appropriate. For partially submerged sump screens, the water level affects the wetted screen area, which affects the water approach velocity used in the calculation of the head loss resulting from the debris accumulation on the sump screen. A lower water level in the pool would result in a lower wetted screen area giving a higher approach velocity, which would conservatively give a higher head loss across the debris bed. For completely submerged screens, the static water level adds to the NPSH margin. The staff further notes that the determination of the minimum level should consider potential water holdup in the upper levels of the containment including water holdup caused by potential debris blockage at water passages such as drains (e.g., refueling pool drains). The minimum level is not merely a conservative assumption, but is consistent with ensuring adequate NPSH margin when the pool is actually operated at that level.

3.7.2.2.2 ECCS Flow Rate

Section 3.7.2.2.2 of the GR recommends using the highest ECCS flow rate in calculating the head loss across a screen (i.e., the maximum pump flows as identified in current NPSH calculations). For multiple sump screens, the flow rate for the head-loss calculation is the flow through each of the screens.

<u>Staff Evaluation of GR Section 3.7.2.2.2</u>: The staff concludes that the recommendation of using the maximum pump flows in the head-loss calculations is the appropriate assumption, although under certain conditions, those pumps might be throttled back to a lesser flow rate. This maximum pump flow assumption removes the uncertainty that a lesser flow rate will be exceeded. The rate of flow through the screen, along with the screen area, is used to determine the velocity of flow through the screen, which is a primary input to the head-loss calculation.

3.7.2.2.3 Temperature

Section 3.7.2.2.3 of the GR makes the following three recommendations for specifying the water temperature to be used in the head-loss calculations:

1. The temperature at which the head loss is evaluated should be consistent with the temperature used for the NPSH evaluation.
2. The head loss is to be evaluated at multiple times when different temperatures and flows exist during an accident.
3. The maximum expected temperature may be used for the NPSH analysis, whereas the lowest expected temperature during ECCS operation may be taken for the head loss analysis.

<u>Staff Evaluation of GR Section 3.7.2.2.3</u>: The water temperature determines the viscosity of the water, which affects head loss. A head-loss correlation typically either includes the viscosity or is only valid for a distinct range of temperatures. A lower water temperature increases the viscosity and therefore conservatively gives a higher frictional head loss across the debris bed on the sump screen. Therefore, Recommendation 3, above, is acceptable for specifying the water temperature. Licensees should calculate the NPSH margin according to their licensing bases (RG 1.82-3).

The estimation of the minimum water temperature may require a different calculation than the typical plant estimation of the maximum water temperature for the design basis.

In calculating the maximum sump pool water temperature, it is conservative to neglect heat transfer processes or systems (e.g., a nonsafety-related heat removal system) either to simplify the calculation or because a system cannot be relied upon to limit the temperature. But in a minimum water temperature calculation, all heat removal systems and processes should be included.

Recommendation 2 allows the time-dependency of the temperature to be evaluated, i.e., the evaluation of multiple times, temperatures, and flows during an accident. Staff concerns with the approach include the following:

1. Recommendation 2 appears to also suggest that the pump flow can vary with time as well, which is in direct conflict with GR Section 3.7.2.2.2, which states that the maximum pump flow should be used.
2. The debris in the time-dependent calculation must be assumed as the worst-case debris accumulation, because the debris transport evaluation capability is not sufficient to predict time-dependent accumulation.
3. If one calculation is used to estimate the pool temperature, it should be sufficiently realistic to capture all important heat transport processes. The systems specified in the accident scenario and the specification of the accident scenario must address whether or not systems such as nonsafety-related heat removal systems are operating.

Recommendation 1 is unacceptable because it does not in any way specify a minimum temperature for the head loss calculation. Licensees should calculate the NPSH margin according to their licensing bases (RG 1.82-3).

Staff Conclusions Regarding GR Section 3.7.2.2.3: The staff concludes that Recommendation 3 for determining the pool temperatures is conservative and adequate, if the minimum and maximum temperatures are properly estimated. Recommendation 2 is also a valid approach if properly evaluated, provided (1) that the flow remain that of the maximum pump flow, (2) the debris bed should be the worst-case debris accumulation throughout the time-dependent temperature transient, and (3) the pool temperature is properly determined. Recommendation 1 is incomplete and unacceptable by itself.

3.7.2.2.4 Debris Types, Quantities, and Characteristics

Section 3.7.2.2.4 of the GR provides a general discussion regarding the parameters needed to specify an accumulation of debris on the sump screen.

Staff Evaluation of GR Section 3.7.2.2.4: The staff notes that the list of important head-loss parameters is incomplete. In addition to quantities specified as volumes or masses, the bulk and fiber densities are needed for fibrous debris, the particle density and limiting porosity are needed for the particulate, and the specific surface areas are needed for each debris bed component. Appendix V to this SE offers guidance for determining the specific surface areas.

3.7.2.3 Head-Loss Methodology

3.7.2.3.1 General Theoretical/Empirical Formulas

3.7.2.3.1.1 Fibrous Debris Beds with Particulate

Section 3.7.2.3.1.1 of the GR describes the NUREG/CR-6224 head-loss correlation by providing the basic correlation equation and the supporting constituent equations for solidity (1 minus the porosity). This section also discusses fibrous debris bed compression resulting from the pressure gradient across the sump screen, as well as compression limiting factors.

The baseline guidance offers the following four options for dealing with debris materials or combinations of materials for which the empirical head-loss data do not exist:

1. characterizing the material with SEM analysis and the establishment of a size distribution
2. choosing an alternate material that conservatively represents the material in question, via similitude arguments
3. testing head loss of the particular material to establish a correlation or validate an existing correlation for that material
4. using other information that may exist to establish head-loss data for the material in question

The section contains a discussion for estimating the specific surface area, S_v, from the constituent characteristic dimension (e.g., particle or fiber diameter). A formula is provided for determining S_v for a mixture of debris constituents that is based on volume averaging the squares of the constituent S_v. The baseline guidance states, “it is best to err on the low side for conservative values of S_v.” In addition, the guidance describes obtaining the aggregate density for both particulate and fibrous debris using a simple volume averaging procedure. Finally, a computational procedure is described for solving the correlation equations to obtain the head loss.

Staff Evaluation of GR Section 3.7.2.3.1.1: The GR options for obtaining head-loss parameters for materials that have not been previously characterized are all valid methods of learning more about that material. Performing head-loss testing (Option 3 above) that can be subsequently analyzed to determine appropriate head-loss parameters is the best option, since it provides results with the least uncertainty. The other three options will improve knowledge, but can leave substantial uncertainty in the resultant head-loss parameters that must be countered through the use of conservative safety factors.

Confirmatory research presented in Appendix V to this SE and head-loss testing reports LA-UR-04-1227 on CalSil and Appendix VII on Latent Debris illustrate the application of the NUREG/CR-6224 correlation to head-loss data to determine applicable input parameters for the correlation. The confirmatory tests performed so far only provide reasonable assurance that NUREG/CR-6224 can be used as a scoping tool to calculate the pressure drop across CalSil and latent debris beds. Therefore, the NUREG/CR-6224 correlation cannot be used as a design tool to calculate the head loss across a

CalSil or latent debris bed on sump screens. Licensees should use other verifiable methods to calculate the pressure drop across CalSil and latent debris beds in design evaluations.

The baseline adequately presents the concept of compression limiting whereby the compaction of the fiber and particulate effectively prevents further compression of the debris bed (i.e., limiting of the solidity of the debris bed). However, the computational procedure described in the GR for solving the NUREG/CR-6224 correlation equations to obtain head-loss does not include steps for determining whether or not the limiting solidity would occur; as well as how to proceed with the calculation should the limiting solidity condition occur within the iterative solution. The reader is left with the impression that the limiting solidity is approximately 0.2 (i.e., limiting porosity of 0.8), which is correct for BWR iron oxide corrosion products. This impression is reinforced in the sample problem (page 3-71 of the GR) in which the mixed-bed solidity is set to 0.2 for a particulate that consists of latent and coating debris. Common sand, a likely component of latent debris, has an approximate solidity of 0.6 (data available in common soil handbooks), which is greater than the GR-implied limit of 0.2. The surrogate latent debris head-loss testing documented in Appendix VII tested common sand and verified the handbook values for sand solidity. When applying the NUREG/CR-6224 correlation, the correct value for the limiting solidity should be used for the postulated particulate, because the limiting solidity governs the head-loss prediction whenever the correlation predicts compression limiting has occurred, as is the case with thin-bed debris accumulations.

An important aspect for predicting the head loss is determining the specific surface area for the debris bed. The head loss from the NUREG/CR-6224 correlation is directly dependent on S_v; in fact, the leading laminar term uses the S_v^2. For example, at lower flow velocities, if the S_v were under-predicted by a factor of 2, then the head loss could be under-predicted by a factor of 4. The baseline guidance statement that, “it is best to err on the low side for conservative valves of S_v,” should be clarified to indicate that it is the debris size that should be selected on the low side, not the value of S_v. It is conservative to estimate S_v high, rather than low.

The baseline guidance for estimating S_v from the constituent characteristic size dimension (e.g., fiber or particle diameter) has been demonstrated to be unreliable, particularly when a particulate is defined by a size distribution. The use of 6 divided by the diameter is reasonable when specifying S_v for the conservative, all-one-size particulate (10 μm) postulated for coatings debris. However, it is unreasonable when a particulate distribution covers a wide range of sizes (e.g., iron oxide corrosion products range from 1 to 300 μm), typically described by 3 or 4 subgroups. The value of S_v calculated is sensitive to the value of the diameter used to represent the size group in the 6/diameter formula. The natural tendency is to select the mean of the size group, but the mean significantly under estimates the specific surface area because all particles in the group less than the mean make a substantially greater contribution to S_v than do those particles larger than the mean value. Selecting an appropriate value within the range is problematic because it depends upon the size distribution within the size group. A conservative solution to this problem is to use the minimum size of each size group. However, this approach can lead to large estimates of S_v, especially when the particles become very small. For example, assume the size group has a uniform distribution ranging from 5 to 100 μm. Using the 5 μm size results in a S_v of 366,000/ft, which is conservative (but too large), whereas using the mean of 52.5 μm results in a S_v of only

34,800/ft, which is much too small. Smaller particles in a debris bed cause greater head loss than do larger particles. Confirmatory research presented in Appendix V to this SE shows significant error in the S_v calculated using simple geometric equations (e.g., 4/d for fibers and 6/d for particles) compared to the error deduced using head-loss data. Where the particulate for a specific material is defined by a size distribution, licensees should use applicable head loss data to determine S_v.

The formula provided in the baseline for determining S_v for a mixture of debris constituents that is based on volume-averaging the squares of S_v is adequate and conservative relative to the formula actually provided in NUREG/CR-6371.

Before using the NUREG/CR-6224 correlation that is recommended in the GR, or any other head-loss correlation, the licensees should ensure that it is applicable for the types of insulations and the range of parameters. Appendix V to this SE gives the procedures for applying the correlation and the ranges of parameters used to validate it that are publicly available. If the correlation has been validated for the type of insulations and the range of parameters, licensees may use it without further validation. If the correlation has not been validated for the type of insulations and the range or parameters, licensees should validate it using head-loss data from tests performed for the particular type of insulations.

<u>Staff Conclusions Regarding GR Section 3.7.2.3.1.1</u>: The staff agrees with the baseline that the NUREG/CR-6224 correlation is an appropriate method for estimating the head loss associated with a debris bed consisting of fibers and particulates. Using the guidance in Appendix V to this SE, the licensees should ensure the validity of this correlation for the application of their type of insulation and the range of parameters.

3.7.2.3.1.2 RMI Debris Beds

GR Section 3.7.2.3.1.2 provides a head-loss correlation for estimating the head loss across a bed of RMI debris. This correlation and the values for the constant known as the interfoil gap thickness were extracted directly from NUREG/CR-6808.

<u>Staff Evaluation of GR Section 3.7.2.3.1.2</u>: The staff agrees with the baseline that the NUREG/CR-6808 is an appropriate method for estimating the head loss associated with a debris bed consisting of RMI, as documented in NUREG/CR-6808.

3.7.2.3.1.3 Mixed Debris Beds (RMI, Fiber, and Particulates)

Section 3.7.2.3.1.3 of the GR provides guidance for mixed debris beds that include RMI, fibrous, and particulate debris. The baseline guidance recommends that the head loss for the fibrous/particulate debris and the RMI debris be estimated separately, and then added together, to obtain the head loss for the mixed debris bed (i.e., superposition of individual head losses).

<u>Staff Evaluation of GR Section 3.7.2.3.1.3</u>: The NRC-sponsored research found the test data for head loss for mixed debris beds to be bounded by the sum of the head loss of the individual constituents. However, it was noted that the mixed bed tests were not comprehensive with regard to all of the types and combinations of debris that may be possible. NUREG/CR-6808 concluded that the head loss associated with a mixed RMI and fiber debris bed should preferably be based on head-loss measurements, but can alternately be calculated as an algebraic sum of the fiber and RMI components after accurately accounting for the strainer geometry. The potential for forming a fiber/particulate thin bed should be evaluated even when mixed-debris beds are possible because there are insufficient data to substantiate the conclusion that the presence of RMI debris can prevent the formation of a thin bed.

3.7.2.3.1.4 Calcium Silicate Insulation

GR Section 3.7.2.3.1.4 discusses the calculation of head loss for debris beds containing calcium silicate insulation debris. It states, “Based on current information, the NUREG/CR-6224 correlation can be used according to the methods for fibrous debris beds with particulate if the application is limited to particulate mixtures containing up to about 20 percent calcium silicate by mass.” The calcium silicate is treated as the particulate in the fiber/particulate debris bed. The guidance referenced the NRC-sponsored calcium silicate test report (issuance pending), which is now available as LA-UR-04-1227.

Staff Evaluation of GR Section 3.7.2.3.1.4: The staff concludes that the baseline guidance regarding the estimation of head loss for debris beds containing calcium silicate debris is not adequate. The staff recognizes that LA-UR-04-1227 was not available in time for it to be reviewed by industry and its results included in the baseline guidance. Therefore, the recommendations from LA-UR-04-1227 are summarized herein. The confirmatory tests performed so far only provide reasonable assurance that NUREG/CR-6224 can be used as a scoping tool to calculate the pressure drop across CalSil debris beds. Therefore, the NUREG/CR-6224 correlation cannot be used as a design tool to calculate the head loss across a CalSil debris bed on sump screens. Licensees should use other verifiable methods to calculate the pressure drop across CalSil debris beds in design evaluations.

Table 3-5 summarizes the staff-recommended parameters for applying the NUREG/CR-6224 correlation to debris beds consisting of fibrous and calcium silicate. The recommendations depend upon whether or not the thin-bed debris configuration is a potential concern. If the potential for a thin-bed debris configuration exists, then the application of the correlation must consider the higher specific surface area deduced from the tests in which the high thin-bed head losses were encountered.

The reproducible thin-bed calcium silicate tests demonstrated that the potential thin-bed accumulation is realistic. Only a small quantity of fibers (or perhaps none) and fine calcium silicate particulate, which tends to remain in suspension, is needed to form a uniform debris bed. The recommended specific surface area of 880,000 ft^{-1} is 10 percent higher than the experimentally deduced area and prudently incorporates a 10 percent to 20 percent safety factor to account for (1) experimental uncertainties, such as instrumentation error, (2) an incomplete examination of the experimental test parameter space, and (3) the variance in the manufacture of calcium silicate insulation.

Table 3-5. Recommended Conservative Calcium Silicate NUREG/CR-6224 Correlation Parameters

Correlation Parameter	Recommended Head-Loss Parameters Thin-Bed Configuration	Recommended Head-Loss Parameters Other Configurations
Particle Density	115 lbm/ft^3	115 lbm/ft^3
Particulate Sludge Density	22 lbm/ft^3	22 lbm/ft^3
Particulate Specific Surface Area	880,000 ft^{-1}	600,000 ft^{-1}

The sump-screen conditions that cannot form a thin-bed configuration include (1) the advanced strainer designs, for which test data have indicated that thin-bed configurations would not uniformly form because of complex surface design, and (2) flow conditions insufficient for the required debris bed formation, which can be substantiated by applicable test data. Examples of advanced strainer designs include the stacked-disk strainers, for which it has been generally accepted, based on testing of prototypical strainers, that a uniform thin-bed configuration will not form under potential debris loadings. An example of insufficient flow conditions includes a maximum screen/strainer approach velocity of less than 0.1 ft/s and particulate-to-fiber mass ratios of less than 0.5. Under these conditions, a thin bed was not achieved in the calcium silicate head-loss tests because the filtration efficiency apparently was not sufficient to remove enough of the fine calcium silicate from the flow to form a granular debris bed. Beyond these conditions, a thin bed was actually formed during the tests or the tests did not cover that part of the parameter space; thus, it is not known if a thin bed can form.

The specific surface area for calcium silicate is not a fixed value as it is for hardened particulates, such as BWR corrosion products. It was demonstrated that calcium silicate particles are somewhat “spongy,” with interior voids so that when compressed, the particulate deforms to fill inter-particle spaces. A working theory that fits the experimental results is that the compression forces water through smaller and smaller interior voids and increases the effective specific surface area of the calcium silicate particles.

The three parameters recommended in Table 3-5 (i.e., particle density, particulate sludge density, and particulate specific surface area) are a parameter set and should be applied as a set. The experimental determination of the specific surface areas depended upon the specification of the debris densities. It is also important to note that the calcium silicate tested was obtained from only one manufacturer, and that these recommendations do not necessarily apply to all types of calcium silicate insulation debris.

Whether or not there is sufficient fiber to form a thin-bed has been generally based on the NUREG/CR-6224 recommendation that the quantity of fibrous debris available must be sufficient to form an accumulation 1/8-in. thick on the screen. Tests conducted using only calcium silicate fragments have demonstrated that calcium silicate debris can accumulate without the aid of fibrous debris. However, tests conducted using only calcium silicate were not definitive enough to accurately determine the conditions under which a thin-bed can form without the presence of fibrous debris, other than the fibers contained in the calcium silicate insulation.

Staff Conclusions Regarding GR Section 3.7.2.3.1.4: The staff concludes that the recommendations shown in Table 3-5 of this report should be followed for debris beds containing calcium silicate debris, unless other data become available which are more applicable to plant-specific conditions. If it can be demonstrated that a thin-bed configuration cannot be formed with calcium silicate debris, then the mixed-bed configuration recommendations can be followed. Otherwise, the thin-bed configuration should be assumed. In determining whether or not enough fibrous debris is available, the determination that it may be possible to form a bed of calcium silicate debris without other supporting fiber should be factored into the analysis.

3.7.2.3.1.5 Microporous Insulation

Section 3.7.2.3.1.5 of the GR acknowledges that microporous insulation (e.g., MinK and Microtherm) is a granular insulation that is used in PWRs. For guidance, the GR refers to insights gained in a limited series of head-loss experiments for which additional background is provided in the supplemental guidance (see GR Section 4.2.5.2.2).

Staff Evaluation of GR Section 3.7.2.3.1.5: The staff finds that the GR did not provide adequate guidance to predict head loss for microporous insulation debris beds because it did not recommend any methodology. The licensees should develop correlations or use test data for predicting head loss for microporous insulation debris beds.

3.7.2.3.1.6 Microporous and Fiber Debris

Section 3.7.2.3.1.6 of the GR provides limited guidance regarding the application of the NUREG/CR-6224 correlation to light loadings of microporous insulation debris on a sump screen for a particulate to fiber mass ratio less than 0.2.

For ratios larger than 0.2, the baseline guidance recommends the following options:

1. Remove microporous or calcium silicate insulation until the particulate-to-fiber mass ratios drops below 0.2.
2. Seek an alternative head-loss correlation to the NUREG/CR-6224 correlation.
3. Perform head-loss experiments using plant-specific debris mixtures, sump-screen configuration, and thermal-hydraulic conditions.

The baseline guidance in this section also discusses concerns for microporous or calcium silicate debris only (i.e., no additional fibers other than those integral to the microporous or calcium silicate debris). This guidance recommends the same three alternatives noted above for situations in which a debris bed can be accumulated with these insulations without significant other fiber.

The baseline guidance addresses mixtures of granular insulation and RMI debris beds by referring to the superposition guidance presented in GR Section 3.7.2.3.1.3.

Staff Evaluation of GR Section 3.7.2.3.1.6: The staff concludes the following regarding the guidance presented in this section:

1. The baseline guidance is adequate for particulate-to-fiber mass ratios less than 0.2.
2. The alternatives for particulate-to-fiber mass ratios greater than 0.2 are adequate with the caveat relative to option 2, above, that the adequacy of the alternate correlation should be verified using applicable test data.
3. Because a debris bed formed of microporous debris without additional fibrous debris would be similar to a fibrous/microporous debris bed with a high particulate-to-fiber mass ratio, the adequacy of the options is the same as for a debris bed with fibers and a particulate-to-fiber mass ratio greater than 0.2.
4. The acceptance of the baseline guidance for thin beds containing microporous insulation types is also subject to the acceptance of the three options defined above.
5. The superposition guidance for mixtures of granular insulation and RMI debris is acceptable.

3.7.2.3.2 Methodology Application Considerations

3.7.2.3.2.1 Total Sump-Screen Head Loss

Section 3.7.2.3.2.1 of the GR recommends adding the clean-strainer head loss to the debris-bed head loss to get the total head loss across the screen.

Staff Evaluation of GR Section 3.7.2.3.2.1: The staff concludes that this guidance is acceptable because it is consistent with general engineering practice. RG 1.82, Revision 3, recommends a different approach, which is based on NPSH margin. Either approach is acceptable.

3.7.2.3.2.2 Evaluation of Breaks with Different Combinations of Debris

Section 3.7.2.3.2.2 of the GR recommends that analysts evaluate a spectrum of breaks with different combinations of debris types to ensure the identification of the break with the mixture of debris on the screen that causes the highest head loss. The guidance notes that the limiting break is not necessarily the break that generates the largest total quantity of debris.

Staff Evaluation of GR Section 3.7.2.3.2.2: The staff concludes this guidance is acceptable because the break size recommended in the GR gives conservatively higher head loss across the debris bed on the sump screen.

3.7.2.3.2.3 Thin Fibrous Beds

GR Section 3.7.2.3.2.3 recommends that the head loss associated with a thin-bed be calculated as a sensitivity analysis. To analyze a thin fiber bed, a fiber quantity sufficient to form a 1/8-in. thick debris bed should be determined to be available and, if present, could be deposited on the sump screen. The head loss calculations are the same as described for fiber and particulate beds using the full value of particulate matter transported to the sump screen. The particulate matter includes the latent debris such as dirt, concrete dust, rust, inorganic zinc, epoxy fines, etc. The particulate layer is characterized by a high sludge-to-fiber ratio; hence a limiting value for the compression is used. If under these conditions, the thin-bed head loss should exceed the NPSH margin, then the allowable particulate loading can be evaluated by reducing the particulate quantity until the calculated head loss is within the NPSH margin.

Staff Evaluation of GR Section 3.7.2.3.2.3: The staff agrees that the potential for developing a thin-bed head loss must be evaluated, regardless of the composition of the potential containment debris. Appendix VIII to this SE provides detailed staff guidance on evaluation of thin bed effects. The following is a summary:

1. The appropriate density to apply to the fibrous debris in the determination of the quantity of debris needed to form a 1/8-in. bed is the as-manufactured density. The 1/8-inch minimum thickness has been based on the NUREG/CR-6224 (Appendix B, page B-60) finding, “The head loss model is applicable only to fiber bed thicknesses where uniform bed formation is expected. Typically, this is valid for fiber bed thicknesses larger than 0.125" (0.318 cm). Below this value, it appears the bed does not have the required structure to bridge the strainer holes and filter the sludge particles.” The NUREG/CR-6224 analysis used the as-manufactured density to specify the “theoretical bed thickness,” which is used to specify whether or not a 1/8-in. thick bed exists. For NUKON™ debris, the accepted as-manufactured density has been 2.4 lb/ft^3. For latent debris, the as-manufactured density is not applicable because latent fibers can come from any number of sources. However, after examining the latent fibers collected from volunteer plants Appendix VII conservatively recommended a density of 2.4 lb/ft^3, which is equal to that of NUKON™.
2. For a thin-bed debris accumulation, the limiting bed compression specified as either the limiting porosity or limiting solidity becomes a controlling parameter in the NUREG/CR-6224 correlation (i.e., the bed solidity essentially approaches that of the granular materials). It is important that the limiting solidity be correctly evaluated for the particular particulate or mixture of particulates in the debris bed. For example, the limiting solidity for BWR iron oxide corrosion products is about 0.2 (NUREG/CR-6224), but for common sand, it varies between 0.57 to 0.60 (standard handbook data). Section 3.7.2.3.1.1 of the GR discusses this issue.
3. Because a number of uncertainties are associated with specifying the 1/8-in. bed thickness criteria, the parameter values that go into the bed thickness determination need to be sufficiently conservative to compensate for uncertainties to ensure adequate NPSH margin. One consideration is the fineness of the fibrous debris accumulating on the screen. Tests have been conducted since the NUREG/CR-6224 study was completed where thin-beds have been formed that were somewhat thinner than one-eighth-inch (e.g., 1/10-in.), principally because the bed was formed from suspended individual fibers rather than from the shredded fiber debris used in the NUREG/CR-6224 testing. Another consideration is the fact that the 1/8in. criteria was based on NUKON™ debris and has not been actually determined for other types of fibrous debris. Another consideration is the indication that calcium silicate can

form a debris bed without supporting fibers (other than the fibers integrated into the calcium silicate).

4. In determining the mass of allowable particulate on the sump screen that is needed to overcome the NPSH margin, the uncertainties associated with predicting this value should be noted. Specifically, the determination of the limiting solidity has a significant uncertainty as a result of inaccurate specifications of the densities of the particulate components or perhaps the mixing of constituents, as well as the involvement of fibers interlaced with the particulate.
5. To compensate for these noted uncertainties, sufficient conservatism should be used in estimating the quantities of fibrous debris available to form a thin bed. This point is particularly important for plants that do not have significant fibrous insulation (e.g., an all-RMI plant), so that the main contribution to the fiber quantities on the sump screen comes from latent debris. In such cases, the estimate of the latent fiber becomes a determining factor, but substantial uncertainty is also associated with that estimate.

3.7.2.3.2.4 Sump-Screen Submergence

Section 3.7.2.3.2.4 of the GR describes the applicable characterization for partially versus completely submerged sump screens. The limiting criterion for submerged screens occurs when the combined clean-sump and debris-bed head loss exceeds the NPSH margin. The limiting criterion for a partially submerged screen is when the debris -bed accumulation on the screen reduces the flow to less than the flow requirements for the sump. An effective head loss across the debris, which is approximately equal to one-half of the pool height, is sufficient to prevent adequate water flow. The head-loss estimate is applied to the submerged portion of the sump-screen area.

Staff Evaluation of GR Section 3.7.2.3.2.4: The staff concludes that the baseline guidance in this section regarding partially and completely submerged sump screens is acceptable because it is consistent with RG 1.82, Revision 3.

3.7.2.3.2.5 Buoyant Debris

Section 3.7.2.3.2.5 addresses the conditions in which buoyant debris could become a problem for strainer head loss. For fully submerged screens, buoyant debris is not considered a problem because it would not reach the sump screens. For partially submerged screens in which buoyant debris is determined to reach the screen, the baseline guidance recommends that the effective area be reduced by the thickness of the buoyant debris layer times the length of the covered perimeter, to the extent that it fully envelops the screen.

Staff Evaluation of GR Section 3.7.2.3.2.5: The staff agrees with the necessity of considering the potential for buoyant debris affecting sump-screen head loss. The baseline guidance is acceptable with the exception that shallow, fully submerged sump screens could still draw buoyant debris down to the submerged screen. An analysis should be performed to determine the submerged depth needed to ensure buoyant debris cannot be drawn down onto the sump screen.

3.7.2.3.3 Methodology Limitations and Other Considerations

3.7.2.3.3.1 Flat Screen Assumption

Section 3.7.2.3.3.1 of the GR states that head-loss data obtained using a vertical pipe test section of a closed-loop test apparatus with a horizontally mounted flat screen yielded conservative data for the development of the NUREG/CR-6224 correlation because all debris was forced onto a very small screen. Further, it states that in the alternative design screens, the direct application of the NUREG/CR-6224 correlation may yield overly conservative results, and that for these alternate geometry screens, independent head-loss correlations should be developed based on actual design configurations, debris loads, and test data to reduce conservatism.

Staff Evaluation of GR Section 3.7.2.3.3.1: The staff finds that the guidance in this section needs the following clarification. The development and application of the NUREG/CR-6224 correlation is based on uniform and homogeneous debris beds. Applicable test data must therefore be measured on test debris beds that match these correlation assumptions. The vertical pipe, closed-loop test apparatus generally meets these conditions, provided the debris is introduced in such a manner that it settled uniformly on the test screen. The baseline statement that “all debris was forced onto a very small screen” does not reflect testing realities. The debris is allowed to settle uniformly but the important point is that the correlation is based on the bed thickness and composition as tested.

A uniform debris bed is a realistic and a likely form of debris accumulation when debris accumulation is accomplished by filtering out suspended fibers. For example, during the conduct of the integrated tank tests (NUREG/CR-6773), the typical accumulation of fibrous debris was primarily a result of suspended debris transport and led to a uniform debris buildup on both horizontally and vertically oriented screens. In addition, the operational incidents at Perry (NUREG/CR-6808) where a coating of fine dirt covered most of the surface of the strainers and at Limerick, where a thin mat of material covered the strainer, must be considered. The flat screen assumption is reality based and is not merely a conservative assumption. It is also not overly conservative.

While it is adequate to develop independent head-loss correlations based on actual design configurations, debris loads, and test data for alternative screen designs, it should also be noted that the NUREG/CR-6224 correlation has been successfully applied to these designs without over conservatism. The application of the NUREG/CR-6224 correlation involves the selection of the appropriate screen area versus debris loading (i.e., total screen area, circumscribed area, or some area in between based on test data), as will any other successful correlation that models an alternate design from a clean screen to its fully loaded condition. The NUREG/CR-6224 correlation has been and can be applied to prototype alternate geometry screens/strainers to determine effective screen areas for specific debris loadings that can be subsequently used in plant specific evaluations.

3.7.2.3.3.2 Non-uniform Deposition on Sump-Screen Surfaces

Section 3.7.2.3.3.2 of the GR discusses the conservatism of the assumption that the debris is uniformly distributed on the screen relative to potential nonconservative accumulation associated with vertical and inclined screens.

Staff Evaluation of GR Section 3.7.2.3.3.2: The staff agrees that it is conservative to assume uniform debris accumulation on all types and orientations of screens.

3.7.2.3.3.3 Very Thin Fiber Beds

GR Section 3.7.2.3.3.2 discusses instances in which the fiber loading is less than that required to form a thin bed. It states that experiments have shown that very thin fibrous beds (with a thickness of less than 1/8-in.) are characterized by large scale, non-uniformities on the screen and negligible head losses. The baseline guidance recommends assuming a negligible head loss whenever the debris bed thickness is less 1/8-in.

Staff Evaluation of GR Section 3.7.2.3.3.3: The staff concludes that it is appropriate to neglect the head loss associated with low-density fiberglass insulation debris beds of less than 1/8-in. provided the concerns expressed in the staff's response to Section 3.7.2.3.2.3 regarding the determination of the thin-bed thickness are adequately addressed. These concerns included using the appropriate density to determine the thickness for a given quantity of debris and the uncertainties associated with the original specification of 1/8-in. as the threshold thickness. The uncertainties include the relative fineness of the insulation debris used to make the threshold thickness determination and the fact that the thickness determination was made only for NUKON™ debris and has not been directly determined for other types of insulation debris. An example in which it is not appropriate to neglect the head loss for a debris bed less than 1/8-in. thick is when there is substantial calcium silicate debris in the bed. There have been experimental indications that calcium silicate can form a debris bed without supporting fibers.

3.7.2.3.4 Sample Calculations

Section 3.7.2.3.4 of the GR provides sample head-loss calculations. The sample calculations assume flat-plate strainer geometry, steady-state ECCS flow conditions, and the final debris loadings. The debris sources were developed in the sample problem sections for debris generation (GR Section 3.4.3), latent debris (GR Section 3.5.3), and debris transport (GR Section 3.4). Sample head-loss calculations were presented for a fiber/particulate debris bed, an RMI-debris bed, a mixed RMI, fiber/particulate debris-bed, and a thin-bed debris condition.

Staff Evaluation of GR Section 3.7.2.3.4: The sample problems are consistent with the baseline methodology discussed above and with the specified head-loss calculational assumptions, with the exception that the sample problem used a fiber density of 175 lbs/ft^3 rather than the 159 lbs/ft^3 density recommended in GR Table 3-2. However, the sample problems fail to clarify the differing volumes and densities associated with each constituent. For example, in the fiber/particulate calculation, two volumes are provided for NUKON™ fibers without distinguishing the type of volume quoted (1) 129 ft^3 for the bulk volume, and (2) 1.77 ft^3 for the material (solid) volume. The reader must take care to use the proper volumes and densities in the appropriate calculational steps.

In Section 3.7.2.3.1.1, the GR discusses maximum solidity for particulates as a material-dependent property. However, this section leaves the reader with the impression that 20 percent is a reasonable limiting value for general use. The staff comments on this section pointed out that many particulates have maximum solidities much higher than 20 percent, (e.g., common sand has an approximate solidity of 60 percent). Therefore, the general use of 20 percent is not appropriate. Rather, the maximum solidity should be determined for each particulate constituent, and then the particulate constituent effective average must be determined. It should also be noted that the maximum solidity also depends upon the particulate-size distribution. The sample head-loss calculations, specifically the thin-bed calculation in which the limit is applied, failed to treat material-specific maximum solidities. The failure to correctly treat the maximum solidities can lead to erroneous and nonconservative head-loss predictions for pack-limited debris beds.

3.8 ACCEPTANCE OF NEI BASELINE GUIDANCE

The purpose of the baseline evaluation methodology is to provide PWR licensees in the United States with a common and consistent approach for evaluating the susceptibility of containment sumps to blockage resulting from the effects of postulated LOCA events. The baseline evaluation methodology is the application of a conservative set of methods that help identify the dominant design factors for a given plant (GR Section 3) that could be subsequently followed by separate guidance on possible analytical refinements to the baseline approach (GR Section 4) and potential design/operational refinements (GR Section 5).

The baseline, however, goes beyond the scoping intent with the statement that, “If a plant uses this method and guidance to determine that sufficient head-loss margin exists for proper long-term Emergency Core Cooling (ECC) and Containment Spray (CS) function, no additional evaluation for head loss is required.” Rather, the baseline methodology becomes an acceptance methodology for plant-specific evaluations. Therefore, the NRC staff’s acceptance of the baseline evaluation methodology is based on whether or not any and all PWRs that determine an adequate head-loss margin by applying the baseline evaluation methodology will actually have adequate sump performance capabilities to support long-term cooling functions.

The NRC staff’s acceptance depends upon providing adequate assurance that the baseline assumptions taken as a whole and applied generically to any PWR will not result in a plant operating without adequate ECC or CS head-loss margin. In addition, the staff’s acceptance considers how follow up analytical refinements will affect the baseline methodology retained in the final evaluation. Specifically, the acceptance of the baseline evaluation methodology as a package must balance conservative assumptions against nonconservative assumptions; therefore, an analytical refinement that decreases the degree of conservatism on a particular assumption has the potential to alter the package balance such that the degree of conservatism is reduced or even reversed to nonconservatism.

The primary difficulties with assessing whether the assumptions used in the baseline guidance result in the baseline guidance as a package being conservative with respect to estimating NPSH margin is that each assumption is variable with respect to the plant evaluated. In addition, the conservatism for each assumption cannot be quantified without actually performing a detailed evaluation. Without quantification for at least the more influential assumptions, it is difficult to judge the baseline package conservatism. For example, assuming that all unqualified coatings fail into 10 μ particles could be overly conservative for containments with large quantities of unqualified coatings. However, for plants with little unqualified coatings this assumption does not provide any extra conservatism to counter the non-conservative assumptions in the baseline guidance. Table 3-6 summarizes the more influential assumptions with potential notable conservatism. Table 3-7 summarizes the more influential assumptions that are clearly not conservative.

Table 3-6. Conservative Assumptions in the Baseline Evaluation Methodology

No.	Baseline Guidance Assumption	Rationale for Assumption	Perceived Level of Conservatism
Debris Generation Assumptions			
1	All unqualified coatings in containment are assumed to fail.	Compensate for lack of data (i.e., no basis for estimating failure of unqualified coatings).	Variable depending upon plant conditions; therefore, the associated conservatism to the baseline package could range from essentially none to excessive.
2	All coatings debris (qualified and unqualified) assumed to become 10μ particulate. The implication of the small particulate size is complete transport to sump screen and complete filtration.	Compensate for lack of data (i.e., no basis for estimating coatings debris-size distributions).	Variable depending upon plant conditions; therefore, the associated conservatism to the baseline package could range from minimal to excessive.
3	100% destruction of materials for which suitable debris generation data are not available, including all such materials inside the ZOI and unprotected materials outside the ZOI.	Compensate for lack of data (i.e., the fraction of the materials that become small fines debris cannot be ascertained without material-specific debris generation data).	Variable, depending upon the types and quantities of such materials. Additionally, it depends upon the relative quantities of such materials compared to dominant insulation with known destruction characteristics. The associated conservatism to the baseline package could range from a minor correction to substantial.

No.	Baseline Guidance Assumption	Rationale for Assumption	Perceived Level of Conservatism
Debris Transport Assumptions			
4	Washdown transport to the sump pool is 100% for fibrous debris, and a large fraction of the blowdown-transported debris is directed to the sump with the end result that all small fibrous debris fines are transported to the sump pool.	Avoidance of complex analyses.	Variable, depending upon containment design. Some containment designs could result in high-washdown transport, (e.g., the volunteer plant study (see Appendix VI to this SE), while others may retain debris in the upper levels of the containment.
5	100% of small fines within the ZOI not allocated to an inactive pool are transported to the sump screens.	Avoidance of complex analyses.	Variable, depending upon the transport characteristics of the pool. Given a fast-flowing pool, the transport could be high; therefore, this assumption would not necessarily be conservative. But for a slow pool, a substantial portion of the small fines debris could sink to the floor and not be transported to the screen (i.e., substantial conservatism with this assumption).
6	All debris generated outside ZOI assumed to be transported to sump screen.	Avoidance of complex analyses and compensation for lack of data.	Variable, depending upon the types and quantities of such materials. The associated conservatism to the baseline package could range from a minor correction to substantial.

Table 3-7. Non-conservative Assumptions in the Baseline Evaluation Methodology

No.	Baseline Guidance Assumption	Rationale for Assumption	Perceived Level of Non-conservatism
Debris Generation Assumptions			
7	The adaptation of the BWROG URG destruction pressures to PWR LOCA jets.	Lack of BWR- or PWR-specific data. Similar application suggests that the BWR data are appropriate for PWRs.	Because an LWR LOCA jet is a two-phase steam/water jet and the destruction pressures cited in the URG were determined using an air jet and because limited experimental evidence exists from the OPG two-phase jets, the BWROG destruction pressures could be too high. The baseline methodology could underestimate debris quantities. Therefore, based on the study of this issue and testing, the staff position is to lower the debris destruction pressure by 40% in order to account for two-phase jet effects (see Section 3.4.2.2).
8	A spherical ZOI is truncated whenever the ZOI intersects a robust structure. The radius of the remaining ZOI is not increased to compensate for jet-reflection effects.	Assumption that jet reflections off the robust structure would not extend further than the unrestrained sphere. This approach was used for resolving the BWR strainer issue.	Jet reflections off the robust structures would reinforce other components of the LOCA jet. A major portion of the energy of the jet may be preserved.
9	The destruction pressures for coatings within the ZOI were based on high-pressure water-jet data rather than two-phase jets typical of a PWR LOCA.	Lack of applicable data.	The water jet data may not properly address thermal shock effects that spalled concrete in the HDR tests (NUREG-0897, page C-2 and Figure C-5). The ZOI coatings debris quantities may be underestimated. Therefore, the staff position is that either

No.	Baseline Guidance Assumption	Rationale for Assumption	Perceived Level of Non-conservatism
			destruction pressures and spherical ZOI sizing for coatings be determined on a plant-specific basis (based on experimental data as described in Sections 3.4.2 and 3.4.3), or a spherical ZOI of 10D be used.
10	Default worst-case paint thickness of 3 mils for unqualified coatings outside ZOI.	Default alternative when plant-specific coating thickness data are not available.	Not worst-case and the assumption was not properly justified. Therefore, the staff recommends plant-specific justification of this thickness, or plant-specific evaluations to determine unqualified coating properties and thicknesses, as described in Section 3.4.3.
	Debris Transport Assumptions		
11	Debris transport into inactive pools based on the ratio of the inactive pool water volume to the total water volume in the sump pool. Implies a uniform distribution of debris throughout the water pools formed following the LOCA.	Assumptions of uniformly distributed (as opposed to preferential) sweeping of debris on the containment floor into inactive pools by thin sheets of high-velocity water, and of 100% transport of small fines to the sump during recirculation.	Baseline assumption that debris entrapment in inactive pools (e.g., reactor cavity) based on ratio of water volumes is not realistic. Debris will not be uniformly distributed in the sump water and washdown transported debris likely to arrive in sump after inactive pools filled. Potentially large nonconservatism that depends upon inactive pool volume relative to total water volume. In addition, the same sheeting-flow mechanism credited by the GR has the nonconservative result of sweeping debris preferentially to the screens.

No.	Baseline Guidance Assumption	Rationale for Assumption	Perceived Level of Non-conservatism
			Therefore, the staff position is that licensees limit the ratio of debris transported to the inactive pools to 15%, unless a higher fraction is adequately supported by analyses or experimental data (see Section 8).
12	Large piece debris (> 4 in.) is assumed not to be transported in sump pool; hence, large piece debris accumulation on sump screen completely neglected.	Avoidance of complex analyses.	The impact of neglecting all large debris on the baseline conservatism depends upon pool transport characteristics and sump-screen geometry. Little impact for a slowly flowing pool, for which detailed analyses would predict little large-debris transport, but potentially a large impact for a fast-flowing pool, for which substantial large debris could accumulate on the screen, or for geometries such as sump screens protected by gratings at floor level.
		Head-Loss Assumptions	
13	The baseline recommends using simple geometric formulas to use characteristic diameters for fibers and particles to determine specific surface areas needed for the NUREG/CR-6224 head loss correlation.	Lack of experimentally determined specific surface areas.	Confirmatory research has demonstrated that this approach is not reliable in that it has the potential to result in large underestimates of debris bed head loss. Therefore, the staff provides additional guidance in Appendix V to this SE to deduce the specific surface areas from applicable head-loss data through the application of the correlation.

The baseline methodology assumptions were apparently made for a variety of reasons. Worst-case conditions were assumed in certain situations for which there is nearly a complete lack of data required to support a more realistic evaluation. These assumptions primarily include the generation of debris, such as the treatment of unqualified coatings, where all unqualified coatings are assumed to fail and then form fine particulate debris that would readily be transported and accumulate in a fibrous bed of debris. In reality, much, if not most, of this coatings debris would either remain attached to the surfaces or would form chip debris that may not be transported so readily. In addition to the unqualified coatings, other materials, both within and outside the ZOI, were assumed to fail into 100-percent small fines debris. The difficulty with judging the impact of these assumptions is that a particular containment may not have much of these materials; therefore the relative conservatism associated with these types of assumptions cannot be quantified for PWR containments in general.

Other baseline assumptions were made so that complex debris transport analyses could be avoided. The baseline methodology does not recommend debris-transport methods, but does credit debris entrapment in inactive pools. In addition, the methodology does not consider washdown transport of RMI debris and does not consider the transport of large pieces of debris. Again, the conservatism and nonconservatism of these assumptions cannot be judged for PWR containments in general, but only by plant-specific analyses. Assuming all fine fibrous and particulate debris washes back down to the sump pool is conservative for all plants. However, neglecting the transport of large piece debris is not conservative for all plants. Judging whether or not a conservative assumption can compensate for a nonconservative assumption requires the consideration of plant-specific features. The assumption that debris entrapment within inactive pools could be made on a simple water volume ratio is not realistic because it does not consider the timing of debris washdown relative to the fill up of the inactive pools, which would occur early in the sequence. The volunteer plant study estimated that a majority of the small fines debris was blown upwards in the containment where it subsequently would be subject to washdown processes. That study estimated a majority portion of the small fines debris returning to the sump pool, but the analytical capabilities cannot determine the timing of the debris entrance into the pool. If the inactive pools filled before the small fines debris washed back to the sump, then only relatively minor quantities might become trapped. Therefore, the inactive pool entrapment assumption is probably non-conservative.

As an illustration of the variability of these assumptions when applied to the fleet of PWR plants, consider the following hypothetical situations. Assume that the application of the baseline guidance to both Plants A and B results in the prediction of adequate NPSH margin. Table 3-8 summarized the importance of the key assumptions. The containment of Plant A is characterized as having relatively large quantities of debris with unknown debris-generation characteristics and debris-transport characteristics, and the containment has debris-transport characteristics that tend to entrap debris, thereby preventing transport to the sump screens. The variability of the baseline assumptions would tend to over predict debris generation and over predict debris transport by substantial amounts. Therefore, if Plant A has sufficient NPSH margin evaluated using the baseline guidance, Plant A should then have an adequate NPSH margin with reasonable certainty. Plant B, however, would be characterized as having limited quantities of debris, other than the ZOI insulation, with reasonably well-known destruction properties. Realistic debris transport fractions to the sump screen would be relatively high. Substantial larger debris transport would be expected with relatively minor quantities trapped in inactive pools. With hypothetical Plant B, there is a concern that the baseline evaluation could predict an adequate NPSH margin, whereas an adequate margin may not actually exist if the collective uncertainties line up in a nonconservative manner.

Table 3-8. Baseline Guidance Application to Divergent Hypothetical Plants A and B

Assumption	Hypothetical Plant A	Hypothetical Plant B
Unqualified coatings (#1 and #2)	Large quantities of unqualified coatings.	Little, if any, unqualified coatings.
100% destruction of ZOI materials with unknown destruction pressures and unprotected materials outside ZOI (#3) and complete transport of the outside ZOI material (#6)	Large quantities of such materials.	Small quantities of such materials.
100% washdown transport for fibrous and particulate small fines debris (#4)	Containment design would likely retain substantial debris at the upper levels	Most debris would likely wash down to the sump pool.
100% pool transport for small fines debris not entrapped in inactive pools (#5)	Relatively slow sump-pool flow velocities result in significant small fines debris entrapment on sump pool floor.	Relatively fast sump-pool flow velocities result in little small fines debris entrapment on sump pool floor.
Debris entrapment in inactive pools (#11)	Inactive pool volumes are relatively small; therefore, debris entrapment in the inactive pools becomes minor consideration.	Inactive pool volumes are relatively large; therefore, debris entrapment in the inactive pools becomes substantial consideration.
Neglect large piece debris (#12)	Relatively slow sump-pool flow velocities result in little actual large piece debris transport.	Relatively fast sump-pool flow velocities result in substantial actual large piece debris transport.

It cannot be conclusively demonstrated that the application of the baseline evaluation methodology can be relied upon to prove that a PWR predicting an adequate NPSH margin will truly have an adequate NSPH margin. However, a reasonable assessment of the methodology is that sufficient overall realistic conservatism exists in the baseline to accept its application with the use of acceptance qualifications or alternative guidance for specific outlier situations, such as the one described below.

For example, consider a hypothetical plant that has extensive unqualified coatings, but insufficient fibrous debris to form a fibrous-debris thin-bed capable of filtering particles.

Under the baseline methodology, all the coating debris would be in the form of 10-μ particles, which would be assumed to simply pass through the screens, thereby not causing a significant head loss. But in a potential LOCA, the coating debris could fail in large quantities and possibly transport as chips that could accumulate on the screen without the aid of fibrous debris, thus resulting in significant head loss.

This example raises two major concerns. First, the baseline guidance excludes transport and blockage of large piece debris. The staff position is that the sump-screen blockage evaluation should address whether outlier scenarios, such as these, exist and evaluate any that are identified. If a plant's sump-pool flow is relatively fast, then neglecting large piece debris could lead to substantially underestimated debris effects. Second, for debris characterization, a caution is needed regarding the determination of whether or not there is sufficient fiber to form a thin bed. If this determination is a close call, then all aspects of that determination become critical. Licensees will need to examine inputs to ensure that each of these aspects is realistic, with appropriate conservatism added before reaching the final conclusion that there is not sufficient fibrous material in containment to form a thin-bed debris accumulation.

The results of supporting confirmatory research and information available in the knowledge base (NUREG/CR-6808) cause concern in several aspects of the baseline guidance acceptability. These concerns include the following:

- Concerns regarding two-phase jet effects, relative to data collected from air jet testing, indicate a potential need to reduce the NEI-recommended destruction pressures (which are based on air-jet testing), unless over-conservatism can be demonstrated in the analytical estimates for debris quantities.
- The baseline evaluation recommendation of truncating a ZOI whenever it intersects a robust structure, without resizing the remaining ZOI to maintain jet volumes, is not conservative. Jet reflections from the robust structure may affect the remaining ZOI.
- The default coating thickness recommended by the baseline evaluation guidance is not the worst-case thickness. Only plant-specific coating thickness evaluations can adequately assess not only the coating debris volumes, but also the appropriate parameters for the head-loss correlation (e.g., the particle densities).
- Because conservative estimates for the debris-specific surface areas used in the NUREG/CR-6224 head-loss correlation are critical to ensuring conservative estimates for the NPSH margins, the staff is concerned that the baseline evaluation methodology recommendations for estimating the areas using only the characteristic diameters will lead to nonconservative head-loss predictions. Confirmatory research recommendations should be addressed.
- The baseline methodology neglects potential erosion of large piece debris by water flows by assuming all large piece debris remains in protective coverings, which debris-generation data clearly show is not realistic. Even though such erosion is not expected to result in large quantities of additional fine debris, it should still be considered in the baseline evaluation, if large portions of the large piece debris are physically located directly below large flows of falling water.

In summary, the baseline evaluation, coupled with the methodology enhancements provided in this SE is acceptable. The baseline evaluation methodology by itself cannot be given a blanket acceptance because (1) the baseline guidance recommends nonconservative assumptions, (2) it is not possible to quantify the degree of conservatism or nonconservatism of each important assumption without performing detailed analyses for comparison, especially considering the diversity in the containment and RCS designs, and (3) confirmatory research has resulted in concerns associated with key aspects of the guidance. Therefore, the baseline evaluation methodology, as modified in accordance with staff positions established in the preceding sections, is acceptable. If the baseline evaluation is based on planned design/operational changes, as opposed to current plant configuration, then acceptance of the evaluation is also based on the implementation of these planned changes. The baseline evaluation guidance does not resolve concerns which are not explicitly addressed by the baseline (e.g., chemical effects and downstream effects).

Subsequent analytical refinements to the baseline evaluation must reconsider the nonconservative assumptions of the baseline evaluation, rather than merely reducing identified over-conservatisms. Supplemental NEI analytical refinements include recommendations for reducing the sump-pool transport fractions by means of evaluating pool-flow velocities and comparing those velocities with test data for threshold velocities for moving debris along the pool floor. If such analyses are performed on small piece debris, then those analyses need to also treat large piece debris transport.

The sample problem developed in the baseline evaluation methodology may serve to illustrate the evaluation process, but is not detailed enough to serve as a template for plant evaluations.

4.0 ANALYTICAL REFINEMENTS

The GR provides some acceptable analytical refinements, and some sections contain additional information to support the development of refinements. For clarity, NEI has presented the following table (Table 4-1) that lists the refinements offered in Sections 4 and 5 of the GR.

For the purpose of this review, the staff provides its position on each of those analytical refinements recognized in this section of the GR for use by the industry. A licensee should present to the staff for approval any analytical refinements in its plant-specific analysis of sump performance which is not addressed by the staff in this section of the SE.

4.1 INTRODUCTION

Section 4.1 defines four main analytical topics for which the GR offers analytical refinements to the baseline evaluation, including (1) break selection, (2) debris generation, (3) debris transport, and (4) head loss.

4.2 METHOD DESCRIPTION

Section 4.2 identifies three main analytical topics for which the GR offers refinements to the baseline evaluation, including (1) debris generation, (2) debris transport, and (3) head loss. Discussions of the other two topics (i.e., break selection and latent debris) are included for completeness.

4.2.1 Break Selection

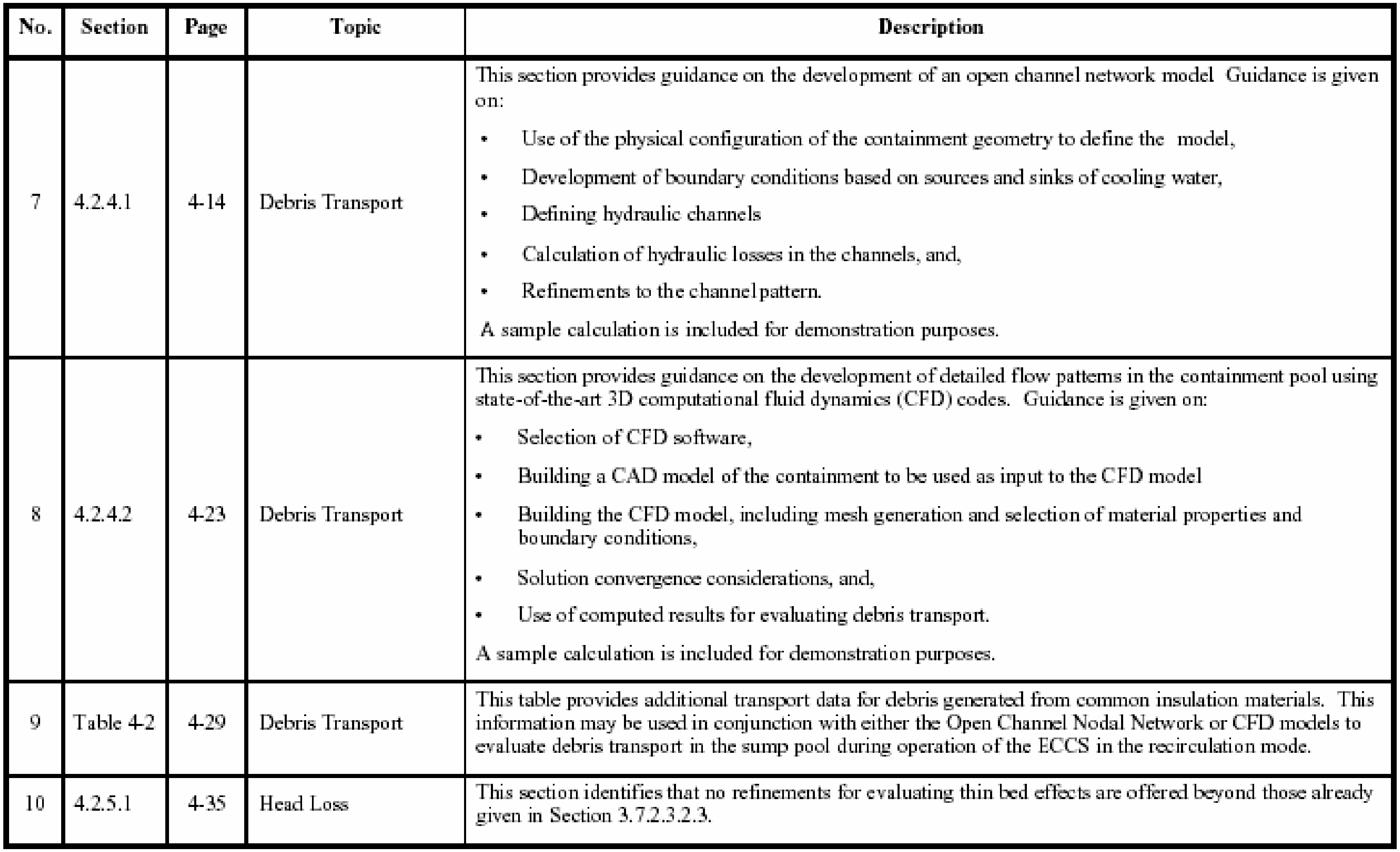
Section 4.2.1 of the GR discusses an analytical refinement involving pipe break locations to be considered when performing PWR-sump analyses. The proposed guidance suggests application of NRC GL 87-11, “Relaxation in Arbitrary Intermediate Pipe Rupture Requirements,” (GL-87-11) to preclude arbitrary, intermediate pipe break locations from consideration in PWR sump analyses. The refinement suggests consideration of only those break locations which are consistent with BTP MEB 3-1, “Postulated Rupture Locations in Fluid System Piping Inside and Outside Containment,” and SRP Section 3.6.2, “Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping.” Application of BTP MEB 3-1 for PWR sump analyses is intended to focus attention on high-stress and fatigue break locations, such as at the terminal ends of a piping system and intermediate pipe ruptures at locations of high stress.

Staff Evaluation of GR Section 4.2.1: The staff’s evaluation of this section considered the proposed GR guidance in conjunction with existing, corresponding guidance on this subject. The staff’s review considered the requirements of 10 CFR 50.46, the staff’s evaluation and conclusions for a similar proposal from the BWROG (URG SE), the guidance provided in RG 1.82, Revision 3 and the Commission’s staff requirements memorandum (SRM) regarding a proposed rulemaking to risk-inform requirements related to LBLOCAs (SECY-04-0037).

Table 4-1 Pressurized-Water Reactor Sump Performance Evaluation Methodology Refinements Table

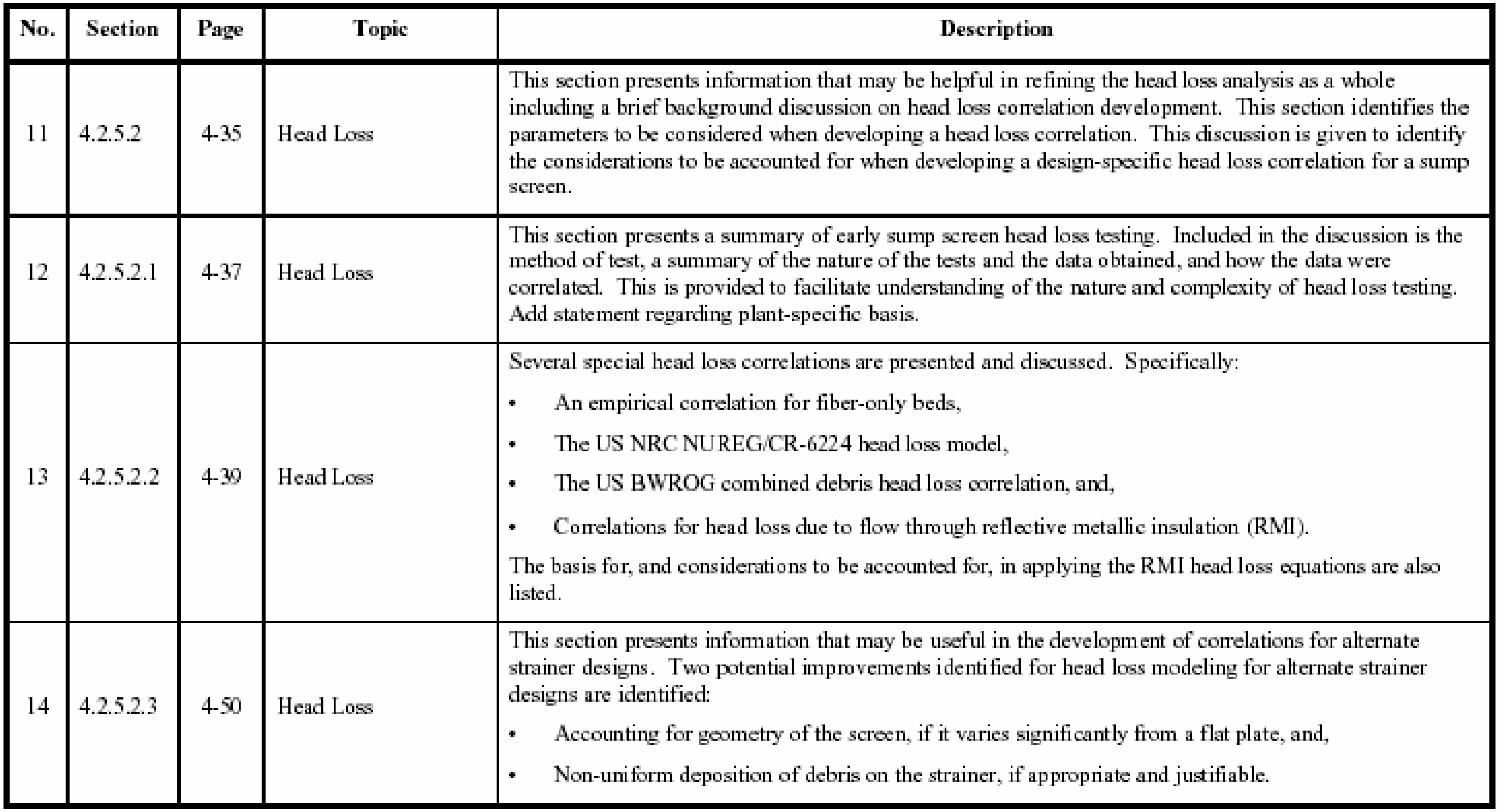
No.	Section	Page	Topic	Description
1	4.2.1	4-1	Break Selection	This section identifies that plants may use Generic Letter 87-11, "Relaxation in Arbitrary Intermediate Pipe Rupture Requirements," consistent with their licensing basis, to select break locations for evaluating post-accident sump operability.
2	4.2.2.1	4-2	Debris Generation	This section identifies that plants may refine the Zone of Influence (ZOI) definition from a single all-encompassing region based on the material with the minimum destruction pressure by assigning multiple ZOIs to each break site. Each ZOI would correspond to the destruction pressure of one insulation species located near the break site.
3	4.2.2.1	4-3	Debris Generation	This section identifies that plants may refine the Zone of Influence (ZOI) definition by modeling two freely-expanding jets, each originating at one end of a postulated DEGB. The ZOI for a specific material would be evaluated as the region enclosed within the calculated isobar corresponding to a given destruction pressure of an insulation species located within the jet.
4	4.2.2.2	4-5	Debris Characteristics	This section provides additional refinements with respect to the characteristics of debris that might be generated from a postulated break. Specifically, the use of plant-specific or publicly available vendor-specific information, where applicable, is identified as source for refining debris sizes considered in the transport and blockage evaluation.
5	4.2.3	4-14	Latent Debris	This section identifies that plant-specific conditions (for example, cleanliness programs) may be used to support improvements to the latent debris source term.
6	4.2.4	4-14	Debris Transport	This section identifies two refinements to evaluate debris transport. • The first refinement is the use of an open channel nodal network to evaluate bulk fluid movement about the containment. • The second refinement is the use of a Computational Fluid Dynamics (CFD) model to calculate a detailed flow field within the containment sump and assess debris transport.

Table 4-1 Pressurized-Water Reactor Sump Performance Evaluation Methodology Refinements Table (Continued)



No.	Section	Page	Topic	Description
7	4.2.4.1	4-14	Debris Transport	This section provides guidance on the development of an open channel network model Guidance is given on: • Use of the physical configuration of the containment geometry to define the model, • Development of boundary conditions based on sources and sinks of cooling water, • Defining hydraulic channels • Calculation of hydraulic losses in the channels, and, • Refinements to the channel pattern. A sample calculation is included for demonstration purposes.
8	4.2.4.2	4-23	Debris Transport	This section provides guidance on the development of detailed flow patterns in the containment pool using state-of-the-art 3D computational fluid dynamics (CFD) codes. Guidance is given on: • Selection of CFD software, • Building a CAD model of the containment to be used as input to the CFD model • Building the CFD model, including mesh generation and selection of material properties and boundary conditions, • Solution convergence considerations, and, • Use of computed results for evaluating debris transport. A sample calculation is included for demonstration purposes.
9	Table 4-2	4-29	Debris Transport	This table provides additional transport data for debris generated from common insulation materials. This information may be used in conjunction with either the Open Channel Nodal Network or CFD models to evaluate debris transport in the sump pool during operation of the ECCS in the recirculation mode.
10	4.2.5.1	4-35	Head Loss	This section identifies that no refinements for evaluating thin bed effects are offered beyond those already given in Section 3.7.2.3.2.3.

Table 4-1 Pressurized-Water Reactor Sump Performance Evaluation Methodology Refinements Table (Continued)



No.	Section	Page	Topic	Description
11	4.2.5.2	4-35	Head Loss	This section presents information that may be helpful in refining the head loss analysis as a whole including a brief background discussion on head loss correlation development. This section identifies the parameters to be considered when developing a head loss correlation. This discussion is given to identify the considerations to be accounted for when developing a design-specific head loss correlation for a sump screen.
12	4.2.5.2.1	4-37	Head Loss	This section presents a summary of early sump screen head loss testing. Included in the discussion is the method of test, a summary of the nature of the tests and the data obtained, and how the data were correlated. This is provided to facilitate understanding of the nature and complexity of head loss testing. Add statement regarding plant-specific basis.
13	4.2.5.2.2	4-39	Head Loss	Several special head loss correlations are presented and discussed. Specifically: • An empirical correlation for fiber-only beds, • The US NRC NUREG/CR-6224 head loss model, • The US BWROG combined debris head loss correlation, and, • Correlations for head loss due to flow through reflective metallic insulation (RMI). The basis for, and considerations to be accounted for, in applying the RMI head loss equations are also listed.
14	4.2.5.2.3	4-50	Head Loss	This section presents information that may be useful in the development of correlations for alternate strainer designs. Two potential improvements identified for head loss modeling for alternate strainer designs are identified: • Accounting for geometry of the screen, if it varies significantly from a flat plate, and, • Non-uniform deposition of debris on the strainer, if appropriate and justifiable.

Table 4-1 Pressurized-Water Reactor Sump Performance Evaluation Methodology Refinements Table (Continued)

No.	Section	Page	Topic	Description
15	5.1	5-1	Debris Source Term	This section identifies possible design and operational activities that may be undertaken to reduce the debris source term, such as: • Improved housekeeping and foreign materials exclusion (FME) programs • Insulation change-out, • Insulation modifications, • System and equipment modifications, and, • Modifications to protective coatings programs.
16	5.2	5-4	Debris Transport	This section identifies information that might be used for debris barriers that might mitigate debris transport about the containment. These barriers include: • Floor obstructions, and, • Debris racks.
17	5.3	5-6	Screen Modifications	This sections identifies options for sump screen modifications, including: • Passive strainer designs, • Backwash strainer designs, and, • Active strainer designs. In addition to the sump screen modification options, a list of considerations for each of the options is identified.

GSI-191 and the concern of PWR sump blockage are directly associated with the long-term cooling acceptance criteria listed in 10 CFR 50.46 (b)(5). To ensure acceptable ECCS cooling capability, 10 CFR 50.46 requires that "ECCS cooling performance must be calculated in accordance with an acceptable evaluation model and must be calculated for a number of postulated loss-of-coolant accidents of different sizes, locations, and other properties sufficient to provide assurance that the most severe postulated loss-of-coolant accidents are calculated." The staff notes that the worst breaks with respect to peak clad temperature and the other acceptance criteria of 10 CFR 50.46 may not necessarily be the limiting breaks for debris generation and sump-head loss. When evaluating ECCS performance for compliance with 10 CFR 50.46, SRP Sections 6.3, "Emergency Core Cooling System," and 15.6.5, "Loss-of-Coolant Accidents Resulting from Spectrum of Postulated Piping Breaks Within the Reactor Coolant Pressure Boundary," should be considered. SRP Section 15.6.5 states that reviewers "evaluate whether the entire break spectrum (break size and location) has been addressed." The proposed GR guidance to consider only those break locations consistent with BTPMEB 3-1 is not in accordance with the requirements of 10 CFR 50.46 because BTP MEB 3-1 may not provide assurance that the most severe postulated LOCAs are calculated.

RG 1.82, Revision 3 provides the NRC's guidance regarding an appropriate spectrum of breaks to be considered when evaluating PWR sump performance. Specifically, Regulatory Position 1.3.2.3 of RG 1.82 states that a "sufficient number of breaks in each high-pressure system that relies on recirculation should be considered to reasonably bound variations in debris generation by the size, quantity, and type of debris." At a minimum, the staff position is that the following postulated break locations should be considered, (1) breaks in the hot leg, cold leg, intermediate leg, and, depending on the plant licensing basis, main steam and main feedwater lines with the largest amount of potential debris within the postulated ZOI; (2) large breaks with two or more different types of debris, including the breaks with the most variety of debris, within the expected ZOI; (3) breaks in areas with the most direct path to the sump; (4) medium and large breaks with the largest potential particulate debris to insulation ratio by weight; and (5) breaks that generate an amount of fibrous debris that, after its transport to the sump screen, creates a minimum uniform thin bed (1/8-in. layer of fiber) to filter particulate debris. The staff considers that RG 1.82 provides the complete scope of breaks which should be evaluated to ensure that the criteria of 10 CFR 50.46 are satisfied. The proposed GR guidance to consider only break locations consistent with BTP MEB 3-1 does not provide an adequate alternative to the guidance provided in RG 1.82, Revision 3, to demonstrate compliance with the requirements of 10 CFR 50.46 because the complete scope of break locations may not be evaluated.

The staff previously reviewed a similar request to apply SRP Section 3.6.2 and BTP MEB 3-1 for identifying break locations to be considered when evaluating ECCS strainer concerns in BWRs. As documented in the staff's SE for the BWRs (URG SE), the staff rejected the BWROG proposal for two reasons. The first reason was that SRP Section 3.6.2 and BTP MEB 3-1 do not provide guidance or acceptance criteria for demonstrating compliance with the requirements of 10 CFR 50.46. The staff noted that the only acceptance criterion specified in SRP Section 3.6.2 is compliance with General Design Criteria (GDC) 4, "Environmental and Dynamic Effects Design Bases." GDC 4 requires that licensees must protect structures, systems, and components important to safety from the dynamic effects (e.g., pipe whip, direct steam jet impingement, etc.) and environmental effects (e.g., temperature, pressure, radiological effects) of postulated pipe ruptures. The staff communicated through GL 87-11, which transmitted the revised SRP Section 3.6.2 and BTP MEB 3-1, that licensees could still provide an adequate and practical level of protection for compliance with GDC 4 by reducing the number of postulated pipe breaks and by physically protecting equipment important to safety from the postulated pipe breaks that have a relatively higher potential for failure (e.g., postulated failures at high-stress and fatigue locations). As a result, when demonstrating compliance with GDC 4, licensees may analyze pipe breaks through the use of pipe-stress analysis methodologies similar to that provided in SRP Section 3.6.2 and BTP MEB 3-1. The staff considers SRP Section 3.6.2 and BTP MEB 3-1 to be inappropriate for postulating break locations for the purpose of determining the extent of debris generated in order to comply with the requirements of 10 CFR 50.46 because these are applied to demonstrate compliance with GDC 4, not 10 CFR 50.46. The second reason given by the staff in rejecting the BWROG proposal was that the BWROG had not demonstrated that break locations selected consistent with SRP Section 3.6.2 and BTP MEB 3-1 would bound the worst-case debris generation scenarios and, therefore, meet the intent of 10 CFR 50.46. The staff finds that this discussion also applies to PWRs and the GR proposal.

Finally, in evaluating the GR proposal, the staff considered the current effort involving a proposed rulemaking to risk-inform requirements related to LBLOCA break size. For a risk-informed 10 CFR 50.46, the staff is revising the design-basis LOCA break size, but does not plan on changing its current position regarding break locations which need to be considered for purposes of meeting the requirements of 10 CFR 50.46. The staff's intention is to ensure that the methodology used to resolve GSI-191 is consistent with the 10 CFR 50.46 rulemaking effort.

Based on the above discussions, the staff concludes that it is inappropriate to cite SRP 3.6.2 and BTP MEB 3-1 as methodology to be applied for determining break locations to be considered for PWR sump analyses because these may not identify the limiting break location. The staff concludes that the guidance regarding break locations, as described in GR Section 3.3 (and as amended in Section 3.3 of the staff's SE) should be followed when performing PWR sump analyses. The staff's conclusion applies for the entire spectrum of pipe-break sizes which are considered. When performing analyses described in Section 6 of the GR, "Alternate Evaluation," this conclusion applies for both Region I and Region II analyses.

4.2.2 Debris Generation

4.2.2.1 Zone of Influence

This section reiterates that, for the baseline calculation, the GR recommends the use of a spherical ZOI to encompass the effects of jet expansion resulting from impingement on structures and components. It notes that two refinements are to be presented for insulation materials, but none are offered relative to coatings.

Staff Evaluation of GR Section 4.2.2.1: The spherical zone is a practical convenience that accounts for multiple jet reflections and mutual interference of jets from opposing sides of a guillotine break. It is important to note that when the spherical volume is computed using an acceptable approximation for unimpeded free jet expansion, the actual energy loss involved in multiple reflections is conservatively neglected to maximize the size of the ZOI. The staff concurs with the use of spherical ZOI as a practical approximation for jet-impingement damage zones.

4.2.2.1.1 Method 1: Debris-Specific Spherical ZOIs

Method 1 refines the evaluation of ZOI by recommending that multiple ZOIs be assigned to each break site, with each corresponding to the destruction pressure of one insulation species located near the break site. The methodology of the ANSI/ANS 58.2-1988 standard determines the pressure isobars used to define the equivalent-volume spherical ZOI pertinent to a particular insulation type. Table 3-1 of the GR presents destruction pressures for several insulation types. This table provides the ratio of the ZOI radius to the break diameter for each insulation type listed. The Method 1 discussion notes that no changes to insulation destruction pressures are to be made to account for differences between dry and saturated-steam jets. Section 3.4 of the GR discusses robust barriers and the effects on the ZOI.

Once the ZOI for each insulation type has been determined, the debris generated within each ZOI is calculated and the individual contributions are summed to arrive at a total debris source term.

Staff Evaluation of GR Section 4.2.2.1.1: The NRC agrees that the definition of multiple, spherical ZOI at each break location that correspond to the damage pressures of potentially affected materials is an appropriate refinement for debris-generation calculations. Furthermore, it is also appropriate to apply this refinement in a selective manner. For example, a separate, well-characterized ZOI can be applied for coatings, and all insulation types can be treated according to the baseline assumption of damage equivalent to the most vulnerable material in containment. The sample calculation presented in GR Section 3.4.2.6 illustrates this approach. Target material inventories within their respective ZOI should be calculated in accordance with the staff evaluations described in Section 3.4 of this SE, including the treatment of robust barriers.

Definition of a Spherical ZOI

Section 3.4 of the GR and Appendix I to this SE review the application of the ANSI/ANS 58.2-1988 jet model, which was found to be an acceptable approach for computing volume-equivalent spherical ZOI. However, material-specific damage pressures that were experimentally determined using high-pressure air as a surrogate working fluid should be treated in a manner similar to that presented in Section 3.4.2.2 to account for potential differences between dry and flashing two-phase water-jets. The listing of damage pressure provided in Table 3-1 of the GR implicitly acknowledges the potential for enhanced destruction by citing two-phase destruction tests for calcium silicate. The staff position to reduce destruction pressure by 40 percent for materials not tested under two-phase conditions is substantial; however, it is less than the decrease measured for calcium silicate.

The following three additional refinements related to the application of the ANSI jet model can be developed on a case-by-case basis for selected breaks if it is advantageous to do so:

1. First, the application of worst-case thermal hydraulic conditions to every break location can be relaxed if there is supporting evidence to demonstrate that a

particular break location or class of break locations exhibits substantially different conditions that can be conservatively calculated or measured. Maximum-damage volumes are generally driven by increased pressure, but these volumes can exhibit unexpected changes related to the degree of subcooling (see Appendix I to this SE).

2. Second, the assumption of equivalent maximum mass flux from both ends of a guillotine break can be relaxed if there are supporting calculations to conservatively substantiate important differences between the thermal-hydraulic conditions upstream in either direction. Damage volumes from each side would be calculated independently and then added similar to the way that damage volumes are doubled for the baseline analysis.
3. Third, some credit can be taken via conservative approximation for friction losses in lines leading to the break location if adequate documentation of roughness coefficients and flow losses in piping components can be provided. This refinement will have the effect of reducing the effective total pressure at the exit plane below the stagnation pressure of the upstream system reservoir. The system stagnation enthalpy should be assumed constant.

It is expected (but not necessary) that these refinements would be pursued on a selective basis for break locations that are found to drive key decision points. For example, limiting breaks identified under the baseline assumptions might be found to impact vulnerable insulation types that are located in high-radiation areas. While replacement of vulnerable insulations with more robust material might be the desired mitigation option, these refinements might demonstrate that the material should be left in place. If these refinements are applied as described for the purpose of exempting specific targets, the corresponding assumed break locations should be located to minimize the flowpath distance between break and target. These refinements can be applied selectively in any combination, and they apply as well to the Method 2 refinement for direct jet impingement.

The ZOI and Robust Barriers

Target material inventories within their respective ZOI or generic ZOI should be calculated as discussed in Section 3.4 of this SE, including the treatment of robust barriers. Section 3.4 does not allow simple truncation for robust barriers, as proposed in the GR.

Evaluating Debris Generation within the ZOI

The NRC agrees that the contributions of each material type to the total debris inventory should be added to determine the debris source term available for transport as described in other sections of the GR. Therefore, this is an acceptable approach.

4.2.2.1.2 Method 2: Direct Jet Impingement Model

This section of the GR offers the refinement of defining the ZOI by modeling two, freely-expanding jets emanating from each broken pipe section as opposed to using the spherical ZOI approach presented in Section 3.4 of the GR. The ANSI/ANS 58.2-1988 standard is recommended for determining the jet geometry. The specific procedures to be followed for determining jet geometry are summarized, and an example calculation is discussed. Appendix D to the GR presents the results of the isobar mapping calculations and an example of a plotted isobar. The treatment of robust barriers and the determination of overall debris generation are the same as for Method 1.

Staff Evaluation of GR Section 4.2.2.1.2: The NRC staff has reviewed this refinement and finds it acceptable. This refinement retains some spatial information inherent to the direction of the severed pipe. It implicitly assumes that the ends of the pipe are fully separated and fully offset, but yet, remain basically aligned in the original direction. The staff notes that there is no specific analysis of pipe-whip potential if this method is used. However, the spherical ZOI approximation carries similar inherent assumptions (basic alignment of pipe segments to create a spherical ZOI from opposing and interfering jets). Although not explicitly stated, the perceived advantage of this method under strict implementation of the GR would follow from truncation of a jet segment that impinges directly on a barrier, such as a wall or floor, as well as the economy associated with the use of ZOI calculations that have already been performed for local dynamic effects (i.e., GDC 4 analyses). Section 3.4 reviewed the practice of ZOI truncation and was judged to be nonconservative compared to the concept of ZOI volume conservation. Licensees electing direct impingement model refinement should retain the volume for conservatism. In fact, the mapping of an independent directional jet segment within containment would be necessary for postulated sidewall ruptures, if they are considered for analysis. Analysis of sidewall ruptures would carry the additional burden of investigating alternative jet directions. In lieu of mapping directional jet segments for sidewall ruptures, Section 6 of this SE reviews the use of directional (worst debris generation) hemispherical break geometry as an acceptable alternative to assuming a sphere for partial breaks in RCS main loop piping (non-DEGB).

The information provided in this section on ANSI jet modeling is identical to that provided in GR Section 3.4.2.1 and was reviewed previously. However, the staff would like to emphasize the GR statement that this refinement relies upon a high degree of rigor in determining what the stagnation pressure to which each insulation type is subjected. The first task is to model unimpeded jet expansion using the ANSI standard and Appendix I to this SE for guidance, and the second task is to map relative spatial geometries of targets and the jet in the vicinity of the break location. It is also true, as stated in the GR, that isobar contours like those presented in Appendix D to the GR and Appendix I to the SE have rotational symmetry and can be rotated about the longitudinal axis to define the three-dimensional surface of equivalent damage potential (i.e., impingement pressure).

As a point of nomenclature consistency, there is a conceptual difference between the classical definition of stagnation pressure in a moving fluid, as approximated by Bernoulli's Law, and the pressures predicted by the ANSI model. The predicted pressures are referred to throughout the SE as impingement pressures because they represent non-isentropic stoppage of the fluid on the face of a target that should be slightly higher than the theoretical stagnation pressure at a free-stream point in the flow field. Other limitations to this interpretation of the predicted jet pressures also apply as, discussed in Appendix I to this SE.

It should be noted that the additional optional refinements discussed above as Method 1 refinements for debris-specific ZOI also apply to Method 2. The choice of using an approximate spherical geometry or the more realistic geometry of a directed jet is largely independent of the thermal-hydraulic assumptions used to compute a jet contour.

The ZOI and Robust Barriers

Target material inventories within their respective ZOI or generic ZOI should be calculated, as discussed in Section 3.4 of this SE. The isobar volume of interest should be mapped and conserved independently for the jet on each side of the break. The total damage volume of the two jets should be preserved in a contiguous region, rather than crediting overlapping reflections.

Evaluating Debris Generation within the ZOI

The guidance offered in this section is identical to that presented in Section 3.4.2.5 and has been reviewed previously. Additionally, the contributions of debris from both independently evaluated jets are added to represent the total debris source term.

4.2.2.2 Debris Characteristics

GR Section 4.2.2.2 provides additional information regarding the characteristics of debris following a postulated break. The section recommends using plant-specific or publicly available vendor-specific information, where applicable, for refining debris sizes considered in the transport and blockage evaluations. The section includes Table 4-1 that contains recommendations for destruction pressures, fabrication and material densities, and debris characteristic sizes. In addition to replicating data presented in baseline Tables 3-1 and 3-2, Table 4-1 includes recommendations for other materials, as well.

Staff Evaluation of GR Section 4.2.2.2: The staff has the following concerns regarding the guidance provided in GR Section 4.2.2.2:

1. In Section 4.2.2.2.1, “Fibrous Insulation,” the guidance states, “Not all generated fibrous debris needs to be assumed to be of a transportable size.” The reality is all debris not specifically attached to a structure can be transported given a sufficient driving force. For example, an entire intact blanket of fibrous debris will move in a pool of water, if the flow velocities are sufficiently fast. Sheeting flows during testing has shown the capability of moving intact RMI cassettes under certain conditions. In short, all debris should be considered transportable until plant-specific analyses determine otherwise.
2. Section 4.2.2.2.2, “Reflective Metallic Insulation (RMI)” cites GR Reference 27 as a source of information for the debris-size distribution for RMI debris. However, Reference 27 is a report on the testing of NUKON™ insulation and does not contain RMI information. Therefore, the GR does not provide an appropriate debris-size distribution for RMI debris. Section 4.2.2.2.3, “Coatings,” also inappropriately cites Reference 27 for evaluating coatings.
3. In Section 4.2.2.2.3.1, “Coatings within the ZOI,” the GR recommends using the properties of a multiple-coating system that produces the post accident debris with the most detrimental effects to the containment sump. However, the GR does not provide guidance regarding which types of properties (e.g., a light- or

heavy-coating density) would produce the most detrimental effects. The most detrimental properties for debris transport may differ from those most detrimental to head loss. The staff is concerned that such ambiguity in the guidance could lead to improperly determined properties from a conservative standpoint and recommends that each component in a multiple-coating system be evaluated separately with its applicable properties. Effective properties for multiple types of debris can then be determined. A similar statement in Section 4.2.2.2.3.2, "Coatings outside the ZOI," directs that the most detrimental properties be assumed for unidentified non-DBA-qualified coatings systems used outside the ZOI; however, more supporting guidance is needed regarding which types of properties are most detrimental.

4. In Section 4.2.2.2.4, the GR recommends assuming that all tape and stickers located in the ZOI are destroyed into small pieces and fibers. The positive aspect of this assumption is that 100 percent of the debris would be subsequently transported to the sump screens. However, it is not a foregone conclusion that assuming the debris is destroyed into small pieces and fibers would cause a higher head loss than if this debris arrived at the screens intact, which is one of the potential realities, at least for no soluble tapes, stickers, and tags. As intact debris, this debris could effectively interdict flow through covered portions of the screen, thereby effectively reducing the size of the screen. Hence, the GR statement that it is conservative to assume that all debris created from tape and stickers is reduced into fine or small pieces or individual fibers is not supported. It is recommended that the head-loss evaluation estimate the head loss by assuming each condition of the debris, and then use the higher head loss in the NPSH margin determination.

5. In Section 4.2.2.2.5, "Fire Barrier Materials," fire barriers consist of many types of insulation and other materials, including board materials, blanket materials, and foam materials. With a few exceptions, debris-generation data do not exist for fire barrier materials that differ from the piping insulations tested. The GR recommends, "For materials that are unique to fire barrier applications and do not have supporting test data, a destruction pressure equal to that of low-density fiberglass may be assumed." While this guidance seems reasonable for fire barrier materials consisting of a low-density fiberglass or even a high-density fiberglass, it is not acceptable to apply data for low-density fiberglass to the variety of fire barrier materials (e.g., board and foam materials).

The staff did not independently verify all the data contained in GR Table 4-1 and has the following concerns:

1. Table 4-1 provides four seam orientation calcium silicate destruction pressures (i.e., 0°, 45°, 180°, and generic orientation) without additional guidance. Furthermore, the 0° reference was not stated. Application of seam-oriented destruction pressures requires orientation-specific jet destruction models. As discussed in Appendix II to this SE, the threshold pressure for destruction is actually less than 24 psi because substantial insulation damage occurred at a jet pressure of 24 psi in the OPG tests (45° orientation), which was the lowest pressure tested. The staff suggests using the recommendation in NUREG/CR-6808 of 20 psi for calcium silicate.

2. Table 4-1 recommends a destruction pressure of 2.5 psi for blanketed and unjacketed Min-K, whereas the baseline Table 3-1 of the GR recommends a destruction pressure of 4 psi. Hence, these two recommendations are in conflict. The staff recommends using a destruction pressure of 2.5 psi for blanketed, unjacketed Min-K in the baseline, as well as in the refinements. The GR-recommended destruction pressure of 6 psi for blanketed, jacketed Min-K with stainless steel bands and latch and strike locks does not specify the jacket construction. Unless a specific jacket construction can be correlated to test data to demonstrate that a pressure of 6 psi or greater is needed to compromise that specific jacket, then the lower destruction pressure of 2.5 psi should be used.

3. It is noted that several data are missing from Table 4-1 that the analyst will require. For example, the material density for Min-K is specified as NA, but will be required when applying the GR-recommended NUREG/CR-6224 head-loss correlation.

4. The destruction pressure for Microtherm was apparently set equal to that of Min-K in Table 4-1, without justifying remarks. Some rationale should have been presented for this action.

5. For Knaupf, with an as-fabricated density of 2.4 lb/ft^3, Table 4-1 recommends a destruction pressure of 10 psi for Knaupf with an as-fabricated density of 4.0 or (blank), the GR does not recommend a destruction pressure. However, in Table 3-1 of the GR, one entry exists for Knaupf which recommends a destruction pressure of 10 psi alone. Because of the inconsistency, application of this guidance for Knaupf should be based on its as-fabricated density, as appropriate.

6. The destruction pressure recommended in Table 4-1 for Kaowool was made without justifying remarks or reference. Some rationale should have been presented for this assumption.

7. Table 4-1 specifies the as-fabricated density of Kaowool as 9.4 lbs/ft^3 which is given as a range of 3 to 12 lbs/ft^3 in baseline Table 3-2. If this density is a manufacturing variable, then the plant-specific, as-applied density should be used. As illustrated in Appendix V to this SE, the head-loss evaluation is very dependent upon this number.

8. The reference number provided for the material density of Kaowool is given as "xx," which is not listed in the GR references section (i.e., Section 9), and should be corrected and/or provided.

9. Table 3-1 of the GR recommends the destruction pressure for Mirror® with Sure-Hold® bands as 150 psi; however, this item is missing from GR Table 4-1. Section 3.4.2 of this SE provides the staff's evaluation of this value. The acceptable value provided in Table 3-2 of this SE should also be used, if applied as a refinement.

10. The destruction pressure recommended in Table 4-1 for silicone foam was made without justifying remarks or reference. Some rationale should have been presented for this assumption.

11. The destruction pressure recommended in Table 4-1 for gypsum board was made without justifying remarks or reference. Some rationale should have been presented for this assumption.

Staff Conclusions Regarding Section 4.2.2.2: The staff finds that use of debris-specific characteristics as a refinement to the baseline is acceptable. However, the cautions listed above should be considered in the use of this refinement and debris-specific data should be sought.

4.2.3 Latent Debris

Although the GR does not identify any generic analytical refinements for quantifying latent debris in this section, other methods the staff identified in Section 3.5 of this SE as acceptable alternatives for sampling plans could be viewed as refinements to a conservatively assumed baseline inventory.

4.2.4 Debris Transport

Section 4.2.4 of the GR recommends two methods of analytical refinements for determining the flow characteristics of the sump pool for the purpose of predicting the transport of debris in the sump pool to the recirculation sump screens. These methods include the open channel flow network method (Section 4.2.4.1) and the three-dimensional CFD method (Section 4.2.4.2). Aspects of the network method discussed included the following the analytical approach, model input development, and the network solution. An example network model was superimposed onto a corresponding CFD result. No discussion was provided regarding the use of network-predicted results to estimate debris transport within the sump pool. Aspects of the CFD method discussed included the selection of software, the building of a computer aided design model that could be used to generate the computational mesh, the CFD analysis, and the prediction of debris transport using the CFD results.

The debris transport discussion associated with the CFD modeling included a discussion of plotting velocity magnitude contours for the minimum bulk transport velocity at selected levels within the containment pool. After the area within this transport velocity contour is determined, the debris within this area is assumed to transport to the sump screen.

The GR also includes Table 4-2, “Debris Transport Reference Table,” which provides transport data, such as the minimum velocities needed to transport debris.

Staff Evaluation of GR Section 4.2.4: Of the two methods of analytical refinements for transport of debris in the sump pool, the staff identified the following challenges in using the open channel network method:

1. The implementation of the network method requires the adaptation of multiple correlations for estimating form-loss coefficients and friction factors (correlations typical of piping pressure-loss calculations). At each network node junction, a form-loss coefficient is required that simulates flow for the connecting nodes. The complexity of the sump pool channel will require the analyst to make engineering judgment adaptations for the application of generic

correlations. The complexity of the model input development can severely limit the detail of the model, resulting in a rather coarse nodalization.

The coarseness of the network method, as illustrated by the example nodalization in GR Figure 4-4, limits the simulation of important aspects of the sump pool, such as the complexity of the flow channel, obstacles to flow, and the complex distribution of containment spray drainage entering the pool. The example nodalization ignored portions of the sump pool without providing a rationale for determining which portions of the pool do not need to be modeled.

2. The model coarseness forces the analyst to rely on predicted bulk velocities between coarse nodes, and therefore the model cannot predict localized flow conditions that are capable of moving debris, even if the bulk flow velocities indicate no movement of debris. An example of localized flow is vortices that could be completely internal to a network node. Testing has shown that vortices affect debris transport (NUREG/CR-6773).
3. The network method is not capable of predicting sump-pool turbulence or its effects on debris transport. Sump-pool turbulence has been shown to affect debris suspension within the pool (e.g., water flows falling into the sump pool can suspend debris that would normally settle in calm water) and the rates of erosion (Section III.3.3.3) for certain types of debris (e.g., fiberglass insulation debris).
4. The network method is not capable of predicting pool characteristics during pool formation that affect the transport of debris during this period, such as the initial spreading of water across the floor or the filling of inactive portions of the sump (e.g., reactor cavity).
5. The large number of input parameters associated with specifying a network nodalization model (e.g., inputs to form-loss correlations) could make the performance of a quality sensitivity evaluation for those input values difficult.

Appendix C to the GR compares the results of the open channel network method to the results of the CFD method. The staff concluded that the results do not agree; this is in contrast to the assertion in the GR that the network and CFD results compare favorably. The difference in flow rates of less than 10 percent was calculated by dividing by the total recirculation flow. For example, the GR-quoted error for Channel 156 is 7.7 percent (Table C-1), but the flow for the network method is in the opposite direction to that of the CFD analyses. If the difference for Channel 156 were calculated as the difference between the network and the CFD-predicted flow rates divided by the CFD the result would have been 56 percent instead of 7.7 percent. In addition, the flows of the network and CFD methods are in the opposite direction.

The GR recommends adding 10 percent to the calculated channel flow rates, but the staff recommends that the safety factor applied to the network calculated results be based on benchmark analyses of the network methodology against experimental debris transport results and/or superior analytical methods. In addition, a method is still needed to perform the required analysis that is well beyond the capabilities of the network method.

Regulatory Position 1.3.3.4 of RG 1.82, Revision 3, states the following:

> An acceptable analytical approach to predict debris transport within the sump pool is to use computational fluid dynamics (CFD) simulations in combination with the experimental debris transport data. Examples of this approach are provided in NUREG/CR-6772 and NUREG/CR-6773. Alternative methods for debris transport analyses are also acceptable, provided they are supported by adequate validation of analytical techniques using experimental data to ensure that the debris transport estimates are conservative with respect to the quantities and types of debris transported to the sump screen.

Consistent with the above regulatory position, the staff accepts the nodal network method as an alternative method to calculate debris transport onto the sump screens. However, the licensees should support this method using experimental data to ensure that their estimates are conservative with respect to the quantities and types of debris transported to the sump screen.

The staff finds that the GR discussion regarding the CFD method and analysis is thorough. Specific staff comments include the following:

1. The GR suggests using turbulent turbine kinetic energy (TKE) profiles in the pool as a pool characteristic, but fails to prescribe how this information would be useful in the debris-transport analysis. The staff recommends a potential adaptation of a CFD method employed in the BWR drywell debris-transport study (NUREG/CR-6369, Vol. 3) in which the CFD code is also used to simulate applicable tests with debris settling correlated to the CFD predicted turbulence indicators.
2. The GR discussions regarding the level of detail or analytical fineness to the model does not adequately address potential plant features that can significantly affect sump-pool hydraulics. For example, the GR statement that, “obstructions less than 6 inches in diameter or the equivalent may be omitted,” is too general a statement. If there is a single 6–in. obstacle, it might be argued that it can be neglected, but if there is a series or array of 6–in. objects, then the array may need to be modeled.
3. Other model development aspects should be properly assessed before selecting modeling options, including the type and size of calculational mesh, boundary conditions inflow and outflow options, and convergence criteria. Many of the modeling options depend upon the CFD code selected, and the model development should properly select the best options for the plant-specific sump-pool evaluation.

The GR recommends using a uniform distribution of debris on the sump floor (i.e., the sump pool debris transport fraction is equal to the floor area fraction where the velocity is greater than the minimum transport velocity. (See GR Section 4.2.4.2.5.)) This recommendation is not acceptable because the debris entrance into the pool is not uniform. The staff provided supplemental guidance in Appendices III and VI to this SE addressing sump pool debris transport and blowdown/washdown transport, respectively, in the volunteer plant. Appendix III demonstrates that the GR floor area transport model would under-predict the sump pool debris transport in the volunteer plant by a wide margin. Debris initially deposited onto the sump floor in the volunteer plant was preferentially deposited within or near the break compartment because of the partial confinement of debris in the break compartment, and debris initially deposited in the upper levels of the containment would wash down with the drainage of the containment sprays entering the sump pool at discrete locations, typically in the faster areas of the pool. Licensees should use the debris transport methodologies presented in Appendices III and IV for refined analyses.

In the GR baseline, a two-group size distribution was recommended in which the small fines would completely transport to the sump screens and the large debris would not transport at all. Therefore, the sump pool debris transport refinement cannot be applied to small fines because at least a portion of this group must be treated as suspended fines with complete transport. A refinement can be applied to the large size group, but in the baseline guidance this group is assumed not to be transportable. In order to proceed with a sump pool analytical refinement, a better-defined size distribution that addresses the key aspects of debris transport should be used. In addition, if the analytical refinement is applied to the small debris, it should also be applied to the large debris that is neglected in the baseline methodology. The licensee should use the four size categories used in both Appendices III and VI to this SE for fibrous debris. This size distribution has (1) fines that remain suspended, (2) small piece debris that are transported along the pool floor, (3) large piece debris with the insulation exposed to potential erosion, and (4) large debris with the insulation still protected by a covering, thereby preventing further erosion.

Also, for the situation where coatings debris are assumed to be larger than the basic material constituent size due to the substantiation of no thin bed at the sump screen, and instead sized as chips or flakes; licensees may choose to justify a transport factor of less than 100 percent for those chips or flakes based on experimental data or analysis.

GR Table 4-2 provides useful data and references NRC-published documents as the source of the data. However, one column in the table provides selected values for TKEs required to suspend debris that are not in the referenced NRC-published documents. The staff has not assessed or accepted the TKE values presented in GR Table 4-2.

Staff Conclusions Regarding GR Section 4.2.4: GR Section 4.2.4 recommends the open channel flow network method and the three-dimensional CFD method for refining the analysis for transport of debris in the sump pool to the recirculation sump screens. Consistent with RG 1.82, Revision 3, the staff accepts (1) the CFD method, and (2) the nodal network method as an alternative method to calculate debris transport onto the sump screens. However, the licensees using the nodal network method should support it with experimental data to ensure that the debris transport estimates are conservative with respect to the quantities and types of debris transported to the sump screen. The GR-recommended debris transport model in Section 4.2.4, which assumes a uniform distribution of debris across the sump floor, is not acceptable because the debris entrance into the pool is not uniform. Appendices III and VI to this SE provide additional staff guidance on adapting the debris transport methodologies for refined analyses.

4.2.5 Head Loss

The GR states that no head-loss refinements are offered other than those given in Section 3.7.2.3.2.3. (See SE Section 3.7.2.3.2.3, “Thin Fibrous Beds,” for the staff evaluation of this section of the GR.) The supporting Appendix E repeats the text found in Section 4.2.5, and provides tables that summarize available domestic and international head-loss testing and results.

Staff Evaluation of GR Section 4.2.5: The staff did not identify any specific analytical refinements offered in Section 4.2.5 or Appendix E. Therefore, no evaluation is provided for analytical refinements to the head-loss analysis.

5.0 DESIGN AND ADMINISTRATIVE CONTROL REFINEMENTS

Industry representatives including the NEI, the Westinghouse Owners Group, and various participants from individual utilities have followed the development, research, and resolution process of GSI-191 for several years. Over this time, practical insights have been gained by the participants regarding the relative importance of each stage of the accident sequence to the overall assessment of recirculation sump vulnerability. This section addresses the phenomenology associated with debris generation, debris transport, debris accumulation, and head loss across beds of mixed composition. As the knowledge base of research data and plant survey information has improved, and as analytic methods have developed to address each aspect of the complex accident sequence, so too has the awareness of potential vulnerabilities grown. Recognition and understanding of the principal contributors to sump-screen vulnerabilities has initiated a discussion about possible mitigation strategies that seek to interdict the accident progression at one or more of the aforementioned stages.

Self assessment of recirculation sump vulnerability and the identification of site-specific contributing factors is a responsibility of each licensee, but this section attempts to share the broader industry perspective on possible improvements that a licensee can make to improve its sump performance posture, regardless of the current plant condition.

Based on the findings of individual licensees, the range of mitigative actions pursued across the industry may range from status quo operation to sump-screen replacement. In many cases, though, new awareness of the issues involved with ensuring sump-screen performance will lead to at least procedural changes that help avoid unnecessary exposure to the risk of sump-screen blockage. With improved understanding of a problem comes a new perspective of common sense regarding the simple things that can be done to improve safety, as well as the detailed knowledge required to affect engineered solutions to a specific technical problem. This section provides insights at both levels. This discussion may be sufficient for a given licensee to address any identified problems. For others it may motivate progress towards a site-specific solution of their own devising. However, successful management of sump-screen vulnerability may require a combination of the approaches presented in this section.

Given the diversity of possible responses to this issue and the variety of site-specific solutions that will be developed at varying degrees of complexity, the NRC cannot endorse any one mitigation strategy that is offered here at this time. Assessments of relative effectiveness expressed in the GR are the opinion of the industry representatives. The staff believes that this information improves the practicality of the GR because licensees are immediately motivated to find workable solutions to any problems that are identified during their vulnerability assessments. Any necessary changes to plant configuration, technical specifications, operating procedures, or other licensing basis changes should still consider the need for NRC staff review and approval. Licensees should consider existing regulatory processes, and if necessary, submit any required information for staff review. An important aspect of the existing review process is the need for applicable testing and analysis of any new equipment or materials that are incorporated into the ultimate resolution strategy. In this manner, the NRC can judge the effectiveness of the approaches chosen by each licensee. For these reasons, the staff's review of Section 5 of the GR is limited. The staff found the technical descriptions in this section to be acceptable as an introduction to the topic of mitigating sump-screen vulnerabilities.

5.1 DEBRIS SOURCE TERM

This section examines five categories for design and operational refinements. Staff comments on each category are summarized below.

1. **Housekeeping and FME Programs:** The GR recommends that if housekeeping or FME programs are implemented or revised to reduce the latent/miscellaneous debris burden, then appropriate procedures should be designed to ensure a high level of performance. The staff wishes to emphasize that such procedures and performance metrics, based on swipe sample analyses, for example, should be used if vulnerability assessments rely on periodic cleaning activities to maintain debris loadings below some minimum level of concern.
2. **Change-Out of Insulation:** The staff notes two items in addition to those identified in the GR. First, while change-out of problematic insulation types may address the issue of maximum debris loadings on the screen, it might not address the issue of minimum loadings required to form a thin filtration bed. To satisfy both concerns, a combination of strategies in addition to change–out, might be needed. Second, the large-scale removal of some insulation types may inadvertently increase the latent debris loading of residual insulation materials, unless removal is performed carefully to minimize the spread of fine materials or effective plant cleaning routines are implemented after insulation removal to recover dispersed material.
3. **Modify Existing Insulation:** This action may effectively address the issue of maximum debris loads on the screen without changing the minimum loadings required to form a thin filtration bed. To satisfy both concerns, a combination of strategies, in addition to a modification of existing insulation, may be necessary.
4. **Modify Other Equipment or Systems:** The staff agrees that changes to non-insulation items should be considered in the context of the entire sump performance evaluation. Discussion of latent debris surveys that identify unique collections of particulate or fibrous material, such as filter housings that are vulnerable to water infiltration, suggested another example of beneficial change to equipment. If such sources can be sealed or protected from containment spray, then the internal inventory will not be released to the sump pool.
5. **Modify or Improve Coatings Program:** Under the conservative assumption that 100 percent of unqualified coatings will fail, the staff agrees that conversion to DBA-qualified systems would reduce the source term contributed by failed coatings. Additionally, the staff does not agree with the statement that DBA-qualified coatings have very high destruction pressures. This statement has not been proven for the simultaneous combination of high-temperature and high-pressure jet impingement. See Sections 3.4.4 and 4.2.2.2.3 for more discussion on acceptable coatings destruction pressures.

5.2 DEBRIS TRANSPORT OBSTRUCTIONS

This section examines various options for redirecting or retarding the movement of debris towards the sump screen. The objective of these approaches is to trap or sequester debris so that it cannot reach the sump screen during recirculation. Transport velocities are highest during pool fill-up when sheeting velocities can move large pieces of debris that are initially impacted on the floor near the break or washed to the floor by the break effluent. During this timeframe, flow direction is not preferentially towards the sump. As the containment pool fills, sheeting velocities decrease. With the onset of recirculation flow, debris transport with a preferential direction aligned towards the sump screen is established. Design of obstructions to provide a barrier to debris transport to the sump screens should consider all phases of pool fill and establishment of recirculation flow.

5.2.1 Floor Obstruction Design Considerations

Careful thought must be given to the stability of the holding location with respect to turbulence introduced by cascading containment spray water. For example, if diversion baffles successfully collect debris during fill-up in a drainage zone that is highly agitated by falling water, the net result may be to increase the fraction of individual fibers and fine material available for transport to the screen under low recirculation velocities. During initial fill-up, curbs may be subjected to significant flow velocities, so heights would need to be designed accordingly in order to be effective. Removable structures, such as debris rakes and baffles, may also experience significant hydrodynamic force loadings during fill-up. The test data cited from GR Reference 54 for the effectiveness of curbs are very rudimentary. Significant opportunity exists for optimizing curb designs to accomplish the complementary objectives of debris capture and/or debris diversion.

5.2.1.1 Test Results

During pool fill-up, flow directions are dictated by the location of the break and the containment geometry. During recirculation, there is a directed flowpath towards the sump screens, but perhaps at lower bulk velocities. None of the data apply to turbulence induced from direct water splashing near the curbing. It is noted that curbs could be an especially important strategy for protecting horizontal sump screens from debris buildup while the sump cavity is filling. To effectively design curbing, a reasonable detailed understanding of water velocity and direction is needed during the phase of transport for which the curbs are intended to be effective. The staff also notes that while curbing may be effective at impeding the migration of larger debris along the floor, curbs do not address the problem of suspended fines. Thus, the overall effectiveness of curbing and debris racks (next section) will depend on the site-specific debris types that they were designed to mitigate.

5.2.2 Debris Obstruction Rack Design Considerations

There is ample room for optimization of rack designs for trapping debris before it reaches the sump screen. One conceptual design that has been discussed involves two or more parallel racks placed across the flowpath to act as weirs over which the water must flow while depositing larger debris in the spaces between the racks. For this to be effective, the mesh size and height of the baffles would need to be optimized for the size of the debris and the depth of the pool to prevent obstruction of water flow. This design concept of interstitial capture between vertical risers might also be incorporated directly into a multilayered suction strainer in which the outer layers serve initially to attract and capture debris, leaving the inner layers clear to provide adequate water flow.

5.2.2.1 Test Results

The test results cited from GR Reference 55 focus on tumbling and sliding of debris along the floor. During pool fill, water velocities could be much higher than the incipient velocities listed in GR Table 5-1. The use of racks may effectively manage larger debris items moving along the floor, but would not stop the migration of individual suspended fines.

5.2.2.2 Debris Rack Grating Size

In this section, the GR emphasizes several of the design considerations mentioned above in Section 5.2.2 of this SE.

5.3 SCREEN MODIFICATION

Staff Evaluation of GR Section 5.3: This section of the GR provides guidance regarding potential sump screen designs and features.

The relative effectiveness of curbs and debris racks depends on the characteristics of the debris that challenge the sump screen. While these design features may be effective at preventing the migration of large volumes of debris along the floor, they may not be effective at preventing transport of suspended fines. Therefore, depending on the dominant debris types at a site, licensees could determine that it may be more cost effective to modify screen configurations to manage the entire range of debris size. The GR considers the attributes of three generic design approaches that licensees might pursue. These include passive strainers, backwash strainers, and active strainers.

The staff emphasizes two performance objectives that should be addressed by a sump-screen design. First, the design should accommodate the maximum volume of debris that is predicted to arrive at the screen, given full consideration of debris generation, containment transport, and auxiliary mitigation systems, such as curbing, that may be in place. Second, the design should address the possibility of thin-bed formation. When fibrous debris is expected, the screen should accommodate a large fraction of the expected fines (both from the ZOI and from potential pool degradation) as individual fibers with the potential to form a uniform layer. The difference between these objectives relates to the degree of uncertainty in debris transport methodology that the screen design should accommodate. While it is difficult to argue that debris will not be transported (first objective), it is equally difficult to demonstrate that it will be transported (second objective). Thus, both extremes should be satisfied by the screen design.

5.3.1 Considerations for Passive Strainer Designs

The large appeal of passive strainers relates to the simplicity of their maintenance and their high reliability for an adequately tested design, both important considerations for safety-related equipment. While the GR accurately presents the general attributes of existing passive designs, the presentation is focused on applications of one-dimensional head-loss correlations that have traditionally led to large strainer designs. Water velocity through the debris bed is an important factor in predicting head loss, so larger surface areas imply lower velocity for a given recirculation flow, and hence, lower head-loss. The challenge with this approach is to achieve a large surface-to-volume ratio by using a convoluted screen geometry that traps debris, while providing adequate recirculation flow without taking up too much space in containment.

Given the requirement in some plants to address thin-bed formation for potentially large amounts of fine fibrous debris, large surface areas alone may not be sufficient. Two alternative design concepts may be effective, perhaps in combination with compact geometries that achieve large surface-to-volume ratios. Generically, these design concepts may be described as disrupting the formation of a uniform fiber layer by (1) using a complex porous filter structure to capture fiber, or (2) designing hydraulic flow paths that amplify velocity gradients across the flat surfaces of the strainer where fiber first approaches.

The first design concept can be imagined as a prefilter, made perhaps of crumpled wire net (approximately 1-in. mesh) or similar material that creates a very porous volumetric filter on the face of a standard sump screen for the purpose of capturing fibers with minimal head loss. Porosity and thickness of the prefilter section would require design optimization to accommodate a specific quantity and size of suspended fiber debris. The second concept utilizes small friction losses internal to the body of a convoluted filter structure that has many fins, fingers, plates, or other protuberances on which to capture debris. Small internal friction losses can be enhanced and designed to create velocity gradients across the external surfaces of the filter. If properly designed, this feature might be effective at directing the buildup of fiber in a controlled way that avoids uniform simultaneous coverage of the strainer face. This might be used to efficiently pack material on an essentially sacrificial surface while leaving other flow areas unobstructed. These concepts, and other innovations, share a common need for adequate design testing, but they may offer effective solutions to the drawbacks of large passive strainers presented in the GR.

5.3.2 Considerations for a Backwash Strainer Design

In addition to the practical considerations for a backwash strainer design offered in the GR, the NRC staff observed the following. The staff agrees that backwash systems may need to undergo design testing and possible surveillance testing to demonstrate that they will work as intended.

1. Any design that attempts to clear an existing debris blockage should give careful consideration to the problem of resuspension and redeposition of that debris. If the working fluid is applied too violently, a cloud of debris may temporarily disperse and then reform a bed on the screen. Testing may show that this is acceptable behavior that reduces the screen loading enough to be effective regardless of bed reformation.
2. The GR suggests implicitly that normal recirculation flow will be stopped during backflushing. This may raise concerns about the restart reliability of the ECCS system. Some backflush designs might be able to operate effectively without interrupting ECCS flow. For example, a continuous water-jet curtain directed across the face of the screen might be effective at preventing debris buildup to unacceptable levels. This water flow might be provided as a side stream from

the main ECCS system so that no additional pumps, actuators, or valves need be qualified.

3. Debris beds, especially fiber-based mats, are effective filters of suspended particulate. If the entire debris mat is disturbed very quickly, the local concentration of material that can pass through the screen is suddenly very high. This may represent a unique challenge to downstream components that is not present during normal recirculation flow.
4. Most debris beds studied to date are held to the screen only by the pressure of the water flowing through them. They form no particular adhesive or mechanical attachment to the screen. Fibrous beds have been observed to slump or slough off of the screen in contiguous mats. For designs in which ECCS flow is interrupted, this behavior presents an opportunity for collecting or trapping the debris that loosens from the screen without dispersing it greatly. Debris racks, or bins, might be designed to sequester the debris mats and minimize redeposition. Minimum-flow backflush systems, in combination with inclined screens that provide gravity assist for the detachment, might benefit the most from this behavior.
5. Item 5 in the GR suggests automated control systems to actuate the backwash cycle based on measurement of pressure drop or flow. For backwash systems that function intermittently upon actuation, some degree of information feedback and/or intervention might be given to operators to increase the flexibility and utility of the backflush system as a recovery alternative for potential sump blockage.

5.3.3 Considerations for an Active Strainer Design

Active strainer concepts offer much greater design flexibility for addressing the challenges of debris accumulation in PWR recirculation pools. Therefore, they offer some unique advantages over the other two generic screen designs. The GR presents several such advantages as favorable technical considerations. One contradiction that the staff would point out relates to favorable technical consideration number 3, which offers the opinion that self-cleaning strainers may avoid uncertainties related to various debris generation and transport phenomenology. However, the same active strainer features that indicate success for some phenomena might also exacerbate problems for other phenomena. As an example, adhesive chemical corrosion byproducts might be smeared into a semi-impervious layer across the sump-screen mesh by a scraping device whereas the same debris might be dislodged by an optimized backflush system.

Active designs can carry a greater burden of proof for effectiveness and operability depending on their complexity, and the staff agrees with additional consideration number 1 that experimental studies would be needed to demonstrate the effectiveness of proposed active strainer designs. In general, many of the considerations for an active strainer design like power supply, control system reliability, and functional reliability are similar to those presented in the GR for backwash systems.[1] Many of the staff observations are also similar. For example, active strainers may be most effective when

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[1] In fact, after correcting a typographical error near the end, item 6 should read, “Margin must be available to initiate *active strainer mode* before sump blockage affects either ECC or CS operation.”

combined with mechanisms for debris collection and sequestration that over time reduce the local suspended debris concentration that poses a challenge to the strainer surface.

To maintain the generality of this discussion, the NRC prefers the terminology “active strainer” over the description of “self cleaning.” The GR accurately defines an active strainer as a design that incorporates active components to maintain flow to the sump, but there the generality of the presentation ends and discussions of self-cleaning mechanisms begin. Because there are no active strainer applications for either BWR suppression pools or PWR sumps, there should be no preconceptions imposed regarding typical active designs. Similarly, while continuous cleaning of the strainer surface area might be one desirable performance metric of an active design, it is not the only method of maintaining flow to the sump.

Another class of design solutions exists that periodically clean the strainer surface, rather than continuously cleaning the surface. An example of such a design is a set of flat, parallel, inclined sump screens that are latched at the top corners and hinged at the bottom corners. When the outer face is loaded with debris, the latches are released and the screen swings to the floor, exposing a fresh screen for debris collection and trapping its debris inventory from further transport. Other methods may be developed using gravity-assisted debris detachment on downward inclined screen surfaces. Internal flows could be alternately switched between separate chambers of the strainer to permit detachment on one side while drawing flow from the other side. Flow baffles might be switched with actuation mechanisms and control logic systems or by simple rotation of a spindle based on hydraulic flow imbalance between the chambers. The success or failure of any innovative design concept depends on how completely it can satisfy the additional considerations presented in the GR, but once the commitment has been made to facing these design challenges, no restrictions should be placed on the options available for a successful plant-specific solution.

5.3.4 Summary

In combination with staff comments provided in this SE, the NRC finds this section of the GR to be a useful and acceptable introduction to the variations in sump-screen design that an individual licensee may pursue for sump modification. The exact definitions of the generic categories and the particular label given to an innovative design are not as important as the generic attributes defined in the GR. These attributes serve as a basis for comparing the technical challenges and benefits, and the potential programmatic costs of alternative design solutions. Any consideration of screen modifications should be made in the context of the comprehensive site-specific vulnerability assessment. Alternative combinations of source mitigation, design changes, and administrative control should be weighed against existing debris types, containment geometry constraints, and NPSH margins.

6.0 ALTERNATE EVALUATION

6.1 BACKGROUND AND OVERVIEW

Section 6 of the GR describes an alternate evaluation methodology for demonstrating acceptable containment sump performance. Option B in Figure 2-1 of the GR depicts the alternate evaluation methodology described in this section.

For the last several years, the NRC has recognized that probabilistic risk assessment (PRA) has evolved to the point that it can be used increasingly as a tool in regulatory decision making. Through its policy statement on PRA (ADAMS Accession No. ML021980535), the Commission expressed its expectation that enhanced use of PRAs will improve the regulatory process through (1) safety decision making enhanced by the use of PRA insights, (2) more efficient use of agency resources, and (3) a reduction in unnecessary burdens on the licensees.

The NRC staff has considered the development of risk-informed approaches to the technical requirements specified in 10 CFR 50.46, and these considerations are documented in numerous communications between the Commission and the staff (SECY and SRM). The NRC Commissioners, in their March 31, 2003, SRM, directed the staff to undertake several rulemakings, one of which would develop a proposed rule to allow, as a voluntary alternative, a redefinition of the design-basis LOCA break size. In a March 4, 2004, letter to NEI (SB, 2004), the staff stated that it would discuss, in public meetings, the use of current or planned work to risk-inform 10 CFR 50.46 as a suitable technical basis for defining a spectrum of break sizes for debris generation and containment sump strainer performance.

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.

On May 25, June 17, and June 29, 2004, the staff met with NEI, industry representatives, and stakeholders in category 2 meetings to discuss alternate, realistic, and risk-informed approaches for resolution of the PWR sump issue. Throughout these meetings, both NRC and NEI staff presented proposals and positions regarding the technical and regulatory elements of alternative approaches.

These interactions between the staff, NEI, industry representatives, and stakeholders yielded an alternative approach which includes both realistic and risk-informed elements. For such an approach, licensees would continue to perform design–basis, long-term cooling evaluations and satisfy design-basis criteria for all LOCA break sizes up to a new 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 in the GR. Long-term cooling must 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 could apply more realistic models and assumptions. This analysis space is referred to as Region II in the GR. Additionally, any physical modifications to plant equipment, or operator actions credited to demonstrate mitigative capability for these larger breaks (Region II) would not necessarily need to be safety related or single-failure proof. Changes to the existing facility designs, and credit for operator actions would include risk evaluations consistent with RG 1.174. Licensees should ensure that the changes to the facility design would have sufficient reliability to provide reasonable assurance that they will perform their intended function.

While not a component of the 10 CFR 50.46 ECCS evaluation model, the calculation of sump performance is necessary to determine if the sump and the residual heat removal system are configured properly to provide enough flow to ensure long-term cooling, which is an acceptance criterion of 10 CFR 50.46. Therefore, the staff considers the modeling of sump performance as the validation of assumptions made in the ECCS evaluation model. Since the modeling of sump performance is a boundary calculation for the ECCS evaluation model, and acceptable sump performance is necessary for demonstrating long-term core cooling capability (10 CFR 50.46(b)(5)), the requirements of 10 CFR 50.46 are applicable. Based on this, such an alternative approach might require plant-specific license amendment requests or exemption requests from the regulations, depending on each licensee’s chosen resolution approach. Licensees could request, on a plant-specific basis, exemptions from the requirements associated with demonstrating long-term core cooling capability (10 CFR 50.46(b)(5)). For example, exemptions from the requirements of 10 CFR 50.46(d) may be required if a licensee chooses to classify new equipment as nonsafety related or not single-failure proof. For purposes of resolving GSI-191, exemption requests would not be applicable to the other acceptance criteria of 10 CFR 50.46 (peak cladding temperature, maximum cladding oxidation, maximum hydrogen generation, and coolable geometry), and would be submitted in accordance with existing NRC regulations (10 CFR 50.12). Additionally, changes in analytical methodology or assumptions may also require license amendment requests. Licensees would assess the need for license amendment requests in accordance with the requirements of 10 CFR 50.59.

The NRC staff review and acceptance of such plant-specific license amendment or exemption requests would consider the following elements:

- application of the principles of RG 1.174, ”An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions On Plant-Specific Changes to the Licensing Basis,” (e.g., defense-in-depth, safety margins, delta (CDF), delta large early release fraction)

- consistency with SRP Section 19, ”Use of Probabilistic Risk Assessment in Plant-Specific, Risk-Informed Decisionmaking: General Guidance”
- design-basis, deterministic analyses necessary to verify compliance with 10 CFR 50.46(b)(5) for break sizes up through “debris generation” break size
- acceptable mitigative capability up through the DEGB of the largest pipe in the RCS equipment needed for mitigative capability would have some functional reliability requirements, but would not necessarily need to be safety-related or single failure proof

One key element of RG 1.174 involves assurance that defense-in-depth is maintained. Although a DGBS is selected to distinguish between customary and more realistic design-basis analyses, the staff would require that licensees demonstrate acceptable mitigative capability for LOCA break sizes up through the DEGB of the largest pipe in the RCS. This philosophy is consistent with 10 CFR 50.46 (b)(5) and recent recommendations made by the Advisory Committee on Reactor Safeguards (ACRS) in its April 27, 2004, letter to the Chairman. Requiring that mitigative capability be maintained in a realistic and risk-informed evaluation of the PWR sump issue for all LOCA break sizes up through a DEGB of the largest RCS piping ensures that defense-in-depth is maintained.

6.2 ALTERNATE BREAK SIZE

The GR methodology provides the following definition for the alternate break size to be applied for an alternate evaluation of sump performance:

- a complete guillotine break of the largest line connected to the RCS loop piping
- for main-loop piping, a break size assumed to be equivalent to a guillotine break of a 14-in. schedule 160 line, and equating to an effective break area of 196.6 square inches (assuming both sides of the break are pressurized)

In defining these break sizes, the alternate break size to be considered by each licensee for lines connected to the main-loop piping is plant dependent, while the alternate break size to be applied to the main-loop piping is identical for each licensee.

The GR also provides guidance for determining whether a DEGB needs to be considered in attached piping. If sufficient energy for debris generation exists on both sides of the break, a DEGB will be used. The GR criteria for determining whether sufficient energy exists are based on the postulated break distance from a normally closed isolation valve and include the following:

- 10 pipe inside diameters for large-bore piping (i.e., greater than a 2 in. diameter)
- 20 pipe diameters for small-bore piping

If a normally closed isolation valve exists within this number of pipe diameters, then a licensee need only consider a single-ended break. These GR criteria are based on the low stored energy in the pipe section between the break and isolation valve with respect to significant debris generation.

Additionally, the GR provides guidance for consideration of the ongoing 10 CFR 50.46 rulemaking effort. The GR states that, "In using this GSI-191 alternate break size, it is recognized that when the 50.46 rule is finalized, licensees can re-perform the sump performance evaluations with the final break size specified in 50.46 and modify the plant design and operation. This would assure coherence in the implementation of 50.46."

Staff Evaluation of GR Section 6.2: The staff has reviewed the alternate break size proposals as described in the GR and finds them to be acceptable.

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.

Several factors comprise the technical basis for the staff's acceptance of the division of the pipe break spectrum for the purpose of evaluating debris generation. First, the staff considered recent information developed by the NRC's Office of Nuclear Regulatory Research (RES) regarding the frequency of RCS ruptures of various sizes. The RES developed this information through an expert elicitation process, as documented in SECY-04-0060, "Loss-of-Coolant Accident Break Frequencies for the Option III Risk-Informed Reevaluation of 10 CFR 50.46, Appendix K to 10 CFR Part 50, and General Design Criteria (GDC) 35." The RES study determined the frequency of primary pressure boundary failures under normal operational loading and transients. Although the results of the expert elicitation are not yet final, the preliminary results support the observation that the probability of a PWR primary-piping system rupture is generally very low and that the break frequency decreases with increasing piping diameter. The selection of a break size equivalent to the area of a DEGB of a 14 in. schedule 160 pipe for RCS main loop piping is consistent with the attached auxiliary piping sizes in PWRs, and is also consistent with the ongoing 10 CFR 50.46 rulemaking direction (at this time).

The staff also considered the fact that there is a substantial difference from a deterministic, "margins to failure" or "flaw tolerance" perspective between 30-in.to 42–in. diameter PWR main coolant loop piping and the next largest ASME Code Class 1 attached auxiliary piping (generally the 12-in. to 14–in. diameter pressurizer surge line). This difference is evident, for example, in leak before break (LBB) evaluations conducted in accordance with NUREG-1061, Volume 3, "Report of the U.S. Nuclear Regulatory Commission Piping Review Committee," wherein main coolant loop piping characteristically passes an LBB evaluation more easily than ASME Code Class 1 auxiliary piping systems. Finally, the staff considered the fact that certain ASME Code

Class 1 auxiliary piping systems may be more susceptible to failure as a result of environmental conditions which are conducive to known degradation mechanisms and/or loading conditions which routinely apply significant stresses to the piping system. An example of both of these considerations would be a typical PWR pressurizer surge line in which Alloy 82/182 dissimilar metal welds are subjected to a high-temperature operating environment known to abet primary water stress-corrosion cracking and which is subjected to significant bending loads during startup/shutdown conditions because of the large temperature gradient between the pressurizer and the hot leg of the main coolant loop.

Based upon the considerations noted above, the staff has determined that the division of the pipe break spectrum proposed for the purpose of evaluating debris generation is acceptable based on operating experience, application of sound engineering judgment, and consideration of risk-informed principles. Licensees using the methods described in Section 6 of the GR can apply the defined DGBS for distinguishing between Region I and Region II analyses.

The staff has reviewed the GR guidance provided regarding the need to consider a DEGB in attached auxiliary piping. The GR provides criteria based on the number of pipe diameters, pipe size, and distance to a normally closed isolation valve for determining if sufficient energy for debris generation exists on both sides of the break. If a normally closed isolation valve exists within a specified number of pipe diameters from a postulated break location, than only a single-ended break needs to be considered. The GR does not provide a technical basis for this criterion. To assess the acceptability of this proposal, the staff considered the fluid volumes available on each side of a DEGB which would fall within the criteria provided in the guidance. Considering that a break occurs at the maximum distance from a normally closed isolation valve, as allowed by the proposed criteria, the staff agrees that there would be an insignificant amount of energy available for destruction from the isolated side of the break when compared to the fluid volume and energy available on the unisolated side of the break. For example, in the case of a DEGB of a 1–ft. diameter auxiliary pipe with a normally closed isolation valve 10 inside pipe diameters away, the fluid volume in the isolated piping portion is less than 10 cubic feet. This fluid volume is insignificant when compared to the RCS fluid volume, which is on the order of 10,000 cubic feet. The fluid and energy blowdown from the isolated side of the break will depressurize and void almost instantaneously, while the blowdown from the RCS side of the break would be significantly larger, on the order of minutes (the staff verified this through a simplified RELAP calculation). Based on this, and considering engineering judgment, the staff finds that the criteria proposed by NEI for evaluating whether a DEGB should be considered in auxiliary piping is acceptable. The staff's engineering judgment takes into consideration that (1) past experiments and analyses have confirmed that debris generation caused by initial blast impulse (which would be from both sides of the postulated break) would be minimal, and (2) that debris generation is dominated by jet loading and/or jet erosion. As confirmed by the staff's estimate, blowdown jet impacts would be dominated by the blowdown from the RCS side of the break.

The staff also considered the GR guidance regarding consideration of the ongoing 10 CFR 50.46 rulemaking effort. The staff agrees with the recommended guidance that licensees may re-perform the sump performance evaluations using the final break size specified in the rulemaking and modify the plant design and operation accordingly. This would assure consistency with the new requirements of 10 CFR 50.46. The staff expects that the DGBS specified in this section will bound the transition break size specified by these new requirements.

6.3 REGION I ANALYSIS

The Region I analysis of recirculation sump performance includes evaluation of all break sizes up to and including the DGBS defined in Section 6.2. The majority of the analyses to be performed for the Region I break sizes are to be conducted in the manner described in Sections 3, 4, and 5 of the GR. For Region I breaks, the GR states that a full range of break locations will be assessed to determine the limiting location considering both debris generation and debris transport. However, as discussed in Section 6.3.2, the GR refers to a Section 4 refinement proposing that BTP MEB 3-1 may be used to limit the break locations considered. Additionally, any design–basis, secondary-side breaks (main steamline break, feedwater line break, etc.) which rely on sump recirculation will be analyzed in accordance with the Region I analyses.

With respect to break configuration, circumferential breaks will be assumed to result in pipe severance and separation amounting to at least 1-diameter lateral displacement of the ruptured piping sections, unless physically limited by piping restraints and supports, or other plant structural members that can be shown through analysis to limit pipe movement to less than 1-diameter lateral displacement. For pipes with a larger diameter than the maximum break size, the maximum attainable break area would be modeled as a partial pipe break with an area equivalent to the DEGB of a pipe with the same diameter as the DGBS. The worst location of the break in terms of orientation around the break location should be considered.

One area of which the GR Section 6.3 guidance differs from the guidance in the baseline analysis of Section 3 involves the ZOI to be considered for debris generation. The guidance in Section 3 regarding the ZOI presumes a DEGB, and for a DEGB, a spherical ZOI is conservatively postulated. A spherical ZOI is appropriate in the Region I analyses for any auxiliary piping attached to the RCS, since a DEGB of any such piping falls within Region I analysis. However, partial breaks of the RCS main loop piping are also included in Region I (breaks up to the DGBS), and would indicate a limited-displacement circumferential break or a longitudinal break, (i.e., “split break”). The GR proposes that the ZOI for such partial breaks in RCS main loop piping be accounted for by applying one of the following two methods:

- For a ZOI based on a hemisphere, the ZOI is simulated as a hemisphere radius determined by the destruction pressure of the insulation that would be affected by the postulated break. The break orientation needs to be simulated at various angles around the loop piping to determine maximum debris generation.
- For a ZOI based on a sphere, because the worst-case break orientation can be difficult to determine, an alternative to assuming a hemispherical ZOI is to translate the hemispherical volume into an equivalent-volume sphere.

The GR also states that the ZOI refinements discussed in Section 4 are available when performing Region I analyses.

The acceptance criteria for containment sump-screen performance continue to be core cooling based on available NPSH equal to, or greater than, the required NPSH for all pumps needed to operate for long-term core cooling. The calculations of required and available NPSH are based on the models and assumptions currently used in design-basis analyses of sump and core-cooling recirculation performance. Additionally, the GR states that if containment spray is credited in the design-basis analyses, the containment sump-screen performance also includes NPSH margin for the minimum required containment spray.

The Region I analyses also consider the impact of the DGBS on event timings, thermal-hydraulic conditions, and NPSH requirements. For example, use of the DGBS will affect key scenario events, such as the timing of transfer from refueling water storage tank (RWST) injection to recirculation mode, the containment sump water properties (e.g., temperature), and containment back-pressure (if credited in the design-basis analyses). The Region I evaluation will consider these revised timings and parameters as appropriate. The guidance also provides for the impact of operator actions to mitigate containment sump blockage, provided that the operator actions meet the criterion for consideration in design-basis analyses. These considerations would include adequate time for operator action in accordance with design-basis rules, proceduralized guidance, job task analysis, training, and other requirements.

Staff Evaluation of GR Section 6.3: The staff has reviewed the Region I alternate evaluation methodology, as described in the GR. The Region I analysis methods described in Section 6.3 are applicable for any break sizes equal to or smaller than the DGBS defined in Section 6.2. The Region I methodology, therefore, applies to any ASME Code Class 1 auxiliary piping (attached to RCS main-loop piping) up to and including a DEGB of any of these lines, as well as RCS main-loop piping (hot, cold and crossover piping) up to and including a size equivalent to the area of a DEGB of a 14–in. schedule 160 pipe. The majority of the Region I analyses are performed in the same manner as the methods described in Sections 3, 4, and 5 of the GR, and as such, the corresponding sections in this SE are applicable for Region I analysis. For example, the guidance in Sections 3 and 4 of this SE is to be used as part of the Region I analyses to determine the debris generation, transport, and accumulation on the containment sump screens. The staff evaluation described below will focus on the differences between this SE and Sections 3, 4, and 5 of the GR.

For Region I breaks, the GR states that a full range of break locations will be assessed to determine the limiting location, considering both debris generation and debris transport. Additionally, as discussed in Section 6.3.2, the GR refers to a Section 4.2.1 refinement which proposes that BTP MEB 3-1 may be used to limit the break locations considered. As documented in Section 4.2.1 of this SE, the staff concluded that it is inappropriate to cite SRP Section 3.6.2 and BTP MEB 3-1 as methodology to be applied for determining break locations to be considered for PWR sump analyses. The staff concludes that for Region I breaks, which are considered as customary design-basis analyses, a full range of break locations should be assessed to determine the limiting location considering both debris generation and debris transport. Section 4.2.1 of this SE provides further details regarding the staff's position. The staff finds that the GR guidance is acceptable with respect to break configuration because the methodology assures that the limiting break location, considering debris generation, debris transport, and the worst location of the break in terms of orientation around the break location, will be evaluated. This methodology provides reasonable assurance that the limiting break conditions for PWR sump analyses will be evaluated. Additionally, considering piping restraints and supports or other plant structural members that can be shown through analysis to limit pipe movement to less than 1-diameter lateral displacement may be acceptable to the staff; however, because the limiting break location and orientation must be evaluated, these locations may not produce the limiting conditions for sump analyses.

Regarding the ZOI to be considered for attached auxiliary piping breaks, the GR states that a spherical ZOI is postulated for breaks smaller than the DGBS for piping connected to the RCS main loop piping because a DEGB of this piping is postulated. For Region I partial pipe breaks, the GR proposes that one of two methods be applied, either a ZOI based on a hemisphere or a ZOI based on translating the hemispherical volume into an equivalent-volume sphere. The staff evaluated the GR with respect to the ZOI to be considered under these conditions and concludes that applying a hemispherical ZOI is acceptable for such partial breaks, and that when doing so, licensees will need to simulate various directions around the RCS main-loop piping to determine the limiting break location. The staff does not accept the proposed approach of a ZOI based on translating the hemispherical volume into an equivalent-volume sphere. The GR does not provide any technical justification for this approach except that it is a simplification because the worst-case break orientation can be difficult to determine. The staff does not have a technical basis for accepting a translation of the volumes, which would result in a different ZOI, and the staff has no basis to evaluate whether this would be conservative, nonconservative, or realistic. For simplification, the staff would accept application of a spherical ZOI with a radius equivalent to that of a ZOI based on a hemisphere.

The application of the ZOI refinements for Region I analyses should be in accordance with the staff's position discussed in Section 4.0 of this SE.

For the Region I sump analyses, the acceptance criteria for containment sump-screen performance continues to be core cooling based on available NPSH equal to, or greater than, the required NPSH for all pumps required to operate for long-term core cooling. The calculations of required and available NPSH are based on the models and assumptions currently used in design-basis analyses of sump and core cooling recirculation performance, and therefore, the staff finds their continued application for Region I analyses to be acceptable. The staff agrees with the GR that the impact of the DGBS on event timings, thermal-hydraulic conditions, and NPSH requirements, as well as crediting operator actions for demonstrating that the acceptance criteria are satisfied, can be applied for Region I analyses consistent with customary design-basis analysis procedures and requirements. Licensee analyses should consider, at a minimum, the following factors:

1. The accuracy of deterministic analyses performed to calculate DGBS event timings, thermal-hydraulic conditions, and NPSH requirements, and their compliance with 10 CFR 50.46. The staff expects that licensees will document, and if necessary, provide to the staff detailed information regarding the analyses and the modeling assumptions. The GR guidance does not explicitly identify which phenomena and parameters will receive time-dependent treatment and will be considered in-scope for estimating timing of events.
2. The experimental data used for estimating debris generation, transport, and head-loss buildup for breaks other than a DEGB. In general, most experimental data were obtained for jet conditions and transport flow rates prototypical of a DEGB. For example, most of the debris generation data were obtained for jet

durations typical of a DEGB (10–30 seconds). Direct use of such data for insulations where erosion is the dominant generation mechanism (e.g., calcium silicate) may not be appropriate for a DGBS break. Similar limitations on the applicability of available experimental data to a DGBS exist for other phenomena as well, including debris transport and debris buildup, especially when operator actions are to be credited in the mix of the analyses being performed. However, application of GR Section 3 baseline methods ensures conservative treatment of erosion concerns for tabulated materials.

3. Because of uncertainties in various phenomena, the staff believes that it is difficult to judge when maximum head loss would occur (e.g., the maximum debris accumulation and the minimum NPSH margin may or may not occur simultaneously, depending on operator actions). Considerable attention and a broad spectrum of evaluations should be devoted to establish that the analyses conducted are customary design-basis analyses.
4. If credit is to be taken for containment overpressure, underlying analyses should conform with the staff guidance for estimating minimum overpressure, as suggested in RG 1.82, Revision 3.

The staff notes that there is a typographical error in the following sentence of Section 6.3.6 of the GR, “In addition, if containment spray is credited in the design basis analyses (containment pressure, radiological consequence, etc.), the containment sump-screen performance also includes NPSH margin for operation of the minimum required containment spray.” The staff believes that this sentence should state that adequate NPSH margin needs to be available for the maximum required containment spray or to allow for an overestimate of the required containment spray.

6.4 REGION II ANALYSIS

The Region II analysis of recirculation sump performance includes evaluations of break sizes in the RCS main loop piping (hot, cold, and crossover piping) greater than the DGBS specified in GR Section 6.2 (approximately 196.6 square inches) and up to a DEGB of the largest pipe in the RCS. Region II considers only RCS main loop piping because all primary-side attached auxiliary piping and secondary-side breaks are fully addressed as part of the Region I analyses. Section 6.4.2 of the GR states that, “if a licensee chooses to use an alternate break size smaller than the largest connected piping to the main coolant loop piping, as discussed in Section 6.2, then connected piping larger than the alternate break size would be addressed as part of the Region II evaluation.” The staff finds that this statement is not consistent with the alternate break size, as defined in Section 6.2, and should be clarified. The NEI and industry representatives informed the staff that this statement is included in the GR to allow for the possibility that the forthcoming 10 CFR 50.46 rulemaking would redefine the design-basis LOCA break size to be smaller than the DGBS described in Section 6.2. As discussed in Section 6.2 of this SE, the staff agrees with the recommended guidance that licensees may re-perform the sump performance evaluations using the final break size specified by rulemaking and modify the plant design and operation accordingly.

Section 6.4.2 of the GR refers to a Section 4 refinement proposing that BTP MEB 3-1 may be used to limit the break locations considered. With respect to break configuration, the Region II analyses are limited to a DEGB of the RCS main loop piping.

These circumferential breaks are assumed to result in pipe severance and separation amounting to at least 1-diameter lateral displacement of the ruptured piping sections, unless physically limited by piping restraints and supports, other plant structural members, or piping stiffness as may be demonstrated by analysis. The GR states that existing plant-specific dynamic loads analyses for postulated primary-side breaks are utilized to determine the break configuration for Region II analyses.

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.

The guidance in Sections 3 and 4 of the GR is also applied to determine the debris generation, transport, and accumulation on the containment sump screens for Region II evaluations. The models presented in Sections 3 and 4 are considered to be bounding models to assure that the debris generation, transport and accumulation are not under-predicted. There are known conservatisms in each portion of these evaluation models described in Sections 3 and 4. However, development of more realistic models in these areas is difficult because of the limited amount of experimental and analytical information available, and this work has not yet been initiated.

The acceptance criteria for containment sump-screen performance for Region II analyses are continued core and containment cooling. The following criteria to demonstrate retained mitigation capability for long-term cooling capability in Region II analyses:

- Positive NPSH margin is maintained for the minimum number of ECCS pumps necessary to demonstrate adequate core cooling flow.
- Adequate containment cooling capability is demonstrated to provide assurance that the containment boundary remains intact.

The first criterion (i.e., positive NPSH margin is maintained for the minimum number of ECCS pumps) can be met by ensuring that the NPSH margin is maintained for one or more moderate to high-capacity ECCS injection pumps. Additionally, for Region II analyses, the GR states that limited operation without an NPSH margin is acceptable if it can be shown that the pumps can reasonably be expected to survive during the time period of inadequate available NPSH. The suggested technical justification for this statement would include vendor information in the form of test data or engineering judgment derived from tests and/or operational events.

The GR states that the second criterion (i.e., demonstration of adequate containment cooling capability) can be met through credit taken for minimal heat removal pathways, including containment fan coolers, permitted by emergency procedures. Additionally, subatmospheric containment plants would not have to demonstrate that the containment remains below atmospheric pressure for the duration of the accident, if permitted by emergency procedures. The GR also states that, “exceeding nominal transient containment design pressure/temperature and environmental qualification (EQ) envelopes is allowed for Region II analysis, if reasonable assurance is provided that containment pressure boundary failure or vital equipment failure would not be expected.”

The Region II analyses also consider more realistic modeling of debris generation, transport, and accumulation on sump screens based on the timing of debris generation, transport, and accumulation in relation to the timing of the available and required NPSH. More realistic modeling of these items considers the following:

- Debris generation, transport, and accumulation are time dependent.
- Available NPSH is time dependent.
- The maximum debris accumulation and the minimum required NPSH may not occur simultaneously.

The GR also allows credit for operator actions and the operation of non-safety equipment.

Staff Evaluation of GR Section 6.4: The staff has reviewed the Region II alternate evaluation methodology described in the GR. The Region II analysis methods described in Section 6.4 are applicable for any breaks in the RCS main loop piping (hot, cold and crossover piping) greater than the DGBS specified in Section 6.2 (approximately 196.6 square inches) and up to a DEGB of the largest pipe in the RCS.

For Region II break locations, Section 6.3.2 of the GR refers to a Section 4.2.1 refinement proposing that BTP MEB 3-1 be used to limit the break locations considered. As documented in Section 4.2.1 of this SE, the staff concludes that it is inappropriate to cite SRP Section 3.6.2 and BTP MEB 3-1 as methodology to be applied for determining break locations to be considered for PWR sump analyses. The staff concludes that for Region II breaks, a full range of break locations should be assessed to determine the limiting location, considering both debris generation and debris transport. Section 4.2.1 of this SE provides further details regarding the staff’s position.

The staff finds that the GR guidance is acceptable with respect to break configuration because the limiting break location, considering debris generation, debris transport, and resulting sump-screen head loss, will be evaluated. This methodology provides reasonable assurance that the limiting break conditions for PWR sump analyses will be evaluated. Additionally, considering piping restraints and supports or other plant structural members that can be shown through analysis to limit pipe movement to less than 1-diameter lateral displacement may be acceptable to the staff; however, because the limiting break location must be evaluated, these locations may not produce the limiting conditions for sump analyses.

Certain portions of the Region II analyses are performed in the same manner as the methods described in Sections 3 and 4 of the GR; the corresponding SE sections are applicable for Region II analyses. The guidance in Sections 3 and 4 is to be used as part of the Region II analyses with respect to ZOI models and assumptions, and for determining debris generation, transport, and accumulation on the containment sump screens. There are known conservatisms in each of these models as described in Sections 3 and 4, and the staff finds them to be acceptable for Region II analyses.

Sections 0 and 4.0 of this SE provide further details regarding the staff's position and review of these models.

The GR proposed the following two acceptance criteria for the Region II analysis:

- Maintain positive NPSH margin for the minimum number of ECCS pumps necessary to demonstrate adequate core cooling flow.
- Demonstrate adequate containment cooling capability to provide assurance that the containment boundary remains intact.

The staff considers a positive NPSH margin to mean that the available NPSH is greater than the required NPSH for each pump. The GR has not specified the amount of NPSH margin necessary. Because the staff has previously accepted the available NPSH equal to the required NPSH (i.e., an NPSH margin of zero), this nonspecificity is acceptable for realistic and risk-informed Region II analyses. Sections 6.4.7.1 and 6.4.7.2, respectively, of this SE address the determination of both the available and the required NPSH.

The GR does not specify what is meant by adequate core cooling. The staff interprets adequate core cooling to mean that the acceptance criteria of 10 CFR 50.46 are satisfied. By maintaining a positive NPSH margin to demonstrate adequate core cooling flow, the 10 CFR 50.46 acceptance criteria should not be challenged.

The GR does not specify what is meant by adequate containment cooling. The staff interprets adequate containment cooling to mean that the containment is in a safe and stable state and is preventing risk-significant fission product releases. Further, the containment has not failed structurally. The GR states that containment design pressure and the containment design temperature may be exceeded for analyses of breaks above the DGBS. The staff will consider this, and licensees should determine, on a plant-specific basis, whether exemption and/or license amendment requests are required if the containment design pressure and/or temperature is exceeded. Licensees should determine whether the containment leakage rate exceeds the value of L_a defined in Appendix J to 10 CFR Part 50 and given in the plant's technical specifications. An exemption to this regulation and/or a license amendment request might be required if a licensee determines that this is the case. The staff will evaluate these requests on a plant-specific basis.

The GR states that the second criterion can be met through credit taken for minimal heat removal pathways, including containment fan coolers, permitted by the emergency procedures. The staff finds that credit taken for minimal heat removal pathways permitted by the emergency procedures would be acceptable in a realistic and risk-informed Region II analysis. The staff expects that licensees will provide detailed information regarding plant equipment and/or operator actions credited in their GL responses. The staff will assess credit taken for minimal heat removal pathways as part of the GL response reviews and closeout process.

The GR also states that it is acceptable to exceed the "nominal" environmental qualification (EQ) envelopes. The staff finds that applying a more realistic EQ envelope could be acceptable in a realistic and risk-informed Region II analysis. For Region II analyses, the staff does not consider it necessary to comply with the guidance of

NUREG-0588, Revision 1, which is the basis for the EQ analyses described in plant updated final safety analysis reports (UFSARs). If any equipment exceeds the appropriate EQ envelope, the licensee should consider whether an exemption to 10 CFR 50.49 is required. The staff expects that licensees will provide detailed information with respect to exceeding nominal EQ profiles in their GL responses. The staff will assess the application of EQ envelopes as part of the GL response reviews and closeout process.

For the Region II evaluation, the GR criteria would allow limited ECCS and containment heat removal pump operation without an NPSH margin. Licensees would need to demonstrate that the pumps can reasonably be expected to survive during the time of inadequate available NPSH margin. Test data or engineering judgment derived from tests and/or operating experience should serve as the basis of the technical justification for this conclusion.

The GR points out that the guidance for determining adequate NPSH margin is currently provided in RG 1.1, which is the licensing basis for some operating reactors, and RG 1.82, Revision 3, which contains the current staff guidance. The GR suggests that it is not necessary to apply the conservative guidance provided in these RGs when analyzing the consequences of breaks larger than the DGBS. The remainder of Section 6.4.7 provides guidance on an alternate, more realistic approach.

Section 6.4.7 discusses the application of GL91-18 with respect to determining a realistic NPSH margin. The GR considers that a “nominal” parameter value used in performing Region II analyses could be exceeded. For this situation, the GR proposes that operability assessments in accordance with GL 91-18 are not necessary. The GR establishes a time limit allowing the nominal value to be exceeded for a period of 30 days. LOCA analyses are typically carried out only to 30 days. The staff finds this proposal to be unacceptable because the Region II analyses remain within the design bases. Exceeding the nominal value of a parameter used the Region II analyses may result in decreasing the available NPSH to the degree that there is no longer positive margin for this DBA. Therefore, the staff concludes that the same conditions apply for a Region II analysis as would apply for a Region I analysis, and the guidance in GL 91-18 should also apply.

The GR discusses the realistic assumptions that may be applied in calculating the available NPSH for breaks larger than the DGBS. Section 6.4.7.1 of the GR discusses these assumptions for each of the factors which contribute to the available NPSH, including suction elevation head, absolute pressure head, vapor pressure head, and friction and form-head losses. The staff finds the GR discussion in Section 6.4.7.1 to be acceptable with one caveat. The discussion of friction losses notes that experience has shown that calculations of friction loss based on handbook values tend to overestimate the friction loss. The GR states that these values may be reduced based on engineering judgment or test results. To quantify the available margin in these calculations, the staff’s position is that a more substantive basis than engineering judgment should be used. Engineering judgment by itself, without further technical basis, does not provide adequate justification for removing conservatism in handbook friction loss values. The staff will accept a reduction in head-loss calculations based on accepted handbook values only if its basis is technically justified.

The pump vendor measures the required NPSH of a pump in accordance with applicable standards. It is usually based on a 3 percent drop in the pump total head (first stage for a multi-stage pump). This value has been selected as an easily recognized level of cavitation. It is not the level at which cavitation first appears. The GR states that, since total head is not necessarily a critical parameter for a centrifugal pump in the LOCA recirculation mode, the pump vendor may be able to provide relief in the amount of NPSH required to avoid pump damage, rather than depend on the formal definition of required NPSH. The staff agrees. In the past, the staff has accepted the pump vendor's technical judgment on pump capabilities. In this case, the conditions the pump will experience and the time period during which the pump will experience these conditions should be well defined and evaluated by the pump vendor. In addition, staff believes that vendors' technical judgments should take into consideration the fact that recirculation water may include debris of different kinds and sizes (i.e., combined effects of debris ingestion and cavitation should be factored into decision making).

The GR states that accounting for the decrease in required NPSH with an increase in pumped liquid temperature, as discussed in ANSI/HI 1.1-1.5-1994 (ANSI/HI 1.1-1.5), should not be used. The staff agrees. This is consistent with the guidance in RG 1.82, Revision 3.

The calculational method section (Section 6.4.7.3) of the GR discusses assumptions that could be applied for more realistic available and required NPSH calculations. It is not clear what is meant by calculating required NPSH because the pump vendor typically measures and specifies the required NPSH. Licensees referencing the GR should clarify this. One of the items listed in this section refers to: "containment pressure head based on absolute pressure rather than vapor pressure." Rather than "absolute pressure," the term "pressure of the containment atmosphere," would be clearer. The staff expects that licensees will provide detailed information regarding the application of more realistic analysis assumptions in their GL responses. The staff will assess these assumptions as part of the GL response reviews and closeout process. Additionally, application of certain assumptions may require plant-specific exemptions and/or license amendment requests.

With respect to timing of events, the GR discusses the realistic modeling of debris generation, transport, and accumulation on sump screens. One bullet in this section states that "the maximum debris accumulation and the minimum required NPSH may not occur simultaneously." It appears that this is referring to the minimum available NPSH margin, rather than the minimum required NPSH. Other than this editorial comment, the staff agrees with the report's proposals in this section. The staff expects that licensees will provide detailed information regarding more realistic modeling of event timing in their GL responses. The staff will assess this modeling as part of the GL response reviews and closeout process.

The staff agrees with the GR's proposal of operator actions that may be credited to compensate for the effects of debris generation on the ECCS and the containment spray system. Credit for these actions will be assessed on a plant-specific basis, and risk calculations supporting the credit should be performed in accordance with RG 1.174.

The GR does not address the analytical methods to be used for performing the Region II analyses (e.g., computer codes and models). In particular, the staff has reservations about how the models and methods described in Sections 3 and 4 could be adopted for these types of analyses. The staff will assess the adequacy of methods used during its review of any plant-specific licensing submission and plant-specific audits performed as part of the GSI-191 and GL closeout process. Part of the staff's assessment would include methods, models, and data used to estimate event timings; thermal-hydraulic conditions; and the calculational uncertainties associated with the debris phenomena. It is known that all aspects of debris phenomena (i.e., generation, transport, and head loss) have large uncertainties. In lieu of explicitly treating these uncertainties, staff used engineering judgment to conclude that these uncertainties are typically small compared to the conservatism introduced by DEGB-type limiting analyses. Licensee evaluations performed under Region-II should be cognizant of such issues and address them explicitly. For example, considerable experimental evidence exists in support of increased head loss resulting from long-term operation. Very limited, if any, experiments are carried out to quantify such a factor mechanistically. Instead traditional correlations developed using short-term tests, corrected based on engineering judgment, were used to account for long-term phenomena. In the past, the staff accepted such approximations because of the large margin of conservatism implicit in DEGB-type analyses.

6.5 RISK INSIGHTS

Section 6.5 of the NEI GR guides the determination of risk acceptability for cases in which a licensee relies on sump mitigation capability (including crediting operator actions) for the Region II analysis (i.e., Section 6.4). Section 6.5 of the NEI evaluation guidance uses the acceptance guideline from RG1.174, which is also used to define an acceptably small increase in CDF to establish a target reliability for the sump mitigation capability. To further ensure the acceptability of this approach, the NEI evaluation guidance also uses a conservative value for the LBLOCA initiating event frequency (LBLOCA:IEF), which is taken from NUREG-1150. Thus, the NEI evaluation guidance provides a method by which a licensee can ensure that any increase in CDF resulting from plant modifications, operator actions, etc., and which is credited in Section 6.4, will be small and will meet the RG 1.174 acceptance guideline by demonstrating that the target reliability of the sump mitigation capability is achieved.

The target reliability is established by first calculating the increase in CDF as the combination of the LBLOCA:IEF and the sump mitigation capability failure probability (SMC:FP). This calculation uses a number of conservatisms to make it simple and straightforward, including the following:

- The base case condition represents the condition in which the current sump meets the regulations without needing credit for mitigation capability and is assumed not to clog (i.e., the sump is perfect, with a clogging probability of 0).
- The mitigation condition case represents the condition in which the sump takes credit for mitigation capability and assumes if the mitigation capability fails, the sump will clog (i.e., the sump always clogs if the mitigation capability fails, with a clogging probability of 1). Further, a clogged sump results in core damage (i.e., no credit for potential recovery actions).
- The calculation is performed for the entire LBLOCA break spectrum (i.e., all breaks greater than about 6 inches), while the NEI evaluation guidelines Region II alternate approach is only used for those break sizes greater than the DGBS,

which is only a portion of the LBLOCA break spectrum (i.e., the calculation assumes all LBLOCAs require mitigation, not just those greater than the DGBS).

Based on this approach, the calculation for the increase in CDF can be simplified to:

$$\Delta CDF = LBLOCA{:}IEF \times SMC{:}FP$$

Recognizing that the target reliability (TR) is the complement of the SMC:FP, resolving the equation results in:

$$TR = 1 - SMC{:}FP = 1 - [\Delta CDF / LBLOCA{:}IEF]$$

The RG 1.174 acceptance guideline for a small change in CDF is less than 1.0x10-5/year. This is an appropriate acceptance guideline for plants where the total CDF can be reasonably shown to be less than 1.0x10-4/year. The NEI evaluation guidance states that the 1.0x10-4/year total CDF value bounds the population of PWRs. The staff accepts that this may be true. However, if a licensee's total CDF is significantly greater than 1.0x10-4/year, considering all modes and initiators, then that licensee should provide additional justification and meet an appropriately higher TR.

The value for the LBLOCA:IEF from NUREG-1150 is 5.0x10-4/reactor-year. The staff recognizes that this value represents a generic bounding value of the LBLOCA frequency and is considerably greater (and thus conservative) than the value used in plant-specific PRAs.

Substituting the above values into the equation results in a TR for the sump mitigation capability of 0.98 per demand (i.e., SMC:FP equals 2.0x10-2/demand).

The staff understands that the reliability of the sump mitigation capability will be determined on a plant-specific basis and ensured with reasonable confidence to be equal to or greater than the above established target reliability. This determination will include evaluations of associated plant modifications, as well as credited operator actions, including those modifications and actions credited in Section 6.4 that represent a change from current operations (e.g., crediting operator action to terminate or reduce containment spray flow to assure NPSH of the low-head pumps).

The staff also accepts that passive components do not need to be considered in the reliability determination, as long as these passive components are demonstrated as being functional by design (e.g., enlarged sump-screen areas) or failure is determined to be extremely unlikely (e.g., less than 1.0x10-5/demand), even given the challenges that passive components might see, such as jet forces or blowdown loads. However, if a measurable and inspectable reliability can be ascribed to a passive component (e.g., passive screen cleaning), then the reliability determination should include these features.

Consistent with the RG 1.174 principles of risk-informed decision-making, the impact of the proposed change must be monitored using performance measurement strategies. Therefore, an implementation and monitoring plan must be developed to ensure that the evaluation conducted to examine the impact of the proposed changes continues to reflect the actual reliability and availability of the SSCs and operator actions that have been evaluated. This will ensure that the conclusions that have been drawn from the evaluation remain valid. Thus, the staff requires licensees to propose, in their plant-specific submissions, a monitoring program that is consistent with RG 1.174, Section 2.3, which includes a means to adequately track the performance of equipment that, when degraded, can affect the conclusions of the licensees' evaluations (i.e., demonstration of the sump mitigative capability to meet its reliability target). The program must be capable of trending equipment performance after a change has been implemented to demonstrate that performance is consistent with that assumed in the traditional engineering and probabilistic analyses that were conducted to justify the change. This must include monitoring associated with non-safety-related SSCs, if the analysis identifies those SSCs to be relied upon to meet the sump mitigative capability TR. The program must also be structured such that feedback of information and corrective actions are accomplished in a timely manner and degradation in performance is detected and corrected before plant safety can be compromised. The staff expects that licensees choosing to apply this methodology will comply with the guidance in RG 1.174 or provide justification for the deviation.

In summary, the staff finds this portion of the alternate approach acceptable for use in the NEI evaluation guidance Region II analyses for the following reasons:

- The TR determination includes a number of conservative simplifications.
- It is performed for the entire LBLOCA break spectrum (i.e., all breaks greater than about 6 inches), while the NEI evaluation guidance Region II alternate approach is only used for those break sizes greater than the DGBS, which is only a portion of the LBLOCA break spectrum.
- The base case condition is assumed not to be susceptible to clogging (i.e., the sump is perfect, with a clogging probability of 0).
- The mitigation condition case assumes if the mitigation capability fails, the sump will clog (i.e., the sump always clogs if the mitigation capability fails, with a clogging probability of 1), and that a clogged sump results in core damage (i.e., no credit for potential recovery actions).
- The NUREG-1150 LBLOCA:IEF of 5.0x10-4/reactor-year is expected to be much greater than the LBLOCA value derived from the ongoing RES expert elicitation process.
- The approach is consistent with RG 1.174 since it uses the acceptance guidelines that define an acceptably small CDF increase in determining the TR of the sump mitigation capability.
- Licensees choosing to apply Region II analyses should implement a performance monitoring program, consistent with Section 2.3 of RG 1.174, to ensure that the conclusions of the licensees' evaluations (i.e., demonstrations that the sump mitigative capability meets the established TR) are maintained valid.

In considering the risk-informing aspects of the resolution of GSI-191, the staff recognized that there is the potential that the containment sump may clog, if the mitigation capability credited in the Region II analysis does not function properly. Based on the industry-proposed approach in the Region II analysis, which also uses the conservative NUREG-1150 LBLOCA frequency to calculate the TR of the mitigation capability, and using the related generic study information, the largest LBLOCA CDF would be 1.4x10-5/year. This indicates that at a minimum, the risk associated with LBLOCAs will be reduced from the current condition by nearly an order of magnitude.

7.0 ADDITIONAL DESIGN CONSIDERATIONS

This section of the GR discusses four extenuating design considerations which are related to the broad issue of recirculation sump operability addressed under GSI-191. These topics include (1) structural analysis of the containment sump, (2) upstream effects that limit water flow, (3) downstream effects related to debris penetration of the screen, and (4) potential chemical effects that contribute to head loss either as an additional debris source or by modifying the hydraulic properties of preexisting beds. Staff evaluations of the GR treatment of these topics follow in corresponding subsections of this SE. The NRC agrees that this list is complete when added to the balance of detail provided in the remainder of the GR, as modified by staff recommendations.

7.1 SUMP STRUCTURAL ANALYSIS

This section of the GR provides general guidance for considerations to be used when performing a structural analysis of the containment sump screen. The GR does not provide specific details on how to perform this analysis. General items identified for consideration include (1) verifying maximum differential pressure caused by combined clean screen and maximum debris load at rated flow rates, (2) geometry concerns (mesh and frame vs. perforated plate), (3) sump screen material selection for the post accident environment, and (4) the addition of hydrodynamic loads resulting from a seismic event. The GR specifically states that section 1.1.1.8 of RG 1.82, Revision 3, may need to be referenced for evaluation of hydrodynamic loads on a strainer.

Staff Evaluation of GR Section 7.1: The staff finds the general statements in Section 7.1 pertaining to the analysis of the structural capability of the containment sump strainer to be acceptable. The staff agrees that potential bending and stretching of existing wire mesh may lead to gaps at the points of attachment between wire and framing structures. The staff further agrees that any modifications to existing sump-screen configurations should employ corrosion-resistant materials that will not be affected by post-LOCA containment conditions.

Consideration of sump structural analysis in the GR and in this SE is limited to the debris loads and the hydraulic loads imposed by water in the sump pool. Dynamic loads imposed on the sump structure and screen by break-jet impingement must be addressed in accordance with GDC 4, including provisions for exclusion of certain breaks from the design basis when analyses reviewed and approved by the NRC demonstrate that the probability of fluid system piping rupture is extremely low.

Paragraph 2(d)(vii) of the information request section of GL 2004-02 requests that addressees verify that trash racks and sump screens are capable of withstanding the loads imposed by expanding jets and missiles. The staff requests addressees to verify that the trash racks and sump screens continue to meet the current design-basis requirements under GDC 4, as discussed above.

The GR does not provide detail in its presentation of criteria for sump-screen performance and comparisons to predicted head loss. To clarify this information, the staff offers the following discussion. It is true that structural loads on a sump screen should be computed using the total pressure drop across the screen. The total pressure drop is the sum of the head loss computed or measured across the clean screen at a rated flow in the absence of debris and the debris-induced head loss computed or measured under the same volumetric flow rate. The limiting conditions for sump-screen structural analysis correspond to a break location and debris source term that induces the maximum total head loss at the sump screen after full consideration of transport and degradation mechanisms. Debris-bed head loss should be calculated for each postulated break scenario according to methods outlined in Sections 3.7 and 4.2.5 of the GR, as amended by these SE recommendations.

Licensing-basis calculations of NPSH margin already include the effects of flow resistance through the clean screen, so it is sufficient to examine the debris-bed head loss separately. For a completely submerged sump screen, if the NPSH margin is smaller than the head loss induced by debris from the limiting break, then the licensing basis has been exceeded and some form of mitigation, modification, or exemption is warranted. For a partially submerged sump screen, a potentially more restrictive condition may apply. In order to supply adequate water flow through the debris bed, the pressure drop cannot exceed one-half of the pool depth in feet of water or the NPSH margin, whichever is smaller. This additional criterion arises because the containment pressure is equal on both sides of the debris bed, and the static pressure of the pool is the only way to force water through the bed (RG 1.82-3).

Thus, different criteria may dictate the structural capacity of the sump screen for supporting water flow through a debris bed under recirculation velocities depending on screen geometry. Other considerations such as maximum water velocities during fill up and hydrodynamic loads during a seismic event may impose additional design constraints.

The guidance presented in the GR would require each licensee to perform a plant-specific evaluation of its respective sump screen to determine structural capability under post accident conditions. The staff agrees with the GR reference of RG 1.82 for evaluation of hydrodynamic loads. This plant-specific analysis would be reviewed on a case-by-case basis.

7.2 UPSTREAM EFFECTS

This section of the GR provides guidance on evaluating the flowpaths upstream of the containment sump for holdup of inventory which could reduce flow to and possibly starve the sump. The GR identifies two parameters important to the evaluation of upstream effects: (1) containment design and postulated break location, and (2) postulated break size and insulation materials in the ZOI. The GR states that the above two parameters provide a basis to evaluate holdup or choke points in the flow field within containment upstream of the containment sump. The GR also advises that the containment condition assessment, as described in NEI 02-01, provides guidance on this review.

The GR provides users of the document the following examples of locations to evaluate for holdup of liquid upstream of the sump screen: narrowing of hallways or passages, gates or screens that restrict access to areas of containment such as behind the bioshield or crane wall, and refueling canal drain. The GR then states that these areas of concern generally apply to all containments, but advises licensees to evaluate their containment for possible holdup at unique geometric features and to evaluate any plant-specific insulation installation.

Staff Evaluation of GR Section 7.2: The staff finds that the above-mentioned items of the GR are appropriate as stated and offers the following amplification. Licensees should use the results of their debris assessments to estimate the potential for water inventory holdup. Based on these assessments and the mapping of probable flowpaths, licensees should use methods provided in Section 5 of the GR for the additional purpose of reducing holdup of blowdown inventory upstream of the sump. Licensees should evaluate the effect the placement of curbs and debris racks intended to holdup debris may have on the holdup of water en route to the sump.

Staff Conclusions Regarding Section 7.2: The staff finds that the GR provides adequate direction regarding the evaluation of holdup of inventory from the sump. The staff provides the above additional comments as amplification to the GR.

7.3 DOWNSTREAM EFFECTS

This section of the GR gives licensees guidance on evaluating the flowpaths downstream of the containment sump for blockage from entrained debris. The GR specifies three concerns to be addressed: (1) blockage of flowpaths in equipment, such as containment spray nozzles and tight-clearance valves, (2) wear and abrasion of surfaces, such as pump running surfaces, and heat exchanger tubes and orifices, and (3) blockage of flow clearances through fuel assemblies. The NRC is currently conducting research in the area of debris bypass through sump-screens and flow blockage of HPSI throttle valves; this SE may be supplemented with the results of this research in early 2005. The staff would then expect licensees to consider the supplemental information in evaluating their plants for downstream effects.

The GR identifies the starting point for the evaluation to be the flow clearance through the sump screen and states that the flow clearance through the sump screen determines the maximum size of particulate debris that will pass through it. The GR states that wear and abrasion of surfaces in the ECC and CS should be evaluated based on flow rates to which the surfaces will be subjected and the grittiness or abrasiveness of the ingested debris. The GR recognizes that the abrasiveness of debris is plant-specific. The GR also states that the pump manufacturer may have addressed the wear and abrasion of pumps caused by ingestion of debris, and advises licensees to contact their vendor regarding the ability of the pump to perform with debris in the process fluid.

Staff Evaluation of GR Section 7.3: The GR states, “If passages and channels in the ECC and CS downstream of the sump screen are larger than the flow clearance through the sump screen, blockage of those passages and channels by ingested debris is not a concern.” In addition, the GR states, “Similarly, wear and abrasion of surfaces in the ECC and CS should be evaluated based on flow rates to which the surfaces will be subjected…”. The staff finds that the GR statements do not fully address the potential safety impact of LOCA generated debris on components downstream of the containment sump. The following represents the staff’s expectations on the review of the effects of debris on components and systems downstream of the containment sump following initiation of containment recirculation (NUREG/CP-0152 Vol. 5, TIA 2003-04).

The evaluation of GSI-191 should include a review of the effects of debris on pumps and rotating equipment, piping, valves, and heat exchangers downstream of the containment sump related to the ECCS and CSS. In particular, any throttle valves installed in the ECCS for flow balancing (e.g., HPSI throttle valves) should be evaluated for blockage potential. The evaluation should also address the effects of entrained debris on the reactor vessel and internal core components (GL 04-02, NRCB, 2003).

In general, the downstream review should first define both long-term and short-term system operating lineups, conditions of operation, and mission times. Where more than one ECC or CS configuration is used during long- and short- term operation, each lineup should be evaluated with respect to downstream effects. The definition of the design and license bases' mission times form the premise from which the short- and long-term consequences will be determined and evaluated.

Once condition of operation and mission times are established, downstream process fluid conditions should be defined, including assumed fiber content, hard materials, soft materials, and various sizes of material particulates. The staff has found that particles larger than the sump-screen mesh size will pass through to downstream components. Debris may pass through because of its aspect ratio or because it is ”soft” and differential pressure across the screen pulls it through the mesh. No credit may be taken for thin-bed filtering effects (NUREG/CP-0152 Vol. 5, TIA 2003-04).

Evaluations of systems and components are to be based on the flow rates to which the wetted surfaces will be subjected and the grittiness or abrasiveness of the ingested debris. The abrasiveness of the debris is plant specific, as stated in the GR, and depends on the site-specific materials that may become latent or break-jet-generated debris.

Specific to pumps and rotating equipment, an evaluation should be performed to assess the condition and operability of the component during and following its required mission times. Consideration should be given to wear and abrasion of surfaces, (e.g., pump running surfaces, bushings, wear rings). Tight clearance components or components where process water is used either to lubricate or cool should be identified and evaluated.

Dirt, dust, and other materials may combine or interact with fiber and cause a matting effect. This matting effect may significantly increase the rate of wear. Test data and operating experience have shown that hard-faced components will wear under long-term exposure to post accident slurry conditions. Soft-surface materials, such as brass and bronze will wear at much faster rates.

Component rotor dynamics changes and long-term effects on vibrations caused by potential wear should be evaluated in the context of pump and rotating equipment operability and reliability. The evaluation should include the potential impact on pump internal loads to address such concerns as rotor and shaft cracking (NUREG/CP-0152 Vol. 5, TIA 2003-04).

As stated in the GR, pump manufacturers may have addressed wear and abrasion of pumps caused by ingestion of debris. Licensees may consider requesting information and/or test data from the pump vendor regarding the ability of specific pumps to perform with debris in the process fluid. Other sources of information available to licensees include information generated to support the closeout of unresolved safety issue (USI) A-43, “Containment Emergency Sump Performance,” such as NUREG/CR-2792, “An Assessment of Residual Heat Removal and Containment Spray Pump Performance Under Air and Debris Ingesting Conditions.”

The downstream effects evaluation should also consider system piping, containment spray nozzles, and instrumentation tubing. Settling of dusts and fines in low-flow/low-fluid velocity areas may impact system operating characteristics and should be evaluated. The matting effect may cause blockages and should be addressed. The evaluation should include such tubing connections as provided for differential pressure from flow orifices, elbow taps, and venturis and reactor vessel/RCS leg connections for reactor vessel level, as well as any potential the matting may have on the instrumentation necessary for continued long-term operation.

Valve (IN 96-27) and heat exchanger wetted materials should be evaluated for susceptibility to wear, surface abrasion, and plugging. Wear may alter the system flow distribution by increasing flow down a path (decreasing resistance caused by wear), thus starving another critical path. Or conversely, increased resistance from plugging of a valve opening, orifice, or heat exchanger tube may cause wear to occur at another path that is taking the balance of the flow diverted from the blocked path.

Decreased heat exchanger performance resulting from plugging, blocking, plating of slurry materials, or tube degradation should be evaluated with respect to overall system-required hydraulic and heat removal capability.

An overall ECC or CS system evaluation integrating limiting or worst-case pump, valve, piping, and heat exchanger conditions should be performed and include the potential for reduced pump/system capacity resulting from internal bypass leakage or through external leakage. Internal leakage of pumps may be through inter-stage supply and discharge wear rings, shaft support, and volute bushings (NUREG/CP-1052 Vol. 5, TIA 2003-04). Piping systems design bypass flow may increase as bypass valve openings increase or as flow through a heat exchanger is diverted because of plugging or wear. External leakage may occur as a result of leakage through pump seal leak-off lines, from the failure of shaft sealing or bearing components, from the failure of valve packing or through leaks from instrument connections and any other potential fluid paths leading to fluid inventory loss.

Leakage past seals and rings caused by wear from debris fines to areas outside containment should be evaluated with respect to fluid inventory and overall accident scenario design and license bases environmental and dose consequences.

Fluids present post-LOCA during long- and short-term recirculation may flow through the reactor vessel and its internal components. The downstream effects evaluation should consider flow passage blockages, such as those associated with core grid supports, mixing vanes, and debris filters. The evaluation should also consider component binding, such as reactor vessel vent valves in Babcock and Wilcox designs.

If flowpaths between upper downcomer and upper plenum/upper head (e.g., hot-leg nozzle gaps and upper head cooling passages) have an influence on long-term cooling, then the potential for plugging these paths should be addressed.

Staff Conclusions Regarding GR Section 7.3: The staff finds that the GR is nonconservative with respect to its statement that the flow clearance through the sump screen determines the maximum size of particulate debris that would pass through it. As stated above, the staff has seen evidence that some particles larger than the flow openings in a screen will deform and flow through or orient axially and flow through the mesh (NUREG/CP-0152 Vol. 5, TIA 2003-04). Licensees should determine, based on their debris generation and transport calculations, the percentage of debris that would likely pass through their sump screens and be available for blockage at the downstream locations discussed above.

The evaluation of downstream effects should include consideration of term of operating lineup (long or short), conditions of operation, and mission times, as stated above.

Consideration should be given to wear and abrasion of pumps and rotating equipment, as discussed above (NUREG/CP-0152 Vol. 5, TIA 2003-04). Licensees' downstream effects evaluations should consider system piping, containment spray nozzles, and instrumentation tubing, as well. Valve and heat exchanger wetted surfaces should be evaluated for wear, abrasion, and plugging. Wear should be evaluated with respect to the potential to alter system flow distribution. Heat exchanger performance should be evaluated with respect to the potential for blockage or the plating of slurry materials. The HPSI throttle valves should be specifically evaluated for their potential to plug and/or wear (IN 96-27). The overall performance of the ECCS and CSS should be evaluated with respect to all conditions discussed above.

Flow blockage, such as that associated with core grid supports, mixing vanes, and debris filters should be considered. Flow paths between upper downcomer and upper plenum/upper head should be evaluated for long-term cooling degradation resulting from flow interruption from plugging.

As stated above, the staff concludes that the GR recommendations do not fully address the potential safety impact of LOCA-generated debris on components downstream of the containment sump. Licensees should address the additional considerations detailed above in the staff's evaluation.

In order to effectively evaluate downstream effects, licensees may need to review equipment specifications, operations and maintenance manuals, and station drawings, such as equipment, piping, isometrics, and flow diagrams. Review of previous physical walkdowns of piping and instrument systems may be necessary to verify low points where debris accumulation may occur, and potential choke points or other areas of concern not readily verifiable from document reviews. Also leakage past seals and rings caused by wear from debris fines to areas outside containment should be evaluated with respect to license bases environmental and dose consequences. Previously issued generic communications regarding downstream effects, HPSI throttle valve clogging, wear of the high-pressure injection (HPI) pump, pipeline clogging, and heat exchanger wear from operation under abrasive or debris-laden conditions should also be reviewed.

7.4 CHEMICAL EFFECTS

Section 7.4 of the GR introduces the potential problems of chemical reactions in the post-LOCA environment of PWR containments. The reaction products formed can contribute to blockage of the ECCS sump screens and increase the associated head loss across the screens. The GR notes that a test plan has been developed to study possible interactions among corrosion products and the resultant effects of those products on sump filtration. The GR defers guidance for dealing with these effects until the testing is completed and the data have been appropriately evaluated.

For the purpose of this SE, the issue of chemical effects involves interactions between the post-LOCA PWR containment environment and containment materials that may produce corrosion products, gelatinous material, or other chemical reaction products capable of affecting sump-screen head loss. The ACRS raised a concern that an adequate technical basis should be developed to resolve the issues related to chemical reactions (ACRS letter dated September 30, 2003). A gelatinous material was observed in a water sample taken from the Three Mile Island (TMI) containment following the accident in 1979. (Oak Ridge National Laboratory Report memorandum dated September 14, 1979). The relevance of the gelatinous material collected at TMI to the evaluation of potential post-LOCA chemical effects during the ECCS recirculation phase in plants today is uncertain for several reasons. The water sample containing a gelatinous material was collected from the TMI containment approximately 5 months after the accident, which is longer than the typical projected mission time for ECCS recirculation following a modern-day PWR LOCA. The source of the water sample collected from the TMI containment was also unique in that water from the Susquehanna River was introduced into the TMI containment after the accident.

The LANL conducted a limited-scope study to evaluate potential chemical effects occurring following a LOCA. This study assessed the potential for chemically induced corrosion products to impede ECCS performance. In some of these tests, LANL added metal nitrate salts to the test water in concentrations above their solubility limits to induce chemical precipitants and assess head-loss effects. Although these LANL tests showed that gel formation with a significant accompanying head loss across a fibrous bed was possible, LANL did not perform integrated testing to demonstrate a progression from initial exposure of metal samples to formation of chemical interaction precipitation products (LANL Report LA-UR-03-6415). In addition, the test conditions were not intended to be prototypical of a PWR post-LOCA environment. Therefore, a more comprehensive study has been initiated to address potential chemical effects.

In a collaborative effort, the NRC and the nuclear industry developed an integrated chemical effects test program. The test characterizes any chemical reaction products, including possible gelatinous materials, which may develop in a representative plant post-LOCA PWR environment. Test conditions (e.g., pH, temperature, boron concentration) were selected to simulate representative, but not necessarily bounding plant conditions. The initial sump conditions experienced during an LBLOCA will not be replicated in order to simplify the experimental test setup and equipment. Instead, the chemical reactions from corrosion and leaching products during the initial LOCA conditions were simulated using the OLI Systems, Inc., suite of thermodynamic equilibrium programs (e.g., Environmental Simulation Program, Version 6.6, and Stream Analyzer, Version 1.2). The simulations varied the amount of key components, different pH moderators (i.e., sodium hydroxide versus trisodium phosphate), pH, temperature, and pressure. The results indicated large-scale corrosion tests using a pressurized test loop were not necessary to capture the period immediately following the LOCA. Thermodynamic simulations and sensitivity analyses of key variables, including corrosion products, were developed to rank species that have a potential for causing sump-head loss through formation of precipitates. Validation of the appropriate OLI Systems, Inc., programs will be performed using available borated water literature and by comparing the program's initial post-LOCA environment species predictions to results obtained in small-scale (e.g., autoclave) corrosion tests in a representative initial post-LOCA environment.

Larger scale corrosion testing will be conducted using facilities at UNM. Corrosion test coupon materials include zinc (galvanized steel and inorganic zinc-based coatings), aluminum, copper, carbon steel, insulation, and concrete. Relative amounts of test materials were scaled according to plant data provided by the industry based on plant surveys. Test coupons will either be fully immersed or placed above the test loop water line, but subjected to a fine spray to simulate exposure to containment spray. The relative distributions of each material were determined based on estimated percentages submerged or subjected to containment sprays following a plant LOCA. If gelatinous material is observed to develop, alternative courses of action will be considered (e.g., head-loss tests). Initial testing is expected to begin in fall 2004.

In order to address chemical effects on a plant-specific basis, licensees will initially need to evaluate whether the chemical effects test parameters are sufficiently bounding for their plant-specific conditions. If the chemical effects test parameters do not bound the plant-specific materials, licensees must provide technical justification to use any results from the chemical effects tests in their plant-specific evaluation. If chemical effects are observed during these tests, licensees will need to evaluate the sump-screen head loss consequences of this effect in an integrated manner with other postulated post-LOCA effects. In addition, a licensee choosing to modify its plant sump screens before the completion of chemical effects testing and analysis of the test results should consider the potential chemical effects to ensure that a second plant modification is not necessary in the event that deleterious chemical effects are observed during testing.

8.0 CONDITIONS AND LIMITATIONS

The guidance in the GR and in this SE is offered for all licensees of domestic PWRs for the evaluation of ECCS sump performance. However, the following conditions and limitations apply to its use:

Debris Generation

1. The destruction pressures cited in the GR for determining ZOI radii are based on air jet data and could underestimate debris quantities for a two-phase jet, as discussed in Section 3.4.2.2 of this SE. Therefore, destruction pressures based on air jet testing should be lowered by 40 percent to account for two-phase jet effects.
2. Table 3-1 of the GR provides calculated and recommended values for ZOI radii for common PWR insulation and coatings materials. The staff determined that the calculated values are nonconservative at higher destruction pressures, but the recommended values are conservative. Therefore, licensees should only use the recommended values.
3. The staff agrees with the characterization of debris in GR Section 3.4.3; however, licensees should apply insulation-specific debris size information, if possible.

Protective Coatings

1. Characterization of failed coatings with the value of 1000 psi as a destruction pressure, with a corresponding ZOI of 1 pipe diameter, is not sufficiently justified and may be nonconservative, as discussed in Section 3.4.2. Therefore, licensees should use a spherical coatings ZOI equivalent determined by plant-specific analysis, based on experimental data that correlate to plant materials over the range of temperatures and pressures of concern, or 10D.
2. The alternative offered to plant-specific data in Section 3.4.3.4 for the determination of coatings thicknesses (i.e., 3 mil equivalent of 10Z) may not be conservative and is therefore not acceptable without adequate plant-specific justification.
3. For those plants that substantiate no formation of a fibrous thin bed, the assumptions and guidance provided in the GR for coatings may be nonconservative. Therefore, for any such plant, assumptions related to coatings characterization must be conservative with regard to sump blockage. Consideration should be based upon the plant-specific susceptibility to thin-bed formation identified by the licensee. Specifically, this includes the plant-specific consideration of larger sized chips, flakes, or other form of breakdown which is realistically conservative, or use of a default area equivalent to the area of the sump-screen openings for coatings size.

Latent Debris

1. Periodic surveys that monitor changes in latent debris inventory are needed to monitor the effectiveness of cleanliness programs for supporting the overall sump-screen blockage vulnerability. The staff considers the steps presented in the GR for direct assessment of dust thickness to be impractical and unreliable, and thereby unacceptable. To provide more accurate results, statistical surface sampling should be performed in accordance with the guidance provided in this SE.
2. If a licensee chooses to take credit for a cleanliness program to account for a fractional surface area for debris accumulation, documentation should be available to verify proper implementation.
3. In addition to the three categories of miscellaneous debris discussed in the GR, the licensee should note the quantity, characteristics, and location of any failed coatings in the survey to the extent available during plant-specific walkdowns.

Transport

1. Those plants with configurations conducive to fast pool velocities should include large piece debris transport in their evaluations. The GR baseline methodology that assumes no transport of large debris to the sump screens is not adequate. A comparison of the characteristic transport velocities to typical debris transport velocities is needed to determine whether or not large piece debris transport is important.
2. Because (1) the method recommended for determining the quantity of fine debris trapped in inactive pools is oversimplified, (2) a survey of the fractions of inactive pool volumes to total sump pool water volumes is not available to better judge the potential industry-wide impact of this assumption, and (3) the comparison of the baseline methodology and a detailed analysis for the volunteer plants differed considerably; a limit on this fraction is needed to control the impact of this non-conservative methodology assumption. Therefore, the staff concludes that an upper limit on this ratio of 15 percent should be assumed, unless analyses or experimental data adequately support a higher fraction.
3. The baseline assumption that all debris in the containment bottom floor is uniformly distributed throughout the entire volume of water in containment is also not conservative. The baseline guidance made this assumption as justification for the inactive pool volume ratio, but otherwise it does not directly affect the acceptance of the baseline guidance because of the 100 percent recirculation pool transport assumption. However, should a plant subsequently perform a pool transport refinement, then this assumption would not apply and alternative approaches, such as those detailed in Appendix III to this SE, would be required.

Head Loss

1. The licensees should ensure the validity of the NUREG/CR-6224 correlation for their application of specific types of insulations and the range of parameters using the guidance provided in Appendix V to this SE.

Alternate Evaluation

1. Consistent with the principles of risk-informed decision-making in RG 1.174, the impact of the proposed change should be monitored using performance measurement strategies. Therefore, licensees should develop an implementation and monitoring plan to ensure that the evaluation conducted to examine the impact of the proposed changes continues to reflect the actual reliability and availability of the SSCs and operator actions that have been evaluated.

   This plan should include a means to do the following:

   a. Track the performance of equipment that when degraded can affect the conclusions of the licensee's evaluation (i.e., demonstration of the sump mitigative capability to meet its reliability target).
   b. Trend equipment performance after a change has been implemented to demonstrate that performance is consistent with that assumed in the traditional engineering and probabilistic analyses that were conducted to justify the change.
   c. Monitor nonsafety-related SSCs if the analyses determine those SSCs to be relied upon to meet the sump mitigative capability target reliability.

   The program should also be structured such that feedback of information and corrective actions are accomplished in a timely manner and degradation in performance is detected and corrected before plant safety can be compromised.

Downstream Effects

1. Licensees should consider that some particles larger than the flow openings in a sump screen will deform and flow through or orient axially and flow through the screen, and determine what percentage of debris would likely pass through the sump screen and be available for blockage at downstream locations.
2. Licensees should consider term of system operating lineup (short or long), conditions of operation, and mission times.
3. Licensees should consider wear and abrasion of pumps and rotating equipment, piping, spray nozzles, instrumentation tubing, and HPSI throttle valves. The potential for wear to alter system flow distribution and/or form plating of slurry materials (in heat exchangers) should be included.

4. An overall ECC or CS system evaluation should be performed considering the potential for reduced pump/system capacity resulting from internal bypass leakage or through external leakage.
5. Licensees should consider flow blockage associated with core grid supports, mixing vanes, and debris filter, and its effect on fuel rod temperature.

Chemical Effects

1. The staff has considered NEI's response and finds that licensees should address chemical effects on a plant-specific basis. Initially, licensees should evaluate whether the current chemical test parameters, which are available in the test plan for the joint NRC/Industry Integrated Chemical Effects Tests, are sufficiently bounding for their plant-specific conditions. If they are not, then licensees should provide a technical justification to use any of the results from the tests in their plant-specific evaluations. If chemical effects are observed during these tests, then licensees should evaluate the sump-screen head loss consequences of this effect. A licensee that chooses to modify its sump screen before tests are complete should consider potential chemical effects to avoid additional screen modification, should deleterious chemical effects be observed during testing.

Overall

Any analytical refinement(s) proposed in its plant-specific analysis of sump performance that is not addressed in this SE should be presented to the staff for approval.

9.0 CONCLUSION

The GR provides the PWR industry with an important tool for estimating the head loss across the licensees' ECCS sump screens based on the generation, transport, and accumulation of debris in containment and on the sump screens. The NEI approach is to provide guidance and leave certain areas to be resolved on a plant-specific basis, as opposed to providing a detailed methodology that applies to all PWRs as a standalone document (as was done for BWRs with the URG), based on the argument of variability among PWRs. NEI did little testing to support and justify assumptions made in the GR (as opposed to the approach by the BWROG to generate data that support the URG). However, the NEI guidance provides historical data, considerations, and engineering judgments that the industry can use to develop those areas not fully addressed in the GR.

The iterative process used by NEI in this GR also creates some challenges in the overall review. Although NEI has characterized this guidance as extremely conservative, the iterative process allows for the reduction of conservatisms in various areas (identified in each affected section of this evaluation) that could affect other areas of the analysis to produce larger reductions in overall conservatism than would be expected.

The staff evaluated each area of the GR, and for those areas where there was a lack of supporting data or where conservatism is questioned, the staff provides alternative guidance based on its engineering judgment and/or additional data generated in testing done mainly at LANL. These data result from testing specifically contracted by the NRC over the last 5 years as part of the GSI-191 resolution effort and involve sump performance research which was completed, but in a few cases not published, and is referenced and/or included as appendices in this document. This additional information is also intended to provide valuable insight to the industry in its effort toward evaluating plant-specific vulnerability to sump blockage and related issues.

The staff concludes that the guidance proposed by NEI, as approved in accordance with this SE, provides an acceptable evaluation methodology that establishes the necessary basis and provides the realistic conservatism for an acceptable PWR guidance document. The paragraphs below document key conclusions in each area of the analysis.

Pipe Break Characterization: The staff finds that the GR guidance is acceptable provided that each licensee adequately addresses the following two outstanding issues:

1. The GR does not provide guidance for those plants that can substantiate no thin-bed effect, which may impact head-loss results and limiting break location.
2. For plants needing to evaluate secondary-side piping, such as main steam and feedwater pipe breaks, break locations should be postulated in a manner consistent with the guidance in Section 3.3 of this SE.

To address these issues, the staff provides enhanced guidance in the appropriate sections of this SE. When the guidance provided in the GR is supplemented with the enhanced guidance offered in the SE, the staff finds this section to be acceptable.

Debris Generation/Zone-Of-Influence: The staff has reviewed the use of a spherical model sized in accordance with the ANSI/ANS standard and finds this approach acceptable. The spherical geometry proposed encompasses a zone which considers multiple jet reflections at targets, offset between broken ends of a guillotine break, and pipe whip.

With regard to the destruction pressures cited for determining ZOI radii, data are referenced from the BWROG URG which were determined using an air jet. However, a LOCA jet is a two-phase steam/water jet. Based on staff study of this difference and because of experimental evidence from two-phase jets, the destruction pressures based on air jets could be too high leading to an underestimation of debris quantities. Therefore, the staff maintains that destruction pressures based on air jet testing should be lowered by 40 percent to account for two-phase jet effects.

The staff's confirmatory analysis (see Appendix I to this SE) verifies the applicability of the ANSI/ANS standard for determining the size of this zone. Use of a ZOI model is identified as an acceptable approach for analyzing debris generation in accordance with RG 1.82, Revision 3. (The staff also used and reviewed this approach in the BWR sump performance SE.)

The staff finds the refinement offered in the GR which allows the application of spherical ZOIs that correspond to material-specific destruction pressures for each material that may be affected in the vicinity of a break to be acceptable.

The staff concurs with the characterization of debris in GR Section 3.4.3. Confirmatory analyses provided in Appendix II to this SE verify the acceptability of the size distributions recommended in the GR. However, the staff urges application of insulation-specific debris size information, if possible.

Protective Coatings: The GR treats coating debris generation separately from other debris types. The GR assumes that coating debris is generated from postulated failure (destruction) of both "DBA-qualified" and "unqualified" coatings within the ZOI, and from postulated failure of all "unqualified" coatings outside the ZOI. For coatings, the GR recommends a ZOI destruction pressure of 1000 psi, with a corresponding ZOI radius of 1 pipe diameter. The GR assumes that all coating debris will fail to a particulate size equivalent to the basic material constituent.

The staff agrees with the approach taken with regard to characterization of coatings; however, the staff considers there to be insufficient technical justification to support a value of 1000 psi as a destruction pressure with corresponding ZOI of 1 pipe diameter. The staff finds that licensees should use a coatings ZOI spherical equivalent, determined by plant-specific analysis and based on experimental data that correlate to plant materials over the range of temperatures and pressures of concern, or 10D.

With regard to the characterization of coatings in Section 3.4.3.4 of the GR, an alternative offered to plant-specific data for the determination of coatings thicknesses is an equivalent IOZ thickness of 3 mils. Because this recommended value may be nonconservative and is unsubstantiated as described in Section 3.4.3.4, the staff finds this value of 3 mils unacceptable without adequate plant-specific justification for any coatings thicknesses used. The performance of a plant-specific evaluation of the "unqualified" coatings within containment is recommended to determine realistically-conservative coating properties, including thicknesses. Further, the staff recommends that licensees incorporate into the methodology the means to periodically assess the amount of “unqualified” coating identified and used in the sump analysis to ensure the quantity remains bounding, and if nonconservative changes in the amount of “unqualified” coating occur, to evaluate the impact of this change.

In addition, for those plants that substantiate no formation of a fibrous thin bed, the assumptions and guidance provided in the GR for coatings may be nonconservative. Therefore, for any such plant, assumptions related to coatings characterization must be conservative with regard to sump blockage. Consideration must be based upon the plant-specific susceptibility to thin-bed formation identified by the licensee. Specifically, this includes the plant-specific consideration of larger sized chips, flakes, or other form of breakdown which is realistically conservative, or the use of a default area equivalent to the area of the sump-screen openings, for coatings size.

Latent Debris: The staff has reviewed the guidance provided for estimating the impact of latent debris and agrees that it is necessary to determine the types, quantities, and locations of latent debris. The staff also agrees that it is not appropriate for licensees to claim that their existing FME programs have entirely eliminated miscellaneous debris. Results from plant-specific walkdowns should be used to determine a conservative amount of latent debris in containment and to monitor cleanliness programs for compliance to committed estimates.

The staff further concludes that the guidance provided in the GR for consideration of the effects of latent debris is informative and prescriptive, but treats certain attributes in an inconsistent manner, lacks consideration of a number of surfaces and unique phenomena that enhance dust collection, and relies on an impractical and imprecise method for estimating the volume of latent debris on surfaces. This section of the SE provides alternate guidance for statistical sampling and sample analysis to allow licensees to more accurately determine the impact of latent debris on sump-screen performance. This revised approach is based on generic characterization of actual PWR debris samples. If desired, a licensee could pursue plant-specific characterization as a refinement.

Debris Transport: The staff finds that the transport guidance for small fines is conservative and acceptable; however, neglect of the large pieces and the neglect of variability and uncertainties because of a lack of data are nonconservative. Therefore, for those plants with configurations conducive to fast pool velocities, consideration of large pieces of debris is necessary. In addition, the method recommended for determining the quantity of fine debris trapped in inactive pools is oversimplified, and therefore, the acceptability of this method will be determined on a plant-specific basis, depending on whether this portion of the analysis maintains overall realistic conservatism.

Head Loss: Computation of head loss in the GR involves input of design characteristics and reflection of thermal-hydraulic conditions into a head-loss correlation (NUREG/CR-6224) that is acceptable to the staff. The licensees should ensure the validity of the NUREG/CR-6224 correlation for their application of specific types of insulations and the range of parameters using the guidance provided in Appendix V of this SE.

However, the staff finds that licensees should consider the following guidance on fibrous thin-bed formation:

- use of the appropriate density in the determination of the quantity of debris needed to form a thin bed (i.e., the as-manufactured density)
- careful evaluation of the limiting porosity for the particular particulate or mixture of particulates in the debris bed
- consideration of uncertainties in specifying a 1/8-in. bed thickness criteria (e.g., the indication that calcium silicate can form a debris bed without supporting fibers)
- consideration of other uncertainties (e.g., uncertainties associated with mixing of constituents, or uncertainties associated with latent debris data collection)

Before using the NUREG/CR-6224 correlation recommended in the GR or any other head-loss correlation, the licensees should ensure that it is applicable for the type of insulation and the range of parameters. If the correlation has been validated for the type of insulation and the range of parameters, the licensees may use it without further validation. If the correlation has not been validated for the type of insulation and the range of parameters, the licensees should validate it using head-loss data from tests performed for the particular type of insulation.

Analytical Refinements: The GR identifies three analytical topics to be included in this section debris generation, debris transport, and head loss. Section 6.0 of the GR addresses a fourth topic, break selection.

For debris generation, the GR proposes use of debris-specific ZOIs versus use of the most conservative debris type applied to all. In addition, the GR proposes use of two freely-expanding jets emanating from each broken pipe section versus use of a spherical ZOI. The staff finds both debris generation refinements to be acceptable.

For debris transport, the analytical refinements section of the GR provides two methods for computing flow velocities in a sump pool, the network method and the computational fluid dynamics (CFD) method. The staff finds both methods to be acceptable for predicting sump pool flow velocities provided the models are properly applied.

For head loss, the only refinement cited by the GR is in GR Section 3.7.2.3.2.3, “Thin Fibrous Beds,” which addresses the need for consideration of fibrous thin-bed formation, and the alternative consideration of latent debris as the primary contributor to this thin bed for all-RMI plants. However, the staff addresses consideration of thin fibrous beds in Section 3.4, “Debris Generation,” of this SE as related to the baseline, rather than as a refinement.

Therefore, the staff finds no specific refinement offered for the head-loss analysis.

Physical Refinements To Plant: Section 5.0 of the GR provides guidance for refinements in the areas of debris source term, debris transport obstructions, and screen modifications.

The staff has reviewed the debris source term refinements involving primarily enhanced housekeeping programs, insulation and/or coatings modifications, and equipment modifications, and finds them to be acceptable. However, with regard to insulation change-out or modification, the staff emphasizes that although this refinement may address maximum debris loadings on the screen, it may not address minimum loadings required to form a thin-bed effect. In addition, with regard to coatings, the statement that DBA-qualified coatings have very high destruction pressures has not been proven (see Sections 3.4.2, 3.4.2, and 4.2.2.2.3 of this SE).

The staff agrees that debris consistent with the materials listed can be effectively trapped with the use of a debris transport obstructions in optimized locations where the local velocities are less than the test results presented. The staff finds the general statements in parts of this section to provide little specific information regarding the methods for determining proper debris transport obstruction design. The lack of specific implementation strategies and simplified concepts presented would require each plant to perform a plant-specific evaluation of its proposed debris obstruction to determine it's effectiveness and structural capability under post accident conditions. To credit debris transport obstructions for trapping debris, plant-specific documentation will also be required to demonstrate an appropriate correlation to the test results in terms of debris type and velocity limits.

With regard to screen modification, the staff finds those discussed in the GR to be acceptable; however, licensees are not limited to those identified in the GR.

<u>Alternate Evaluation</u>: NEI has proposed an alternative evaluation approach which incorporates realistic and risk-informed elements to the PWR sump analysis, as described in Section 6.0. In considering risk-informing aspects of the resolution of GSI-191, the staff recognized that the containment sump may clog if the mitigation capability credited in the Region II analysis does not function properly. Based on the industry proposed approach in the Region II analysis, which also uses the conservative NUREG-1150 LBLOCA frequency to calculate the target reliability of the mitigation capability, and using the related generic study information, the largest LBLOCA CDF would be 1.4x10-5/year. This indicates that at a minimum the risk associated with LBLOCAs will be reduced from the current condition by nearly an order of magnitude. The staff concludes that GR Section 6.0 provides an acceptable approach for evaluating PWR sump performance. Application of more realistic and risk-informed elements is technically justified based on the low likelihood of such breaks occurring.

<u>Sump Structural Analysis</u>: The GR is not detailed in its presentation of criteria for sump screen performance and comparisons to predicted head loss. Therefore, the staff provides additional guidance for assurance that the ECCS sump can accommodate both the clean-screen-head loss and the debris-induced head loss associated with the limiting break, while providing adequate flow through both the ECCS injection pumps, and the CS pumps if needed. For those structural design considerations mentioned in the GR, each should be assessed for applicability on a plant-specific basis.

<u>Upstream Effects</u>: The GR identifies certain holdup or choke points which could reduce flow and possibly cause blockage upstream of the sump. The staff finds the guidance with respect to upstream blockage to be acceptable.

Downstream Effects: This section provides guidance on the evaluation of entrained debris downstream of the sump causing downstream blockage. Because the GR provides limited guidance on how downstream effects should be evaluated, the staff provides the following alternative guidance with regard to downstream blockage:

- Licensees should consider that some particles larger than the flow openings in a sump screen will deform and flow through or orient axially and flow through the screen, and determine what percentage of debris would likely pass through their sump screen and be available for blockage at downstream locations.
- Licensees should consider the term of system operating line-up (short or long), conditions of operation, and mission times.
- Licensees should consider wear and abrasion of pumps and rotating equipment, piping, spray nozzles, instrumentation tubing, and HPSI throttle valves. The potential for wear to alter system flow distribution and/or form plating of slurry materials (in heat exchangers) should be included.
- An overall ECC or CS system evaluation should be performed considering the potential for reduced pump/system capacity resulting from internal bypass leakage or through external leakage.
- Licensees should consider flow blockage associated with core grid supports, mixing vanes, and debris filter, and their effects on fuel rod temperature.

Chemical Effects: The staff has considered NEI's response and finds that chemical effects should be addressed on a plant-specific basis. Initially, licensees should evaluate whether the current chemical test parameters, which are available in the test plan for the joint NRC/industry integrated chemical effects tests, are sufficiently bounding for their plant specific conditions. If they are not, then licensees should provide a technical justification for the use of any results from the tests in their plant-specific evaluation. If chemical effects are observed during these tests, then licensees should evaluate the sump-screen head-loss consequences of this effect. A licensee that chooses to modify its sump screen before tests are complete should consider potential chemical effects to avoid additional screen modification, should deleterious chemical effects be observed during testing.

Overall Conclusions: The staff has reviewed the GR and finds portions of the proposed guidance to be acceptable. For those areas found to need additional justification and/or modification because of inadequate detail, lack of supporting data, or lack of analysis to support the technical basis, the staff has provided identified conditions and limitations and required modifications, including alternative guidance, to supplement the guidance in the NEI submission. The resultant combination of the NEI submission and staff safety evaluation provide an acceptable overall guidance methodology for the plant-specific evaluation of ECCS or CSS sump performance following all postulated accidents for which ECCS or CSS recirculation is required, with specific attention given to the potential for debris accumulation that could impede or prevent the ECCS or CSS from performing its intended safety functions.

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13 NRCB, 1995 Bulletin 95-02, "Unexpected Clogging of a Residual Heat Removal (RHR) Pump Strainer While Operating in Suppression Pool Cooling Mode," dated October 17, 1995;

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47	Mtg, 2002e	Summary of Public Meeting Held October 24, 2002, Nuclear Regulatory Commission, the Nuclear Energy Institute, and Interested Stakeholders Concerning Generic Safety Issue 191, “Assessment of Debris Accumulation on PWR Sump Performance,” (TAC No. MA6454) dated October 31, 2002.
48	Mtg, 2002f	Summary of Public Meeting Held December 12, 2002, Nuclear Regulatory Commission and Interested Stakeholders Concerning Generic Safety Issue 191, “Assessment of Debris Accumulation on PWR Sump Performance,” (TAC No. MA6454) dated December 31, 2002.
49	Mtg, 2001	Summary of July 26-27, 2001, Meeting with Nuclear Energy Institute and Industry on ECCS Strainer Blockage in PWRs, dated August 14, 2001.
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