1.0 GENERAL REQUESTS

1. Please provide a high-level description of the overall blockage evaluation that describes each of the key components of the evaluation (i.e., break selection, debris generation, debris transport, and head loss), and explains how the results of one component are used by the next. An organizational chart of the evaluation process would be an asset for the reader. Please also explain in the overview whether the various "options" to be encountered in later technical sections are to be viewed as completely interchangeable or as fixed tracks -- i.e., does the choice of Option 1 for debris generation dictate the choice of Option 1 for all other aspects of the evaluation? If there are important dependencies between the options of each analysis step, noting them in the overview and then emphasizing them when the various options are presented, would be useful.

   Response

   A high-level description of the overall PWR containment sump evaluation methodology is provided in Section 2 of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004. Section 3 of that document is structured such that each component of the evaluation (i.e., break selection, debris generation, latent debris, debris transport, and head loss) is described, as sample application of the method is given, and ties between sections are given. Refinements to the basic methods and approaches described in Section 3 are given in Section 4 of the May 28, 2004 document. The refinements are a more realistic but still conservative approach to the component (break selection, debris generation, debris transport, etc.) of the evaluation. The impact of implementing a refinement approach is discussed in the refinement description.

2. Please address the level of conservatism that the guidance was intended to support or recommend conservatisms that the utilities should use in their respective evaluations. For example, should each step in the evaluation assume bounding conditions as was assumed in the boiling water reactor (BWR) drywell debris transport study [NUREG/CR-6369], or should analytical assumptions be more realistic? Addressing the issue of appropriate conservatism at the beginning of the guidance, and then aligning subsequent assumptions for each evaluation step with the stated objectives, would be useful. The NEI guidance frequently uses broad assumptions to compensate for missing data and models, and it does not provide suitable justifications that are needed to ensure that engineering judgments are conservatively bounded. Presently, the NEI report contains a mix of assumptions, both over conservative and under conservative. However, the over-conservative assumptions cannot be relied

upon to counter the under-conservative assumptions in the overall assessment. In many instances, the phrase "conservatively assumed" was used without any justification to support this position or to clarify the degree of conservatism. For some of these statements, NRC-sponsored research indicates that the associated assumption is *not* conservative. Whenever analyses cannot argue convincingly for a realistic approach, you should consider assuming bounding conservatisms to ensure long-term emergency-core-cooling-system (ECCS) performance.

Response

Section 3, "Baseline Evaluation," of the "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004, provides a set of assumptions and methods that ensure a sufficient level of conservatism such that if a plant is evaluated using the baseline method and acceptable sump performance is determined, no further evaluation is required. Analytical refinements identified in Section 4, "Analytical Refinements," provide more realistic but still conservative guidance to address analytical methods. The reorganization of the presentation of the PWR Containment Sump Evaluation Methodology was undertaken, in part, to more clearly demonstrate the conservatisms in the PWR methodology.

3. Please address the potential need for additional testing in the NEI guidance. For example, two areas where testing could be beneficial to a utility include the following: (1) when data are lacking for a specific aspect of the evaluation (e.g., insulation-specific destruction pressures), the conservatisms needed to compensate for the lack of data could be so restrictive that the utility could elect to conduct tests to obtain the missing data; and (2) when the plant-specific resolution involves new strainer or screen designs, or significant variations on existing designs, these designs need to be tested to ensure their functionality, especially the ability of the design to negate the formation of a thin fibrous debris bed. Please address these potentialities in the guidance.

Response

No generic testing is planned by the PWR Industry for addressing GSI-191, with the exception of chemical effects testing. Section 3, "Baseline Evaluation," of the "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004, provides information required to perform a clearly conservative sump performance evaluation without further testing. The possibility of plant-specific testing is identified in the appropriate places in the Evaluation Methodology. In the PWR Containment Sump Evaluation Methodology, plant-specific testing is associated with analytical refinements and or design changes. With regard to potential sump

screen design changes, it is expected that testing would be performed by the screen vendor to provide the particular plant with the information necessary to support the evaluation the performance of the replacement screen.

4. Please explain the basis for applying an extrapolation of existing test data to other untested materials. In the NEI guidance, many parameters -- such as destruction pressures, transport parameters, and head-loss parameters -- were simply assumed with no justification provided. Please provide adequate justification and/or applicable test data, or else consider setting the assumed parameters to a conservative extreme (e.g., an unknown destruction pressure set to the lowest damage pressure known for the most vulnerable insulation type).

Response

Consistent with the NRC recommendation, extreme conservative assumptions have been taken in the analytical approach identified in Section 3, "Baseline Evaluation," of the "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004. This strategy has been applied to destruction pressures, transport parameters, and head loss parameters, where applicable. Analytical refinements are presented in Section 4, "Analytical Refinements," and includes guidance identifying where material-specific testing may be needed to implement the described refinements.

5. Why were more analytical tools and methods for the more detailed, complex evaluations, not recommended in the NEI guidance? For example, one area that would benefit from detailed guidance is the systematic estimate of debris generation quantities where these quantities must be evaluated for a relatively large number of break types and locations. Previously, these analyses have used computer codes designed specifically for this purpose -- e.g., the PWR volunteer-plant analyses used a computerized analysis that employed a CAD model of the plant piping systems. The BWR industry also used computerized tools. Also, NUREG/CR-6224 (parametric study of BWR sump blockage) illustrated how this analysis was performed by hand for the BWR volunteer-plant analysis.

Response

While it is acknowledged that computerized tools can be beneficial to performing sump performance evaluations, it is recommended that the computerized tools are the prerogative of the licensee to choose on a case-specific basis. The document, "PWR Containment Sump Evaluation

Methodology," submitted to NRC on May 28, 2004 does provide information regarding the choice of computerized tools in the discussion of CFD model generation since the choice of tools is considered important for this particular analytical refinement.

6. The NEI should consider summarizing the technology and experience gained during the BWR strainer-blockage resolution. At a minimum, the guidance could describe the advanced strainer designs, how the screen design features work once implemented (for both, passive and active designs), and the testing of those designs. In particular, the guidance could address how the advanced convoluted designs prevented the formation of thin fibrous debris beds. The guidance could also address the advice given in the NRC SER to the BWROG URG, where NRC staff positions were offered on several of the existing deficiencies discussed above.

<u>Response</u>

While it is acknowledged that the technology and experience gained during the BWR strainer-blockage resolution may be of general interest to those addressing PWR sump performance concerns, the whole of the BWR-related knowledge base has not been summarized in the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004. Key elements the BWR strainer-blockage resolution that were used in the PWR Containment Sump Evaluation Methodology have been documented in the NRC on May 28, 2004 document. Also incorporated into the document is guidance in the selecting and implementation of alternate strainer designs (including passive and active designs).

7. Does the NEI intend to undertake substantial technical review and editing of the rough draft guidance report, to ensure clarity, accuracy, report integration, and correctly cited references? For example, the draft has place holders that need to be completed on the topics of: 1) downstream effects, 2) comparison to regulatory guide requirements, and 3) the emerging concern regarding chemical effects. A number of references were incorrectly cited or missing. Personal communications need to be documented. Please address the overall integration effort intended for consistency in the report (e.g. the treatment of tags & stickers as small pieces in the debris-generation section, but treatment of such debris as sheets that cover the screen in the head-loss section).

<u>Response</u>

In light of the NRC response to the October 31, 2003 submittal, the document submitted on May

28, 2004 has been extensively revised and amended. The goals of the undertaking revision and amendment included addressing the NRC concerns regarding clarity, accuracy, and report integration. The structure of the revised document provides an easy to follow, integrated methodology. In addition, information and general guidance has been added regarding evaluation downstream effects and chemical effects.

8. Could the treatment of coating debris benefit from providing more detailed information, clarification, and integration throughout the report? For example, the likely forms of paint debris is not addressed -- i.e., in some locations, the report treats coating debris as fine particles and in other locations, data for paint chips is presented. The treatment of coating debris as very fine particulate will lead to high transport estimates and associated high head losses. Conversely, the treatment of coating debris as overly large chips could lead to nonconservative transport and head-loss estimates. Please consider providing a realistic size distribution.

Response

The Evaluation Methodology now includes more detailed information regarding debris generated from coating systems. Specifically, Appendix A has been added to address debris generation from coatings due to a postulated high energy line break.

9. Why is buoyant debris not assessed more thoroughly? Even though buoyant debris is not likely to cause sump screen blockage in situations where the debris would float well above the sump screen, it should be considered. Situations where it could have a significant impact on long-term cooling include:

- For a nonsubmerged sump screen, especially in a shallow pool, the buoyant debris that floats to the screen could effectively reduce the screen area available to flow.
- Buoyant debris can block upper level drains, thereby reducing the sump pool water level.
- For newly designed sump screens, the buoyant debris could impact the screen in other ways. For example, given the new “tea-cup” design developed for Davis Besse, where the top of the cup is near the water surface, buoyant debris could potentially be drawn down into the cup and impede the flow of water.

Response

The issue of buoyant debris has been addressed in Section 3.7.2.3.2.5, “Buoyant Debris,” of the document, “PWR Containment Sump Evaluation Methodology,” submitted to NRC on May 28,

2004.

Specifically, for fully submerged screens, buoyant debris is not considered a problem since it would not reach the sump screens. However, for partially submerged screens, the effects of buoyant debris should be considered. Note that the transport analysis may indicate that the quantity of buoyant debris reaching the sump screen is negligible, since trash racks and gates may largely prevent this.

For buoyant debris that is determined to reach a partially submerged screen, this baseline methodology recommends that the effective screen area be reduced by the thickness of the buoyant debris layer times the length of the covered perimeter, to the extent that it fully envelopes the screen. This is very conservative, since floating debris will have gaps and large pore space among pieces that will admit flow.

10. Please consider an appendix that contains a data sheet for each type of insulation, fire barrier material, and perhaps for coatings as well. Each data sheet containing product descriptions, manufacturer data, and data determined from relevant strainer/sump-screen testing, would be useful.

<u>Response</u>

Key information regarding the characteristics of common types of insulation, fire barrier material, and coatings has been provided in the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004. Specifically, the information is included in Table 3-1, "ZOI Radii for Common PWR Insulation and Coatings Materials," Table 3-2, "Mass Insulation Material Debris Characteristics," Table 3-3, "Coating Debris Characteristics," Table 4-1, "Damage Characteristics of Common Fibrous Insulation Materials inside PWR Containments," Table 4-3, "Size Distribution of Suppression Pool Sludge," Table 5-1, "Test Results for 'Lift at Curb Velocity'," and Table 5-2, "Test Results for Floor Transport." Information regarding the characteristics of less common materials was not included in the May 28, 2004 submittal.

11. Please address the use of active strainers.

<u>Response</u>

The use of active strainers has been addressed in , Section 5.3.3, "Considerations for an Active

Strainer Design," of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004. This sections provides a discussion on features associated with active strainers.

2.0 REQUESTS CONCERNING PARTICULAR ASPECTS OF THE BLOCKAGE EVALUATION

2.1 Break Characteristics

NRC Inquiry

The NEI guidance offers five options for estimating the characteristics of postulated breaks. The first two options are based on strategies previously used to resolve the boiling-water-reactor (BWR) strainer-blockage issue, i.e., either to assume that (1) all of the insulation inside the crane wall is turned into debris or that (2) a pipe is completely severed leading to a spherical damage zone as described in RG 1.82. The third and fourth options employ fracture mechanics and LLB arguments, respectively, to substantially reduce the size of the break and, hence, the postulated quantity of debris. However, since the concepts of using fracture mechanics and LLB in sump screen blockage evaluations have not been accepted by the NRC; should these concepts be included in the NEI guidance? (One concern with reducing the postulated break size is that unusual types of breaks may not be bounded by these assumptions -- e.g. Davis Bessie upper head erosion or perhaps seismically-generated breaks.) And although Option 5 bases the assumed break characteristics on a reactor-coolant-pump (RCP) seal loss-of-coolant accident (LOCA), which is certainly one possible type of LOCA; should it be included in the guidance if it is unlikely to represent a conservative break scenario?

Please clarify Section 4.2.2.5, entitled "Other Considerations," in the guidance. Please consider determining the worst-case breaks using a systematic, coupled process evaluating debris generation, debris transport, and sump-screen head-loss for each break to determine which results in the most challenging scenario. For example, consideration of breaks near high concentrations of the more problematic insulations (i.e., Cal-Sil or MinK) and fire barrier material, as opposed to locations with two or more types of insulation as suggested by the guidance, would be useful. The determination of the particulate-to-insulation debris mass ratio (better described as the particulate-to-fiber mass ratio) for each break location depends upon the containment-wide evaluation of the latent/resident debris in addition to the LOCA-generated debris. Unless there is significant particulate insulation debris, the selection of the worst-case break may depend greatly on the amount of resident debris. Due to transport processes like the initial pool fill, breaks located away from the sump screens could actually result in more debris deposited close to the screen than breaks located nearer the screens. The final paragraph in this section regarding the evaluation of probability of failure and the predicted mode of failure could be expanded to include more explanation, evaluation criteria, and examples.

Response

The Leak-Before-Break and Fracture Mechanics approaches to defining the break scenario, these

approaches have been excluded from the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004. The two approaches included in the May 28, 2004 submittal are:

1. Postulate Double-Ended Guillotine Breaks (DEGBs) at intervals along the RCS piping and un-isolatable piping connected thereto.

2. Postulate breaks assuming an alternate break size, based on a risk-informed consideration of the potential for a break of a given size that is less than the DEGB. This approach has been submitted to the NRC for consideration.

Determining the worst-case break does involve a systematic, coupled process evaluating debris generation, debris transport, and sump-screen head-loss for each break. The process to postulate breaks and evaluate the consequences thereof is:

1. Determine break sites to be postulated based on plant layout and potential debris sources. Consider that breaks near high concentrations of the more problematic insulations are likely candidates for limiting break locations.

2. Define the break size by either postulating a DEGB or an alternate break size, using a risk-informed approach that has been accepted by the NRC for the plant in question.

3. Determine the Zone of Influence resulting from the postulated break, taking robust barriers into account.

4. Evaluate the production of debris resulting from the postulated break, based on the inventory of potential debris sources and the characteristics thereof. Include miscellaneous debris sources such as latent debris and failed coatings.

5. Evaluate the transport of debris to the ECCS sumps, based on the quantity and characteristics of debris.

6. Define the characteristics of the debris bed formed on the sump screens based on the debris characteristics and sump screen configuration. Calculate the head loss across the sump screen resulting from debris accumulation.

7. Catalog the results and repeat the process for the next postulated break. Compare the results of each postulated case to the preceding cases until the break resulting in the highest head loss is

identified.

It is acknowledged that, for some cases, determination of the particulate-to-fiber mass ratio is dependent on the results of the containment-wide evaluation of latent and resident debris. Since latent debris is included in the debris source term (and therefore is included in the debris transport and head loss analyses), the effects of latent debris are integrated with the methodology as a whole.

The submittal of May 28, 2004 recommends that the following activities are performed to quantify the amount of latent debris inside containment:

- Calculate the horizontal and vertical surface area inside containment. Since latent debris is typically small and settles on horizontal surfaces, this calculation will determine the total area with the potential for accumulation of debris.

- Evaluate the resident debris buildup. It is necessary to determine the amount of debris present on surfaces inside containment.

- Define the debris characteristics. This information will be used in subsequent steps of the sump performance evaluation.

- Calculate the total quantity and composition of debris. This information will also be used in subsequent steps of the sump performance evaluation, such as evaluation of the transport of latent debris to the sump screen and the resulting head loss.

Detailed guidance for accomplishing the recommended activities for quantification of the amount of latent debris is provided Section 3.5, “Latent Debris,” in the document submitted to NRC on May 28, 2004.

2.2.1 Zone-of-Influence

NRC Inquiry

Please provide guidance for accomplishing the mapping of a typical PWR jet to a sphere beyond simply stating the concept of equivalent damage-pressure volumes. The NEI guidance recommends using a spherical-shaped ZOI as was recommended by the BWROG in the URG, repeatedly recommending a spherical radius of 12 times that of the broken pipe diameter (L/D=12). However, this radius was developed for a BWR jet and is not directly applicable to a PWR jet. Please consider that the volume within a particular pressure isobar in a PWR jet could be significantly larger than that for a BWR jet because the primary system pressures are substantially higher in a PWR than in a BWR. In addition, a PWR jet will contain more liquid water to vaporize during depressurization than a BWR jet. Also, limited NRC testing of debris generation in two-phase jets indicated a modest decrease in damage pressure thresholds and an increase in the proportion of smaller, more transportable debris sizes. Therefore, more rigorous mapping guidance aimed at PWRs would be useful.

The BWROG URG mapping model which resulted in the 12 pipe diameters was based on a saturated steam jet at 1070 psig. The BWROG used a computational fluid dynamics (CFD) code to determine pressure isobar volumes within a BWR jet for a number of pipe-break configurations. Please consider using a similar analysis for PWRs if the spherical ZOI method is to be used. If the NEI does not provide this analysis, then please consider having each utility perform the analysis since the model in the BWROG URG does not apply to a PWR. A misapplication of the previous model may under predict the volume of debris. It is noted in the guidance that an L/D of 12 was used in the parametric evaluation [NUREG/CR-6762], but that study only had the objective of determining whether or not there was a credible concern. A credible concern was demonstrated using a smaller sized sphere than may be appropriate for PWRs; therefore, although its use was valid for that study, please consider that it may not be valid for plant-specific analyses.

The mapping of a PWR jet to an equivalent sphere was not mentioned in the NEI report. Was such mapping performed to justify recommendations regarding the dimension of the sphere? Please also consider that the dimension of the ZOI should be related to the specific insulation products that are impacted. For example, a 12-diameter ZOI implicitly referred to the destruction of unjacketed fiberglass, but this distinction is not carefully explained in the NEI guidance. The uniformity of plant-specific analyses would benefit greatly if this technical topic were addressed thoroughly and accurately in the NEI guidance.

Response

The mapping of a PWR jet to an equivalent sphere was accomplished through the use of the

ANSI/ANS 58.2-1988 standard. The steps below were followed:

1. The reservoir conditions were defined as 2250 psia and 540 ˚F, which is meant to represent typical PWR cold-leg conditions[1].
2. The pressure isobars of interest were mapped, using destruction pressures of potential debris sources to define the stagnation pressures of interest. The jet expansion calculations performed were appropriate for a flashing jet.
3. The volumes encompassed by the isobars of interest were calculated and the radius of an equivalent sphere containing twice the isobar volume (to account for a double-ended break) was calculated.
4. The calculation output was rounded up for conservatism.

The dimension of the ZOI has been related to the specific insulation products that are potential sources of debris. The results of the calculations are summarized in the table below. Additional details concerning the calculation of the equivalent spherical volumes are contained in Section 3 of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004.

This approach is provides for a conservative large ZOI. The ZOI is calculated as the equivalent volume of two freely expanding jets, one from each end of the postulated pipe break. This provides for a maximum region influenced by the postulated break, and hence, a maximum ZOI.

Changes in insulation destruction pressures based on the differences between dry or saturated steam jets and flashing jets were not addressed because the stagnation pressure is the key parameter to determine the destruction of insulation. Furthermore, there is no technical basis besides one anecdotal test to modify the destruction pressures determined in support of the BWR strainer issue resolution.

Analytical refinements to the definition of the Zone of Influence are presented in the NEI Guidance. Two analytical refinements are offered:

- Use the insulation-specific equivalent spherical ZOIs listed above to assign a ZOI to each insulation species. This is a refinement as compared to the Baseline Evaluation Methodology, which recommends assigning a single spherical ZOI based on the insulation with the lowest destruction pressure located near the break site.

[1] To represent hot leg conditions, the calculations were performed using a pressure of 2250 psia and temperature of 610º F. The equivalent ZOI radii were calculated to be smaller than those predicted for 540º F. Thus, using pressures and temperatures representative of cold leg conditions provides for a ZOI that bounds both hot-leg and cold-leg breaks.

- Use the isobar maps created in the process of calculating equivalent spherical ZOIs to determine the jet loads on targets. Details of this refinement, along with isobar maps in tabular format, are included in the NEI Guidance Document.

Insulation Types	Destruction Pressure (psi)	ZOI Radius/Break Diameter	
		Calculated Value	Recommended Value
Protective Coatings (Epoxy and Epoxy-phenolic Paints)	1000	0.24	1.0
Protective Coatings (Untopcoated Organic Zinc)	333	0.55	1.0
Transco RMI Darchem DARMET	190	1.11	1.3
Jacketed Nukon® with Sure-hold® bands Mirror® with Sure-hold bands®	150	1.51	1.6
K-wool	40	3.73	3.8
Cal-Sil (Aluminum cladding, SS bands)	24	5.45	5.5
Temp-Mat with stainless steel wire retainer	17	7.72	7.8
Unjacketed Nukon®, Jacketed Nukon® with standard bands Knauf	10	12.07	12.1
Koolphen-K	6	16.97	17.0
Min-K Mirror® with standard bands	4	21.53	21.6

For a number of other plants, a 10 D value is used for the limit of jet damage. This is based on NUREG/CR-2913 dated January, 1983. The acceptability of this approach is documented in the plant Safety Evaluation Reports (SER's). To quote one SER:

> "The applicant has given the staff information requiring the analysis of jet impingement loads for postulated breaks. In FSAR section 3.6A.1.1.2, test data and analysis developed

> in NUREG/CR-2913, "Two Phase Jet Loads," dated January 1983, are used to establish the criterion that unprotected components located more than 10 diameters from a pipe break are without further analysis assumed undamaged by a jet of steam or subcooled liquid that flashes at the break. The staff has previously reviewed the methodology used in NUREG/CR-2913 for determining the effects of such a jet on components at a distance greater than 10 diameters and has found it acceptable."

The 10D value is associated with a 10 degree half angle jet or a total jet spread of 20 degrees. Thus, a spherical ZOI of 10 D is conservative on volume by a factor of approximately 16 for a single ended rupture and 8 for a double ended rupture. Assuming a 3 foot diameter pipe and using a jet with a 10° half angle, with a damage inducing length of 30 feet (10D) would produce a cone with a volume of approximately 853 ft^3. The volume of a cone is $1/3\ \pi r^2 h$. A triangle 30 feet high with sides a and b of equal length, the angle opposite side c of 20 degrees gives a base of about 10.5 feet. One half of this value is r used in the cone equation. The volume of a sphere is $4/3\ \pi r^3$. The "r" in the sphere equation for a 3 foot diameter pipe is 15. This gives a volume of 14,137 ft3. Dividing the volume of the cone into the volume of the sphere gives the amount of conservatism. For a double ended rupture assuming that the two jets expanded without contacting each other results in the factor of eight.

2.2.2 Destruction Pressures

The NEI guidance cites primarily BWROG URG data for insulation destruction pressures, i.e., the threshold pressure where insulation starts to be damaged by the jet. This data was obtained from testing that used an air jet as a surrogate for steam to cause damage to the insulation materials. The jets from postulated PWR breaks would be two-phase; hence, please address the applicability of air-jet-determined destruction pressures to PWR jets. It was noted in NUREG/CR-6762, Vol. 3 that the destruction pressures could be lower for two-phase jets than for air jets based on limited Ontario-Power-Generation (OPG) two-phase test data. If an analytic assessment or additional two-phase testing is not able to validate the applicability of the air jet data for PWR breaks, then please consider assuming conservative reductions of the destruction pressures to ensure long-term ECC. Please correct and clarify the destruction pressures recommended in the NEI guidance (Tables 4.2.5.1-1, 4.2.5.2-1 and 4.2.5.6-1). Specific requests pertaining to recommended destruction pressures include:

Response

The document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004, has adopted the destruction pressures listed in Table 3-1 of NUREG/CR-6808. These destruction pressures were determined at the Air Jet Impact Tests (AJIT) conducted by the Boiling Water Reactor Owner's Group (BWROG) and indicated the conservative threshold of damage that a material in the Zone of Influence (ZOI) will generate debris. Additionally, the listed damage pressures are those approved by the NRC on the Safety Evaluation Report (SER) to the BWROG URG.

These AJIT, however, were conducted with compressed air as a surrogate for steam. The AJIT tests confirmed that the destruction mechanism is two fold: a pressure blast causing the initial damage followed by an erosion damage caused by the flow of air. The damage caused by the blast overpressure is independent of the media of the pressure wave and relies on a dynamic overpressure pulse to cause the damage. As such, the AJIT determined damage pressures are applicable to material subjected to dynamic overpressure blast caused by postulated instantaneous PWR DEGB.

In order to assure conservatism of the higher potential for erosion by two phase flows that was shown in single Ontario-Power-Generation (OPG) two-phase test of an unspecified generic light density fiberglass, the worst case debris size distribution for NUKON® as fines was adopted for the size distribution of damaged fibrous insulation within the ZOI. Furthermore, to add to the conservatism this worst case debris size distribution was adopted for all fibrous materials listed in Table 3-1 of NUREG/CR-6808 with destruction pressure equal to or greater to for NUKON® - note that the materials with a higher destruction pressure are less fragile than for NUKON® and the debris size distribution would be no worse than the

worse size distribution for NUKON®.

As further conservatism, all material that is listed in Table 3-1 of NUREG/CR-6808 with a destruction pressure less than NUKON® are considered to be 100% fines. For material that is not listed in Table 3-1 of NUREG/CR-6808 the NEI guideline recommends adopting the lowest destruction pressure of all the materials listed in Table 3-1 of NUREG/CR-6808 (4 psi) and consider the size distribution to be 100% fines.

If analytical refinements are to be made, it is appropriate to use a less-conservative size distribution for the debris species in question. An alternate size distribution may be determined using plant-specific or vendor-specific information regarding the behavior of the specific materials under PWR DBA conditions.

1. The NEI guidance recommends a destruction pressure of 10 psi for NUKON®, which was previously accepted by the NRC in the staff evaluation of the BWROG URG. Please note that BWROG air jet Test 6-2 in the URG clearly shows substantial damage to a NUKON® blanket with Velcro® band closures at a pressure of 6 psi (i.e., 1.9% fines and small debris and 6.3% large piece debris), demonstrating that NUKON® would be damaged outside the ZOI prescribed by 10 psi. The volume of the ZOI would increase by 30% if the destruction pressure was decreased from 10 to 6 psi. Please consider this concern when estimating the debris size distribution within the 10 psi ZOI, i.e., the acceptance of 10 psi as the destruction pressure likely considered conservative debris generation. In addition, please also consider potential reductions to destruction pressures to offset uncertainties associated with air jet testing (see above).

Response

As noted above, the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 has adopted the destruction pressures listed in Table 3-1 of NUREG/CR-6808. These destruction pressures were determined at the AJIT tests conducted by the BWROG and indicated the conservative threshold of damage that a material in the ZOI will generate debris. The listed damage pressures in Table 3-1 of NUREG/CR-6808 are those approved by the NRC on the SER to the BWROG URG and includes unjacketed NUKON® with a destruction pressure of 10 psi.

Since the NRC did approve the 10 psi damage pressure for BWRs, and since the damage pressure was determined to be from an overpressure pulse whose damage mechanism is independent of the media of the pressure pulse, it is appropriate for the NEI guideline to adopt the 10 psi as the damage pressure for NUKON®. To add conservatism and account for the potential additional damage caused by erosion due to

two phase flows, the NEI guideline adopts the worst case size distribution of any of the NUKON® AJIT tests with the additional conservatism of lumping all non-jacketed debris as fines.

This approach yields a debris size distribution as 60% as fines, a significantly larger fraction of highly transportable fines than the 8.2% of the 6 psi test. As such the approach taken by the NEI guideline for the damage pressure for NUKON® is appropriate for PWR conditions, has been previously accepted by the NRC, and the debris size distribution ensures further conservatism for transport and head loss analysis.

If analytical refinements are to be made, it may be appropriate to use a less-conservative size distribution for the debris species in question. The alternate size distribution should be determined using plant-specific or vendor-specific information regarding the behavior of the specific materials under PWR DBA conditions.

2. The NEI guidance recommends using the NUKON® destruction pressure for generic fiberglass. Please provide justification for this assumption or simply recommend a conservative, lesser pressure. Note that some insulation types were damaged at a pressure of 4 psig or less.

Response

The document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 has adopted the lowest destruction pressures listed in Table 3-1 of NUREG/CR-6808 for any material that was not listed in the table. As such generic fiberglass is considered to have a destruction pressure of 4 psi and 100% of the material in the ZOI is considered to become fines.

If analytical refinements are to be made, it may be appropriate to use a less-conservative size distribution for the debris species in question. The alternate size distribution should be determined using plant-specific or vendor-specific information regarding the behavior of the specific materials under PWR DBA conditions.

3. NEI guidance recommends using a destruction pressure of 17 psi for Temp-Mat fiberglass with stainless steel wire retainers (per the URG), but then recommends using the same pressure for all other Temp-Mat configurations and states that this is conservative. Is data available for these other configurations, to verify that 17 psig is conservative? If not, please consider using a substantially lower pressure to ensure conservatism. In addition, please also address the comment section of Table 4.2.5.1-1, which recommends using the NUKON®

destruction pressure for Temp-Mat, which conflicts with the earlier guidance.

Response

The document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 has adopted the lowest destruction pressures listed in Table 3-1 of NUREG/CR-6808 for any material that was not listed in the table. As such other forms of Temp-Mat are considered to have a destruction pressure of 4 psi and 100% of the material in the ZOI is considered to become fines.

For the materials listed in Table 3-1 of NUREG/CR-6808 the PWR Containment Sump Evaluation Methodology guideline uses the destruction pressures listed in Table 3-1 of NUREG/CR-6808. These destruction pressures were determined at the AJIT tests conducted by the BWROG and indicated the conservative threshold of damage that a material in the ZOI will generate debris. Additionally, the listed damage pressures are those approved by the NRC on the SER to the BWROG URG.

These AJIT, however, were conducted with compressed air as a surrogate for steam. The AJIT tests confirmed that the destruction mechanism is two fold: a pressure blast causing the initial damage followed by an erosion damage caused by the flow of air. The damage caused by the blast overpressure is independent of the media of the pressure wave and relies on a dynamic overpressure pulse to cause the damage. As such, the AJIT determined damage pressures are applicable to material subjected to dynamic overpressure blast caused by postulated instantaneous PWR DEGB.

In order to assure conservatism of the higher potential for erosion by two phase flows that was shown in single Ontario-Power-Generation (OPG) two-phase test of an unspecified generic light density fiberglass, the worst case debris size distribution for NUKON® as fines was adopted for the size distribution of damaged fibrous insulation within the ZOI. Furthermore, to add to the conservatism this worst case debris size distribution was adopted for all fibrous listed in Table 3-1 of NUREG/CR-6808 with destruction pressure equal to or greater than for NUKON® - note that the materials with a higher destruction pressure are less fragile than for NUKON® and the debris size distribution would be no worse than the worse size distribution for NUKON®.

Hence the use of the destruction pressure in Table 3-1 of NUREG/CR-6808 for Temp-Mat fiberglass with stainless steel wire retainers is appropriate for PWR conditions and conservatism is further assured by the use of a highly conservative debris size distribution based on a material that is more fragile than Temp-Mat fiberglass with stainless steel wire retainers.

If analytical refinements are to be made, it may be appropriate to use a less-conservative size distribution for the debris species in question. The alternate size distribution should be determined using plant-specific or vendor-specific information regarding the behavior of the specific materials under DBA conditions.

4. The NEI guidance cites NUREG/CR-6369 for the destruction pressure of Transco fiberglass. Did this document determine any destruction pressures? Was this simply a reference citation error? Please address the destruction pressure of Transco fiberglass.

Response

The reference cited was erroneous. Transco blankets were not tested by the BWROG at the CEESI Air Jet Impact test facility. Transco blankets were used, however, by the NRC at the CEESI Air Jet Impact test facility as documented in NUREG/CR-6369. The study suggests that the Transco blankets tested behaved similar to the NUKON®. As such, the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004, adopts the position that the Transco blankets will have the same conservative destruction pressure as NUKON®, i.e. 10 psi. The PWR Containment Sump Evaluation Methodology guideline also uses the value of 60% for small fines and 40% for large pieces as the size distribution of NUKON® inside a pipe break ZOI.

Engineering judgment suggests that Transco low density fiberglass blankets would behave similarly to the NUKON® fiberglass blankets when subjected to prototypical PWR DEGB DBA conditions, hence the destruction pressure and size distribution adopted for Transco fiberglass blankets in this guideline is conservative.

If analytical refinements are to be made, it may be appropriate to use a less-conservative size distribution for the debris species in question. The alternate size distribution should be determined using plant-specific or vendor-specific information regarding the behavior of the specific materials under DBA conditions.

5. Min-K is listed as miscellaneous fiberglass insulation, whereas NUREG/CR-6762, Vol. 2, lists it as a particulate insulation in the same classification as calcium silicate. Although these types of insulation do contain small fibers for added strength, it is unclear that these small-size fibers will form a fiber bed similar to those formed by the fiberglass insulations. Min-K, like calcium silicate, can create unusually high head losses across a preexisting fiberglass debris bed. The NEI-recommended destruction pressure for Min-K is <4 psi (like the NRC SER to the URG), but it does not recommend how much less than 4 psi should be considered. Additional

guidance would be useful.

Response

The NEI Guideline incorporates the classification of Min-K as "Fibrous" as given in Table 3-1, page 3-4 of NUREG/CR-6808. Since the NUREG/CR-6808 is a more recent document than NUREG/CR-6762, Vol. 2, the NEI guideline adopted the destruction pressures listed in Table 3-1 of NUREG/CR-6808. These destruction pressures were determined at the AJIT tests conducted by the BWROG and indicated the conservative threshold of damage that a material in the ZOI will generate debris. Additionally, the listed damage pressures are those approved by the NRC on the SER to the BWROG URG.

These AJIT, however, were conducted with compressed air as a surrogate for steam. The AJIT tests confirmed that the destruction mechanism is two fold: a pressure blast causing the initial damage followed by an erosion damage caused by the flow of air. The damage caused by the blast overpressure is independent of the media of the pressure wave and relies on a dynamic overpressure pulse to cause the damage. As such, the AJIT determined damage pressures are applicable to material subjected to dynamic overpressure blast caused by postulated instantaneous PWR DEGB.

In order to assure conservatism of the higher potential for erosion by two phase flows that was shown in single Ontario-Power-Generation (OPG) two-phase test of an unspecified generic light density fiberglass, the worst case debris size distribution for NUKON® as fines was adopted for the size distribution of damaged fibrous insulation within the ZOI.

Furthermore, to add to the conservatism all fibrous material listed in Table 3-1 of NUREG/CR-6808 with destruction less than for NUKON® is considered to be 100% fines. As such, the PWR Containment Sump Evaluation Methodology guideline adopts a destruction pressure of 4 psi for Min-K and a size distribution of 100% as highly transportable fines.

If analytical refinements are to be made, it may be appropriate to use a less-conservative size distribution for the debris species in question. The alternate size distribution should be determined using plant-specific or vendor-specific information regarding the behavior of the specific materials under PWR DBA conditions.

6. Does the entry in NEI-guidance Table 4.2.5.2-1, apply to calcium-silicate insulation? If so, then clearly stating so would be helpful. And what destruction pressures are being recommended for calcium silicate? In addition,

please address an incorrect reference cited in the guidance related to some OPG test pressures and corresponding recommendations from an NRC reference. The original recommendation of a 20-psi destruction pressure for calcium silicate came from NUREG/CR-6808 (Page 3-18, Footnote 17), not from the NRC SER to the BWROG URG as cited in the draft guidance.

Response

The NEI guideline adopted the destruction pressures listed in Table 3-1 of NUREG/CR-6808. These destruction pressures were determined at the AJIT tests conducted by the BWROG and indicated the conservative threshold of damage that a material in the ZOI will generate debris. Additionally, the listed damage pressures are those approved by the NRC on the SER to the BWROG URG.

These AJIT, however, were conducted with compressed air as a surrogate for steam. The AJIT tests confirmed that the destruction mechanism is two fold: a pressure blast causing the initial damage followed by an erosion damage caused by the flow of air. The damage caused by the blast overpressure is independent of the media of the pressure wave and relies on a dynamic overpressure pulse to cause the damage. As such, the AJIT determined damage pressures are applicable to material subjected to dynamic overpressure blast caused by postulated instantaneous PWR DEGB.

In order to assure conservatism of the potential for erosion by two phase flows the NEI guidance adopts the debris size classification for Calcium Silicate within the ZOI as 100% fines. As such, the NEI guideline adopts a destruction pressure for Calcium Silicate as listed in Table 3-1 of NUREG/CR-6808 and a size distribution of 100% as highly transportable fines.

If analytical refinements are to be made, it may be appropriate to use a less-conservative size distribution for the debris species in question. The alternate size distribution should be determined using plant-specific or vendor-specific information regarding the behavior of the specific materials under PWR DBA conditions.

7. The NEI guidance does not include a destruction pressure for mineral wool, asbestos, unibestos, Microtherm, gypsum board, or any of the various foam insulations. This information would be useful.

Response

The NEI guideline has incorporated the lowest destruction pressures listed in Table 3-1 of NUREG/CR-6808 for any material that was not listed in the table. As such generic mineral wool, asbestos, unibestos, Microtherm, gypsum board, or any of the various foam insulations are considered to have a destruction pressure of 4 psi and 100% of the material in the ZOI is considered to become fines.

If analytical refinements are to be made, it may be appropriate to use a less-conservative size distribution for the debris species in question. The alternate size distribution should be determined using plant-specific or vendor-specific information regarding the behavior of the specific materials under PWR DBA conditions.

8. The NEI guidance did not contain a reasonable recommendation for five out of six common fire barrier materials listed in Table 4.2.5.6-1. Except for a single entry (Koolphen) in Table 4.2.5.6-1, please address the bases for assumptions made for the other five entries. If the caveat of "conservatively assumed" is applicable for these entries, then please address the justification for the caveat.

Response

As noted above, the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 has adopted the lowest destruction pressures listed in Table 3-1 of NUREG/CR-6808 for any material that was not listed in the table. As such generic fire barrier materials are considered to have a destruction pressure of 4 psi and 100% of the material in the ZOI is considered to become fines.

If analytical refinements are to be made, it may be appropriate to use a less-conservative size distribution for the debris species in question. The alternate size distribution should be determined using plant-specific or vendor-specific information regarding the behavior of the specific materials under PWR DBA conditions. Furthermore, the method used to assign the debris size distribution must be consistent with the method used to assign the zone of influence (a debris size distribution that is dependent on insulation seam orientation must not be used with a homogenized ZOI such as the spherical ZOI described in Section 3 of the Evaluation Methodology).

Please consider that testing has clearly shown that destruction pressure depends upon the orientation of the jacket seam. However, the OPG data were not comprehensive enough to provide destruction pressures as a function of seam orientation, and yet, the NEI guidance suggests that credit can be taken for seam orientation (discussed in

Section 4.2.5.2) when considering calcium-silicate insulation. For a specific jet and insulation arrangement, an analysis of the seam orientation could be valid, but the plant would then have to maintain these orientations throughout plant operation. However, the seam orientation model is not compatible with the equivalent-sphere ZOI method. The spherical ZOI functionally homogenizes all of the break orientations and jet reflections associated with unspecified obstructions. Hence, jacket-seam orientations can no longer be correlated with jet orientations. Please consider addressing this in the guidance.

Response

The document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 has incorporated the destruction pressures listed in Table 3-1 of NUREG/CR-6808. These destruction pressures were determined at the AJIT tests conducted by the BWROG and indicated the conservative threshold of damage that a material in the ZOI will generate debris. Additionally, the listed damage pressures are those approved by the NRC on the SER to the BWROG URG. These AJIT determined destruction pressures were selected independent of the seam orientation to the blast. The NEI Guideline now does not factor in the seam orientation in the determination of the destruction pressure or determination of the ZOI. Furthermore, in order to assure conservatism of the potential for erosion by two phase flows the NEI guidance adopts the debris size classification for Calcium Silicate within the ZOI as 100% fines.

If analytical refinements are to be made, it may be appropriate to use a less-conservative size distribution for the debris species in question. The alternate size distribution may be determined using plant-specific or vendor-specific information regarding the behavior of the specific materials under PWR DBA conditions.

2.2.3 Debris-Size Distributions

The degree of damage to insulation debris is a necessary input to the debris transport analysis and is usually presented as a size distribution for each type of debris. Please consider correcting or improving specific problems identified in the NEI guidance for estimating the size distributions of LOCA-generated debris. They are as follows:

1. The NEI guidance for a suitable debris-size distribution for NUKON®, which was recommended as a surrogate for several other types of insulations as well, simply referenced NUREG/CR-6772. The NUKON® debris described in NUREG/CR-6772 was created by passing NUKON® insulation through a leaf shredder to create a reasonable substitute debris type for the purposes of those tests. No size distribution was provided. Please consider providing guidance for a size distribution for NUKON® which includes the fraction of the insulation that is destroyed into very fine and highly transportable debris, the fraction of small-piece debris (similar to the debris produced by the leaf shredder), and the fraction of larger size debris (illustrated in the NEI Table 4.3.3.6-1). For example, it was found in the DDTS experiments [NUREG/CR-6369] that 15 to 25% of an insulation blanket that was completely destroyed by the air jet was degraded into debris so fine that it could not be collected by hand. Much of this fine debris was small enough to pass through a fine-mesh collection screen and would almost entirely transport in a PWR to the sump pool where it would remain suspended until it was filtered from the flow at the sump screen. Accounting for this very fine debris fraction in the debris generation and transport analyses would be useful. Other valuable sources of data for debris-size distributions are the descriptions of damage found in the BWROG URG for their air-jet debris-generation tests.

<u>Response</u>

The document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 has been changed significantly as to the debris characteristic size distribution from materials within the ZOI. For materials within the ZOI the debris size distribution is now divided into two (2) broad categories: small fines and large pieces. Small fines will be defined as any material that could transport through gratings, trash racks, or radiological protection fences by blowdown, containment sprays, or post-LOCA pool flows. Furthermore, the small fines are assumed to be the basic constituent of the material for fibrous blankets, (i.e. individual fibers) and pigments for coatings.

This guideline assumes the largest openings of the gratings, trash racks, or radiological protection fences to be less than a nominal 4 inches by 4 inches (less than 20 square inches total open area). The remaining material that cannot pass through gratings, trash racks, and radiological protection fences is classified as large pieces. The nominal 20 square inch opening is a nominal upper bound of the typically encountered grating of 1" by 2" openings or radiological protection fencing with wire meshes typically 1.5" by 1.5'. The

nominal 20 square inch opening is conservative from a sump screen head loss perspective[2] in that it maximizes the total quantity of debris that can be transported to the sump. Large pieces are considered to remain covered with jacketing. (Note that this debris size categorization may be amended to address grate sizes other than 1"x2" in size.)

NUKON® was the insulation material most tested at the AJIT test series and was adopted in the NEI Guidance as the standard for size distribution to which all other fibrous insulation tested was compared. For conservatism from a transport and head loss perspective, the AJIT test that generated the largest percentage of fines was adopted to represent the size distribution of all the debris within a ZOI irrespective of the proximity to the postulated break.

Further conservatism was adopted by interpreting the test results as small fines to be all the debris that was not jacketed. This resulted in a size distribution of NUKON® with the ZOI to be 60% small fines and 40% large pieces. Although there has been no direct testing of typical materials found within the ZOI of US PWRs at prototypical PWR temperatures and pressures, the size distribution of 60% fines is considered to be an upper bound given the conservative assumptions regarding the independence of the size distribution to break distance and the classification of all un-jacketed debris as fines.

The main source of data on debris size distribution of material subjected to simulated pipe break conditions are those reported in the BWROG URG AJIT tests and the NRC debris transport set of experiments described in NUREG/CR-6339. This NEI Guideline selected the test of the insulation that had the most data points (NUKON®) that produced the smallest fines and adopted this point as the bounding values of fines production for un-jacketed fibrous blankets. The data of size distribution following exposure to simulation of a pipe break close to PWR prototypical conditions is depicted in Table 3-7 of NUREG/CR-6808 for a low-density fiberglass tested at Ontario Power Generation. That test indicates 52% were of the category defined as small fines adopted by this guideline. This test suggests that the size distribution for NUKON® blankets in the NEI guideline to be conservative for PWR applications.

For fibrous insulation materials that underwent testing at AJIT, this guideline adopted the NUKON® blanket size distribution for fibrous blankets whose destruction pressure was the same or higher than for NUKON® blankets. If a material has a higher destruction pressure it signifies that the material has a higher

[2] As was discussed at NEI/NRC meeting of March 16/17 of 2004, the size distribution adopted by the NEI Guideline may not be conservative with respect to upstream blockage. The position adopted in the NEI Guideline is that the issue of upstream blockage should be addressed in the plant water level calculations and not in the sump performance calculation. For upstream blockage the debris size should be skewed to the larger pieces instead of to the small fines. Additionally, it is also appropriate and conservative to consider higher transport factors for "large pieces" from an upstream blockage perspective.

resistance to damage. As such, the size distribution would tend to 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. For material with an equivalent destruction pressure as NUKON® blankets, engineering judgment suggests that the fraction of fines should be no worse than for NUKON® blankets.

2. The NEI guidance recommends assuming the debris-size distribution of NUKON® for several other types of insulation including Temp-Mat, mineral wool, generic fiberglass, and most of the fire barrier materials. No physical foundation is provided for this recommendation. Please consider conservatively skewing the size distribution towards the smaller and more transportable sizes to compensate for the lack of debris-size data, or conducting appropriate testing to obtain the missing information.

Response

The document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 now recommends using the NUKON® size distribution of 60% small fines and 40% large pieces for all fibrous material whose destruction pressure listed in Table 3-1 of NUREG/CR-6808 are equal to or greater than the unjacketed NUKON® destruction pressure of 10 psi, i.e. Jacketed NUKON®, Knaupf, Temp-Mat/SS wire retainer, and K-wool.

The basis for adopting the size distribution of NUKON® for all fibrous material of equal of greater destruction pressure that NUKON® is that for those material to have the same or larger destruction pressure they have inherently the same or less fragility than NUKON®, hence they will generate the same or less fines. For fibrous insulation that are listed in Table 3-1 of NUREG/CR-6808 with a destruction pressure lower than 10 psi, the debris characteristic in the ZOI is 100% small fines. For any material that has not been tested the NEI guidance now presumes the material to be 100 % fines at the size of constituent material, e.g. individual fiber for fibrous materials. This approach to debris size characteristics in the ZOI provides a conservative debris size distribution that has been skewed toward the values for maximum transport and head loss.

If analytical refinements are to be made, it may be appropriate to use a less-conservative size distribution for the debris species in question. The alternate size distribution should be determined using plant-specific or vendor-specific information regarding the behavior of the specific materials under PWR DBA conditions.

3. For Min-K insulation, the NEI guidance simply noted an observation made from a SEM photo. Providing a size-distribution recommendation for Min-K, would be useful. For calcium silicate, OPG data is provided stating that 75% of the debris will be fines. Noting that calcium-silicate debris has a strong tendency to further degrade into fine particulate, especially in hot water, it could be assumed that all of the calcium-silicate debris is in the fine size category and that nearly 100% transport to the sump screens will occur if the containment sprays activate. Please consider that it is likely that Min-K would behave in a manner similar to calcium silicate. If applicable data is lacking, then please consider assuming that Min-K is also reduced completely to a fine and highly-transportable debris size.

Response

The document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 uses a conservative 100% small fines debris size distribution for Min-K and Cal-Sil. These small fines are the size of the constituent material, are highly-transportable and will maximize the head loss.

If analytical refinements are to be made, it may be appropriate to use a less-conservative size distribution for the debris species in question. The alternate size distribution should be determined using plant-specific or vendor-specific information regarding the behavior of the specific materials under DBA conditions.

4. For RMI insulation debris, the NEI guidance recommends a size distribution from Ref. 7-32 without including the distribution in the guidance. Does Ref 7-32 (an industry report for NUKON®) include a size distribution for RMI? Was the intended reference the NRC-sponsored Siemens test summarized in NUREG/CR-6808 (Figure 3-7, Page 3-15)? If this is the case, then the recommended size distribution is very conservative for the overall ZOI because the RMI cassette in the Siemens test was placed directly over the break jet to ensure complete destruction. In addition, please consider that this data applies specifically to DPSC Mirror SS RMI cassettes and may not be applicable to other types or manufactures of stainless-steel RMI.

Response

For RMI, the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 uses two (2) broad categories for the debris size distribution for debris within the ZOI: small fines and large pieces. Small fines will be defined as any RMI debris that could transport through gratings, trash racks, or radiological protection fences by blowdown, containment sprays, or post-LOCA pool flows. This

guideline assumes the largest openings of the gratings, trash racks, or radiological protection fences to be less than a nominal 4 inches by 4 inches (less than 20 square inches total open area). The remaining material that cannot pass through gratings, trash racks, and radiological protection fences is classified as large pieces.

The nominal 20 square inch opening is a nominal upper bound of the typically encountered grating of 1" by 2" openings or radiological protection fencing with wire meshes typically 1.5" by 1.5'. The nominal 20 square inch opening is conservative from a sump screen head loss perspective[3] in that it maximizes the total quantity of debris that can be transported to the sump.

The NEI Guidance takes the size distribution provided in Figure 3-7 of NUREG/CR-6808 and rounds up the percentage of debris size less than 4″ from 71% to 75%. The AJIT tests of all other RMI indicate a very high percentage of the debris was significantly larger than 4″, as such, adopting the size distribution of the NRC sponsored Siemens test for other RMI materials is conservative from a transport and head loss perspective.

If analytical refinements are to be made, it may be appropriate to use a less-conservative size distribution for the debris species in question. The alternate size distribution should be determined using plant-specific or vendor-specific information regarding the behavior of the specific materials under DBA conditions.

5. Debris-size distributions can only be obtained from applicable experimental data, i.e., debris-size distributions observed for specific insulations damaged at specific jet pressures. Insulation near the break is typically totally destroyed resulting in fine or small debris, whereas debris nearer the threshold pressure may only suffer minor damage resulting in larger debris pieces. Please include a discussion in the NEI guidance addressing the conversion of type-specific and pressure-specific damage data to a spherical ZOI. Such a method is outlined in Section 3.3.3, of NUREG/CR-6808, and may be useful. Note that directly applicable data exists for only a few types of insulation.

<u>Response</u>

[3] As was discussed at NEI/NRC meeting of March 16/17 of 2004, the size distribution adopted by the NEI Guideline may not be conservative with respect to upstream blockage. The position adopted in the NEI Guideline is that the issue of upstream blockage should be addressed in the plant water level calculations and not in the sump performance calculation. For upstream blockage the debris size should be skewed to the larger pieces instead of to the small fines. Additionally, it is also appropriate and conservative to consider higher transport factors for "large pieces" from an upstream blockage perspective.

The Air Jet Impact Tests conducted by the BWROG indicated a dependence of the size distribution of the debris as a function of distance from the nozzle, i.e., the higher the pressure the larger the quantity of small debris. As discussed in NUREG/CR-6808 Section 3.3, an analytical model could be applied that correlates the size distribution to the spherical ZOI. This type of modeling requires the understanding of the damage distribution based on applicable experimental data. Unfortunately there is a paucity of applicable debris generation test data applicable for PWR conditions.

Therefore, the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 now uses two size distributions for material inside of the ZOI of a postulated DEGB DBA: 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-LOCA pool flows. Furthermore, the small fines are assumed to be the basic constituent of the material for fibrous blankets, (i.e. individual fibers) and pigments for coatings. This guideline assumes the largest openings of the gratings, trash racks, or radiological protection fences to be less than 4 inches by 4 inches. The remaining material that cannot pass through gratings, trash racks, and radiological protection fences is classified as large pieces. For plants that may have openings greater than 4 inches all debris should be classified as small fines.

The main source of data on debris size distribution of material subjected to simulated pipe break conditions are those reported in the BWROG URG AJIT tests conducted at the CEESI test facility and the NRC debris transport set of experiments also conducted the CEESI test facility. The NEI guideline selected the test of the insulation that had the most data points (NUKON®) that produced the smallest fines and adopted this point as the bounding values of fines production for un-jacketed fibrous blankets. Furthermore, the test results were interpreted as all material not jacketed is considered as fines.

There are no data of NUKON® blankets subjected to PWR prototypical conditions. The only public data of size distribution following exposure to simulation of a pipe break close to PWR prototypical conditions is depicted in Table 3-7 of NUREG/CR-6808 for an unspecified low-density fiberglass tested at Ontario Power Generation. That test indicates 52% were of the category defined as small fines adopted by this guideline.

Engineering judgment suggests that the size distribution for NUKON® blankets in this guideline to be conservative for PWR applications based on the one Ontario Power Generation two phase test. For fibrous insulation materials that underwent testing at AJIT, this guideline adopted the NUKON® blanket size distribution for fibrous blankets whose destruction pressure was the same or higher than for NUKON® blankets.

If a material has a higher destruction pressure it signifies that the material has a higher resistance to damage. As such, the size distribution would tend to 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. For material with an equivalent destruction pressure as NUKON® blankets, engineering judgment suggests that the fraction of fines should be no worse than for NUKON® blankets. For material whose destruction pressure depicted in Table 3-7 of NUREG/CR-6808 is lower than for NUKON® blankets or material that are not in Table 3-7 of NUREG/CR-6808 the debris size characteristic adopted within the ZOI is 100 % fines.

If analytical refinements are to be made, it may be appropriate to use a less-conservative size distribution for the debris species in question. The alternate size distribution may be determined using plant-specific or vendor-specific information regarding the behavior of the specific materials under PWR DBA conditions.

6. Over time, various studies have described the size distributions of debris differently. NUKON debris has been categorized in as many as 7 classes and as few as 2 classes depending upon the analytical treatment. The NEI guidance currently presents multiple classification systems, but to improve understanding and consistency, please consider settling on a classification system(s) and relating all further guidance to that description. A system based on debris-transport characteristics would be effective -- e.g., NEI Table 4.3.3.6-1 for fibrous debris.

Response

As noted, there have been numerous schemes developed for classifying debris size distribution of material inside a ZOI. Most of the classifications schemes developed were for low-density fiberglass blankets manufactured by Performance Contracting Inc. (PCI) and Transco. NUREG/CR-6369 (Ref. 19) employed 5 fibrous debris size classification schemes, with 3 to 6 size designations (e.g. large, medium, and small). NUREG/CR-6264 (Ref. 21) adopted a classification scheme of 7 size categories for fiber. As noted in NUREG/CR-6369, the BWROG URG adopted a fiber classification scheme of 2 sizes: fines and large pieces.

The document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 has been changed significantly from the October 31, 2003 submittal with respect to the debris characteristic size distribution from materials within the ZOI. For materials within the ZOI the debris size distribution is now divided into two (2) broad categories: small fines and large pieces. Small fines will be defined as any material that could transport through gratings, trash racks, or radiological protection fences by blowdown,

containment sprays, or post-LOCA pool flows. Furthermore, the small fines are assumed to be the basic constituent of the material for fibrous blankets, (i.e. individual fibers) and pigments for coatings.

This guideline assumes the largest openings of the gratings, trash racks, or radiological protection fences to be less than a nominal 4 inches by 4 inches (less than 20 square inches total open area). The remaining material that cannot pass through gratings, trash racks, and radiological protection fences is classified as large pieces. The nominal 20 square inch opening is a nominal upper bound of the typically encountered grating of 1" by 2" openings or radiological protection fencing with wire meshes typically 1.5" by 1.5'. The nominal 20 square inch opening is conservative from a sump screen head loss perspective[4] in that it maximizes the total quantity of debris that can be transported to the sump. Large pieces are considered to remain covered with jacketing.

NUKON® was the insulation material most tested at the AJIT test series and was adopted in the NEI Guidance as the standard for size distribution to which compare all other fibrous insulation tested. For conservatism from a transport and head loss perspective, the AJIT test that generated the largest percentage of fines was adopted to represent the size distribution of all the debris within a ZOI irrespective of the proximity to the postulated break. Further conservatism was adopted by interpreting the test results as small fines to be all the debris that was not jacketed. This resulted in a size distribution of NUKON® with the ZOI to be 60% small fines and 40% large pieces. Although there has been no direct testing of typical materials found within the ZOI of US PWRs at prototypical PWR temperatures and pressures, the size distribution of 60% fines is considered to be an upper bound given the conservative assumptions regarding the independence of the size distribution to break distance and the classification of all un-jacketed debris as fines.

The main source of data on debris size distribution of material subjected to simulated pipe break conditions are those reported in the BWROG URG AJIT tests and the NRC debris transport set of experiments described in NUREG/CR-6339. This NEI Guideline selected the test of the insulation that had the most data points (NUKON®) that produced the smallest fines and adopted this point as the bounding values of fines production for un-jacketed fibrous blankets. The data of size distribution following exposure to simulation of a pipe break close to PWR prototypical conditions is depicted in Table 3-7 of NUREG/CR-6808 for a low-density fiberglass tested at Ontario Power Generation. That test indicates 52% were of the category defined as small fines adopted by this guideline. This test suggests that the size distribution for

[4] As was discussed at NEI/NRC meeting of March 16/17 of 2004, the size distribution adopted by the NEI Guideline may not be conservative with respect to upstream blockage. The position adopted in the NEI Guideline is that the issue of upstream blockage should be addressed in the plant water level calculations and not in the sump performance calculation. For upstream blockage the debris size should be skewed to the larger pieces instead of to the small fines. Additionally, it is also appropriate and conservative to consider higher transport factors for "large pieces" from an upstream blockage perspective.

NUKON® blankets in the NEI guideline to be conservative for PWR applications.

For fibrous insulation materials that underwent testing at AJIT, this guideline adopted the NUKON® blanket size distribution for fibrous blankets whose destruction pressure was the same or higher than for NUKON® blankets. If a material has a higher destruction pressure it signifies that the material has a higher resistance to damage. As such, the size distribution would tend to 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. For material with an equivalent destruction pressure as NUKON® blankets, engineering judgment suggests that the fraction of fines should be no worse than for NUKON® blankets.

For material whose destruction pressure depicted in Table 3-7 of NUREG/CR-6808 is lower than for NUKON® blankets or material that are not in Table 3-7 of NUREG/CR-6808 the debris size characteristic adopted within the ZOI is 100 % fines.

If analytical refinements are to be made, it may be appropriate to use a less-conservative size distribution for the debris species in question. The alternate size distribution should be determined using plant-specific or vendor-specific information regarding the behavior of the specific materials under PWR DBA conditions.

2.2.4 Latent Debris

NRC Inquiry

The NEI guidance states that samples collected during insulation walkdowns resulted in no more than 3 lbs of debris per 10,000 ft^2 of horizontal surface area and that a generic upper bound for the latent debris is 150 lbs. How and where was this debris collected? Please provide detailed information regarding these debris samples to allow an evaluation of the quality of the data. Do horizontal floor-surface estimates consider latent debris in more remote places such as cable trays and on and around equipment? Based on past descriptions of latent debris and ongoing research, is it possible that 150 lbs represents a typical quantity of latent debris rather than an upper bound? The debris characterization tests ongoing at Los Alamos National Laboratory (LANL) may provide additional insights on this matter.

The guidance cites the foreign material exclusion (FME) program as justification for limited latent debris; therefore, please provide guidance that validates the effectiveness of this program for a recent period of operation. Consider that GL-98-04 compiled information from plant inspection reports as recent as 1996 that clearly showed substantial quantities of debris found during maintenance outages -- e.g., five 55-gallon drums of sludge removed from the Haddam Neck ECCS sump [LER 96-014-00] along with an assortment of miscellaneous debris. If the FME program is used to limit latent debris in sump-screen-blockage analyses, recent inspection reports ensuring the effectiveness of the program would be useful. Please consider additional evaluation on this issue.

Response

The samples collected during insulation walkdowns were collected from surfaces such as:

- Floors
- Cable trays
- Piping
- Other structures and equipment

The debris was collected and examined on a mass-by-surface-area basis using collectors such as vacuum cleaners and clean, unused wipes.

Because of the various plant configurations and the inevitable variation in performance of FME and housekeeping programs, it is possible that the 150 lbs of debris represents a typical quantity of latent debris present inside containment. For this reason it is recommended that latent debris buildup is evaluated by each plant. Guidance given in Section 3, “Baseline Methodology,” of the document, “PWR Containment Sump Evaluation Methodology,” submitted to NRC on May 28, 2004 provides the information necessary for plants to quantify the amount of latent debris inside containment available for transport to the sump

screen. The steps used in the process are summarized below:

- Calculate the horizontal and vertical surface area inside containment. Since latent debris is typically small and settles on horizontal surfaces, this calculation will determine the total area with the potential for accumulation of debris.

- Evaluate the resident debris buildup. It is necessary to determine the amount of debris present on surfaces inside containment.

- Define the debris characteristics. This information will be used in subsequent steps of the sump performance evaluation. It is agreed that the ongoing tests may provide additional insights on this matter.

- Calculate the total quantity and composition of debris. This information will also be used in subsequent steps of the sump performance evaluation, such as evaluation of the transport of latent debris to the sump screen and the resulting head loss.

Debris found inside the sump is considered separately from debris sources outside the sump and the resulting sump screen pressure drop, since debris located beyond the sump screen is considered a downstream effect. The effectiveness of FME and housekeeping programs with respect to reduction or elimination of latent debris sources is evaluated by latent debris surveys as per the guidance Section 3, "Baseline Methodology," of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 and NEI-02-01.

Periodic inspection of containment to ensure continued effectiveness of the FME and housekeeping programs is recommended in the Baseline Methodology document. Evaluation of the presence of foreign material as described in NEI-02-01 provides the basis for assessing the FME and housekeeping programs.

2.2.5 Generation of Debris by Containment Sprays

The NEI guidance describes conditions whereby debris could be generated by the sprays; however, little data is provided regarding erosion rates for exposed insulation or failure rates for nonqualified coatings. Please address these erosion and failure issues in the guidance. Some erosion rate data was reported in NUREG/CR-6369, which may be useful. A model is offered there for the erosion of insulation where the jacketing does not overlap, but the basis of this model is not supplied or validated. Please also more thoroughly address the erosion of larger debris that does not transport to the sump pool, but is also subject to erosion by the sprays. Because spray operation may be of relatively short duration, degradation rates may be useful to estimate the total amount of fine transportable material generated during this time.

Response

Some material in the post-DBA environment will be eroded by the water flows. Additionally, some debris material may be disintegrated by the water flow. The classification for fibrous material in the ZOI adopted by this guidance assumes that all fibrous material classified as small fines are essentially reduced to the individual fibers. As such, the debris classification implicitly considers the erosion and disintegration of the debris by conservatively assuming that they are already of a characteristic size that cannot be further decreased by erosion or disintegration. 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.

The same conservatism was applied for coatings in the ZOI where this guideline assumes that all coatings in the coating ZOI are considered to be small fines of the size of the original pigment, hence not capable of being subjected to erosion or disintegration. 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. This assumption is based also on NUREG/CR-6369 tests that showed no erosion of damaged jacketed material, hence the same applies to un-damaged jacketed material.

Additionally PCI has conducted tests on undamaged NUKON® blankets to demonstrate that they do not subject to erosion in a post-DBA environment. The NRC issued an SER on the tests accepting the PCI results. For other material outside the ZOI the NEI Guidance recommends:

- Fire Barrier. Applying the same logic as was concluded in NUREG/CR-6339 for partially torn insulation that retained their covers/jackets, all jacketed or covered fire barriers are presumed not to degrade by the post-LOCA environment, hence not generate debris. Fire barrier materials that are unjacketed are presumed to fail as small fines.

- Lead Wool. The lead wool blankets have the same general covers as the NUKON® and Transco blankets. As such the conclusion of the NRC experiments are applicable. The NEI Guideline considers that all lead wool blankets outside the ZOI will not be damaged by the post-DBA environment.

- Unjacketed insulation. All material outside the ZOI that is unjacketed, e.g. fiberglass bats without any covering are presumed to fail to small fines.

- Coatings. DBA-qualified / acceptable coatings[5] located outside the Coatings ZOI are considered in this guideline not to fail when subjected to containment spray or immersed in the post-DBA pool. All indeterminate and DBA-unqualified / unacceptable coatings are considered in this guideline to fail. This baseline guideline considers all indeterminate and DBA-unqualified / unacceptable coatings as a single category of coating, producing debris of the same characteristic independent of the type of coating, when subjected to containment spray or immersed in the post-DBA pool. All types of coatings on piping or components covered with undamaged insulation are considered in this guideline not to contribute to the post-DBA debris source term.

[5] For definitions of DBA-Qualified / acceptable, DBA-unqualified / unacceptable and indeterminate coatings, see ASTM D5144-00, "Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants."

2.3 Blowdown/Washdown Debris Transport

1. The NEI guidance refers to NUREG/CR-6762, Vol. 4, as the basis for transport logic charts. Please note that the charts developed in that report, including the assigned distributions, applied to the generic parametric evaluation and are not plant-specific. The NEI guidance is so simplistic (i.e., Figure 4.3.3.2-1) that it does not illustrate much of the complexity associated with this transport analysis, and it does not show the possible variations in the analysis that would be associated with different plant containment designs. Each step in the simplified charts represents a fairly difficult analysis for which guidance is not provided. Please address how each plant is expected to apply this chart, considering that a realistic debris transport analysis is much more complex than the NEI guidance illustrates.

Response

The fidelity of the logic chart is clearly a function of the level of complexity. The NEI Baseline Methodology now presents a simplified logic chart that captures the major phases and paths of debris transport: Blow down, wash down, pool fill-up and recirculation transport. The debris logic chart can be as complicated or as detailed as those presented in the Drywell Debris Transport Study (DDTS) Study, or as simple as 100% transport. The NEI Baseline Methodology provides a logic tree that assumes conservative transport fractions for the major phases of transport and for the most part is based on inactive versus active sump areas, an approach applicable to any containment type. The Baseline Methodology does not prevent the user from developing a more refined transport logic tree based on detailed analysis of their containment configuration, their specific insulation debris types, and applicable test data.

For each major type of debris, event-tree considerations for the user include but are not limited to:

- Initial destruction fraction of debris (small pieces vs. large pieces)
- Distribution of small debris between Upper and Lower Containment as result of break
- Grating presence/locations
- Inactive Sump locations and volumes
- Debris retention & trapping on structures
- Fraction of debris that is washed down to floor pool by sprays
- Erosion fraction for large debris
- Benefits of insulation encapsulation or jacketing relative to erosion
- Presence of gates, trash racks, and coarse gratings
- Debris transport velocities (both incipient and bulk motion)
- Pool turbulence, ECCS flows and particle size, relative to debris settling in floor pool

- Transport fractions for debris once it is in the pool
- Effects of curbs, particularly near the sump

Plant-specific analysis, using information from walk downs and plant drawings, are required to assess the above effects as they pertain to each individual Unit. Specifically, the following guidance applies to each branch of the simplified logic chart.

Blowdown Transport: The "blowdown transport" branch point on the logic chart quantifies the initial post-blowdown distribution of debris in containment. The initial debris location bins are "deposited on containment structures", "transported to the containment pool floor", and "transported to inactive sump volumes." This is important because debris in the latter location would be unlikely to be transportable to the sump, and some fraction of the material initially deposited on containment surfaces may be retained there and thus also would not transport to the sump. To quantify this branch point, the analyst must consider the size and location of the break, as well as the containment geometry around the break location. The initial blowdown would tend to disperse at least the fine debris material in all directions (large debris is conservatively assumed to only transport downwards). Thus, if sufficient relief paths above the break location existed, the analyst could estimate the fraction of debris deposited on upper containment surface based on the relative flow areas in the upward versus downward direction. Any debris transported downward is automatically assumed to be transportable. Similarly, transport to inactive sump volumes could be estimated based on the volume of such inactive sump volumes versus the total pool volume that is calculated to form. Care must be exercised by the analyst to ensure that any inactive pool volumes credited are in fact reachable by the debris generated. This requires a qualitative evaluation of water transport pathways from the break location to such inactive sump volumes. The final fraction, "transported to the containment pool floor," is the remainder of all debris generated. Thus, this fraction starts off at 100% and is only reduced by the justified quantification described above.

Washdown Transport and Erosion: Most of any fine debris deposited on upper containment structures would be transported to the containment pool by the action of containment sprays. The analyst could estimate the fraction of such debris not transported based on several considerations:

- Those surface in the upper containment not subject to impingement by containment sprays,
- Those horizontal surfaces subject to sprays where the resulting surface flows are insufficient to transport the debris, or the transport is affected by curbs, etc. Generally, small fibrous debris and particulate would be expected to transport under any containment spray conditions. However, RMI debris is less readily transportable and thus could continue to be retained on containment surfaces.
- The transport of materials initially trapped on containment surfaces to inactive sump volumes.

For the larger fibrous and particulate (Cal-Sil for example) debris transported downwards to the pool, it is important to consider erosion of this material through the action of the containment sprays and pool turbulence. The default assumption in the baseline methodology is that all such debris not retained within its protective covering would erode to fine debris. Alternatively the analyst may consider less than 100% erosion for such material if it can be demonstrated that some of this material is trapped on gratings above the pool, and if the action of containment sprays is limited in time relative to experimentally-determined erosion rates for their respective debris materials. Thus, this is clearly a plant-specific analysis dependent upon that plant's accident scenario.

Recirculation Phase Transport: During the recirculation phase of the accident, debris transported to the pool could be entrained in the flow and deposit on the sump screen. Alternatively, if local flow rates are sufficiently low and the debris in question is relative heavy, a certain amount of this debris is expected to sediment to the containment floor and thus not deposit on the sump screen. The quantification of this is dealt with in subsequent sections.

2. Airborne/washdown transport of fine debris (e.g., individual fibers) is likely to be nearly complete when the containment sprays operate. Although some portion of the fine fibers will be trapped at various locations, non-transport can only be justified when airborne fibers are deposited at some location not impacted by sprays. Such locations represent only a small portion of the containment surface area. Please consider verification of the assumption of nearly-complete transport of fines using an NEI calculation. A time-saving consensus recommendation could thereby be made to emphasize nearly-complete transport. Alternatively, NEI may consider emphasizing those aspects of the analysis that were found amenable to refinement to help prioritize licensee analysis efforts.

Response

The document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 used a conservative transport of all non-RMI fines (100%) to the recirculation sump pool upon completion of wash down, making this material available for transport to the sump. For RMI small pieces the Containment Sump Evaluation Methodology adopts a 0 % transport factor for small RMI pieces by washdown based on the low pool velocities expected for pools that may form on the operating deck or elsewhere other than the containment floor pool. For the small RMI pieces that are on the containment floor, Section 3, "NEI Baseline Methodology," of the Containment Sump Evaluation Methodology adopts a transport factor of 100% for both the pool fill up and recirculation phases. Although simplistic, the overall approach above is considered conservative.

Relative to wash down of fine debris, plant-specific assessments may indicate that effects such as channeling of flow by curbs, assessment of spray coverage, floor slope, flow to inactive sumps, etc. may also warrant evaluation. Coarse grating, if covered with large debris, may also holdup a percentage of fine debris. However, flow to inactive sumps is likely the only significant factor here. Thus, a utility should have a strong basis (an unusual configuration, for example) to warrant the effort of justifying such effects for fine fibrous and particulate debris. Generally speaking, fine debris is usually treated as highly transportable by sprays unless it can be shown that mitigating factors are involved.

3. A statement is made (Page 78) that if the containment sprays terminate, the washdown of debris from the upper levels of containment is also terminated. However, the present ability to predict washdown debris transport is not sufficiently developed to support a time-dependent debris-transport estimate. Hence, if the sprays operate for any period of time, please consider that the washdown transport fraction is complete, unless a more thorough physical model can be presented to support the contrary. Please note that existing containment-water inventory calculations do, however, provide valuable insights into the time and location dependent drainage paths that introduce debris to the sump pool.

Response

The document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 uses a conservative transport of all non-RMI fines (100%) to the recirculation sump pool upon completion of wash down, making this material available for transport to the sump. For RMI small pieces the NEI guideline adopts a 0 % transport factor for small RMI pieces by the washdown based on the low pool velocities expected for pools that may form on the operating deck or elsewhere other than the containment floor pool. For the small RMI pieces that are on the containment floor, the NEI Baseline Methodology adopts a transport factor of 100% for both the pool fill up and recirculation phases.

As noted under the response to Item 2 above, plant-specific features may reduce the wash down fraction of non-RMI fines to something less than 100%. However, the current guidance does not attempt to credit the time-dependence of washdown transport relative to the timing of spray termination but rather relies on such considerations as the fraction of containment not subject to spray coverage.

4. Generic retention fractions are offered in the NEI guidance for the washdown transport analysis. Please justify each of these fractions, not only for review purposes, but also so that plant personnel can evaluate under what

conditions they may wish to deviate from these numbers. Also, please note that the fractions offered in the draft guidance are not comprehensive and that retention fraction can be plant-specific.

Response

The guidance of Section 3, "Baseline Methodology," of document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004, provides for conservative, bounding washdown transport fractions of 100% for fibrous/particulate fines and 0% for small RMI pieces. The basis for the 0% transport fraction of small RMI pieces by the washdown is based on the low pool velocities expected for pools that may form on the operating deck or elsewhere other than the containment floor pool.

As discussed in the response to item 1 of this section, improvement in the above transport fractions may be possible by plant-specific analysis. For example, some fraction of small debris will be blown into the upper containment through gratings, but not all of this would be washed down, because of debris trapping on the operating floor, flow to inactive regions, etc. Spray coverage and floor sloping may also be important. For example, depending on the floor slope, debris may be washed preferentially from the operating deck to either the containment annulus or else back inside the crane wall of the lower containment. Debris entering the annulus may fall in relatively quiescent regions and settle. In the latter case, the debris inside the crane wall may not be so readily transportable to the sump area.

Use of any numbers beyond what is provided in Section 3, "Baseline Methodology," must be justified with plant-specific evaluations (more robust logic trees, nodal network calculations or computational fluid dynamics calculations) of the debris flow paths. These results can then utilize available experimental data such as that found in Table 4.3.3.6-2, which is based on NUREG/CR-6369 & 6808. These transport properties in Table 4.4.3.4.2.5-1 each has a reference listed. However, the analyst should review this information to ensure the applicability of the results to their particular plant layout.

5. Please consider noting in the guidance, that NUREG/CR-6369 has information applicable to the erosion of fibrous debris by falling water. This may be useful.

Response

The NEI Baseline Methodology has implicitly included erosion in the development of the debris size distributions. The fibrous material classification scheme for material that has undergone air-jet impact testing (AJIT) assumes that the large pieces will still remain jacketed and based on NUREG/CR-6369 will

not be eroded by either containment spray or break flow. Medium-sized debris without the insulation covering has been assumed to be eroded and thus has been incorporated into the "fine" debris size classification. The small fines are already considered to be of the elemental material size, e.g. individual fibers for fibrous insulation, and as such will not undergo further erosion by falling water.

If the insulation is protected (e.g. encapsulated large pieces) then the erosion is zero. On the other hand, if the covering is damaged, then the erosion fraction may be large. This also depends on the jacket construction and the fraction of the jacket or covering that is damaged.

It is judged that erosion by break flow will be small. The spill zone is limited in the region it affects and water tends to flow away from this region instead of carrying debris to it. Relative to erosion by sprays, refinements might be available by considering timing of operation (thereby limiting the time of erosion) and also for scenarios in which sprays do not operate. These assessments are made on a plant- and scenario-specific basis.

6. Please consider noting in the guidance, that debris trapped in the upper reaches of the containment -- e.g., debris blockage of a refueling-pool drain -- can also retard water drainage and subsequently affect the sump-pool water level.

Response

The document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 presupposes that plant drain designs and plant water level calculations will account for the possibility of debris blockage in pools that could impact the sump-pool water level. The guidance has a debris size characterization of "small fines" that can be transported during blowdown to the upper parts of containment. This size characterization is considered to easily pass through any openings such as large gratings and radiological protection fences. The refueling-pool drains are generally pipes of 4 inches or larger. As such, the NEI Guidance considers that the "small fines" will not clog the refueling-pool drains, assuming the drain pipe is not covered by a grate, recognizing that this has to be confirmed on a plant-specific basis. The ability of larger material to clog a drain depends largely on whether or not it can get to the drain volume in the first place.

Plant-specific evaluation (nodal network or computational fluid dynamics methods) of floor water velocities in the upper containment should address the potential presence of debris in these areas and the effect such debris has on water flow if it becomes trapped at gratings on drains, etc. In some cases, it may

be necessary to investigate screen or trash rack designs to protect the drains and keep them flowing. Ensuring that the drains do not plug can be important to the floor water level calculation.

2.4 Sump-Pool Debris Transport

2.4.1 Initial Debris Distribution

The NEI guidance recommends assuming that the break-flows uniformly distribute debris about the floor of the compartment where the postulated break occurs and that, if the containment design is open, then the debris may be distributed uniformly about the entire containment floor. For additional guidance on introducing the debris to the sump pool, please consider that, in reality, the introduction of debris is both plant-specific and transport process-specific. For example, in the volunteer-plant analysis, most of the debris deposition at the sump level during blowdown transport occurred in the steam generator compartment where the break occurred, which concurs with the NEI guidance; however, in a more open containment design, uniform deposition across the entire containment floor is not necessarily the correct assumption. Rather, please consider that each plant could assess the proper distribution pattern to assume for initial debris deposition. This distribution can have a significant impact on the debris transport results depending on the relative location of the sump. Further, it can be estimated by examining the steam expansion flow paths around the break in combination with existing debris-generation test data describing the recovery locations of various debris-fragment sizes. Also, a large portion of the debris, if not most of the small-size and fine debris, would be transported throughout the containment building and reintroduced to the pool, along the containment-spray drainage pathways.

Response

Section 3, "Baseline Methodology," of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 considers two transport phases in the containment floor: pool-fill transport and recirculation transport. During pool formation the break and containment spray water will preferentially fill the "inactive sumps" – those volumes that are below the containment floor elevation. All movable debris that is on the containment floor during pool formation will tend to be preferentially washed into the inactive sumps by the thin sheets of fast moving water. Only when the inactive sumps are filled will the water level in the containment basement floor begin to increase and the pool turbulence decrease. During this fill process of the containment floor pool, as depicted in Figure 1-4 and 1-5 of NUREG/CR-6808, the switchover to recirculation has not occurred hence there is no preferential direction for water to flow to the sump. In the pool-fill transport, the guidance of Section 3 considers that all debris in the containment floor is uniformly distributed throughout the entire volume of water in containment. The guidance of Section 3 for debris transport then considers 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. This assumption is clearly conservative since it ignores the preferential sweeping of the debris on the containment floor to the inactive sumps by the thin sheets of

high velocity water. To add to the conservatism, the guidance of Section 3 then considers that all debris classified as “small fines” or “small RMI pieces” is transported to the sump during recirculation.

To summarize, the guidance of Section 3, “Baseline Methodology,” is considered conservative. In particular, there is potential for improvement to the floor-pool transport fractions. By evaluating fluid movement on floors on a plant-specific basis to account for scenario-specific ECCS flows, it should be possible to identify stagnant or near-stagnant floor regions where debris will settle. In addition, the floor velocities can be compared to the velocities for incipient movement and bulk tumbling (given in Table 4.4.3.4.2.5-1 of the document, “PWR Containment Sump Evaluation Methodology,” submitted to NRC on May 28, 2004) to see whether debris will transport to the sump.

While the basic approach to initial debris distribution is considered to be conservative, it is recommended that the analyst review the configuration of their plant relative to break location, blowdown transport pathways, and containment spray transport pathways to ensure that there are no plant specific considerations that would impact the baseline assumptions.

2.4.2 Pool Formation Debris Transport

Please consider providing guidance regarding the pool formation water flows and the concurrent debris transport. The guidance document simply states that engineering judgment is to be used to determine the movement of debris about the containment floor. Analyses performed by LANL have demonstrated the pool formation process, and experiments have shown the effectiveness of the initial sheeting flow at moving debris. Please address that sheeting flow could move the debris preferentially towards the sump screens, away from the screens, or even into dead-ended spaces. Please also note that these processes also depend on the location and size of the break. Because inspection could lead to incorrect and non-conservative debris transport results, it would be useful if engineering judgments were supported by meaningful analyses such as CFD pool-formation calculations or open-channel drainage-flow calculations. The obvious conservative position would be to assume that all initially-transported debris is located adjacent to the recirculation sump screens, but significant reductions in transport may be found by appropriate credits for sequestration in dead-end sump areas that are not affected by spray-drainage cascades. In fact, some licensees could consider diversion of debris during the pool-fill phase as a cost effective mitigation strategy that takes advantage of existing containment-floor geometries.

Response

There is agree with several of the LANL statements concerning debris transport and deposition during pool fill-up, and good suggestions are made. However, in general transient CFD simulations of pool formation are not considered to be viable as there are a number of variables to be considered, in addition to the intractability of a temporal approach.

To address localized deposition of debris during pool formation, plant-specific analysis would be required to determine either the benefits or the adverse effects. This would have to consider flow paths, floor sloping, location of inactive sumps, break location(s), etc. In general, the break and spray flows will fill the inactive volumes first, clearly the volumes beneath the floor, once flooding above any curbs is complete. (Plant-specific features may vary from this general statement.) This behavior may suggest possible plant-specific improvements such as notching of curbs to admit flow. Also, the sump itself should be considered in this evaluation. Debris trapping by volume ratios is considered conservative, since the fill-up flow should preferentially transport debris to the inactive volumes.

Section 3, “Baseline Methodology,” of the document, “PWR Containment Sump Evaluation Methodology,” submitted to NRC on May 28, 2004 assumes that debris transport in the basement floor pool during fill up will transport 100% of the small fines. Some of the small fines will be transported to the inactive volumes of the pool that will not participate in the recirculation flow, e.g., the cavity under the

reactor vessel. As noted above, the transport factor to the inactive pools is calculated by calculating the ratio of the volumes of the inactive pool to the total pool volume. No transport of large pieces is assumed to occur during pool fill up.

At most plants, the sump volume is relatively small by comparison to volumes such as the reactor cavity, therefore, no significant preferential accumulation of debris at the sump is expected during floor pool formation, i.e. the debris accumulation should be small because the sump is small. The initial sheeting flow should move most debris toward the larger inactive volumes. Naturally, these statements will be tempered by features such as local floor sloping and the presence of curbs, gratings, flow trenches, etc. and will necessitate plant-specific evaluation. As LANL suggests, diversion and trapping of debris during pool fill-up should be considered in the transport analysis.

2.4.3 Distribution of Debris Washed Into the Pool

In the NEI guidance, please address how debris washed down from the upper containment is to be introduced into the sump pool. Please include proper distributions in estimating debris transport within the pool. For example, debris trapped within the compartment containing the break would wash to the bottom of that compartment, but consideration that the debris distributed to regions outside of the break compartment would enter the pool at as many locations as the spray drainage enters the pool, would be useful. Another example is, assuming distribution of the debris in proportion with the spray drainage -- e.g., if 10% of the drainage enters the pool from a given stairway, then 10% of the debris washed down from the upper containment also enters the pool at that location. Alternatively, the guidance could recommend that all debris washed down from upper containment be considered transportable because of degradation in the turbulent splash zone, thereby obviating the need for location-specific distributions. Please consider these approaches to addressing this issue.

Response

Section 3, "Baseline Methodology," has established wash down and recirculation transport (pool transport) conservatively at 100% for small fines of fibrous debris. Latitude is provided for plant-specific evaluations to improve this assumption. The guidance of Section 3 identifies a number of items that can be considered, including spray coverage, floor sloping on the operating deck, grating presence, curbs, drainage to upper containment inactive volumes, etc. Once debris enters the floor pool, there is also potential for settling as well as transport to inactive volumes beneath the main floor during fill-up.

Thus far, none of the guidance has addressed localized deposition of washed-down debris on the main floor. Since most of this debris will be relatively fine fibers and fine particulate such as latent debris, since the spray wash down flow is distributed as opposed to being localized at the sump, and since there is some amount of floor pool turbulence once the ECC systems initiate, the assumption of uniform debris distribution in the floor pool is considered reasonable. Fine debris is conservatively sized and preferential transport to the splash zone and further disintegration is considered undue penalty. If anything, debris should wash away from the break splash zone during pool formation.

2.4.4 Debris Transport Estimates in the Pool

Please provide a degree of fidelity for pool transport modeling, perhaps above any other single aspect of an ECCS vulnerability assessment, in the proper context with respect to assumptions made in the other phases of the accident analysis. For example, please consider the focus in the guidance, on the details of computing water-flow velocities that induce debris transport. NRC-sponsored research has systematically examined all of the phenomena associated with the realistic accident sequence, and the expectation for such research tends to be the eventual development of a predictive, deterministic approach for modeling the entire progression from debris generation to ultimate head loss. Consider that this level of detail may be warranted in some circumstances, but in others, it will not be.

In the focus of the pool transport analysis, please consider reflecting the type and size of debris transported, specifically considering debris that is not so likely to transport to the screen. Hence, the results of the blowdown/washdown debris transport and the assumptions associated with that analysis impact the focus of the debris transport analysis. The aspects of debris transport that will have the most significant effect on reducing the transport fractions will depend upon both the characteristics of the debris and the conditions and geometry of the pool. For example, in a slowly-flowing pool where substantial debris-curbing surrounds the recirculation sump, little large debris would be expected to transport to the screen. In a situation where substantial small debris enters the pool and subsequently settles to the pool floor and the transport conditions are marginal, then a larger analytical effort could well payoff in a reduced transport estimate. Suspended debris, such as individual fibers will almost certainly transport to the screen over long term operation. Illustrated practical tradeoffs throughout the guidance would help licensees prioritize their analytic investments as well as reinforce the integration and interaction of assumptions throughout the assessment.

Response

Section 3, "Baseline Guidance," of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 has established recirculation transport (pool transport) conservatively at 100% for small fines and small RMI debris. Detailed analysis (nodal network and computational fluid dynamics approaches) is an option and should be expected to significantly reduce these conservative values. The amount of conservatism that can be tolerated is largely plant-specific, depending on debris types and quantities, floor geometry, curbs, floor water level, NPSH margins, sump screen area, etc. Depending on the plant, alternative techniques may be warranted that take into consideration the information provided in this section. This is discussed further below.

Specific requests on this section of the NEI guidance include the following:

1. NEI guidance regarding the CFD approach appears to focus on floor-level debris transport -- i.e., tumbling and sliding. Again, please consider that the fine suspended debris would all transport to the screens. Please consider using velocity contours to estimate floor fractions where the flow velocities are less than a particular transport velocity. This approach is then very dependent upon where the debris is introduced to the pool (see above discussion). Although the guidance appears to recommend a uniform initial debris distribution, please consider that high water velocities during pool formation would skew debris into geometry-specific patterns. Also, consider that washdown debris would enter with the drainage flows; hence, the debris may enter the pool in proportion to the volumetric flow of the drainage paths. Please also address consideration for debris initially introduced at locations of higher velocity that subsequently move into locations of lower velocity, and the finer pool details such as eddies and turbulence, in the guidance. Regarding code convergence criteria in the NEI guidance, please consider referring the user to specific software recommendations because implementations of these types of criteria can be code-specific. These improvements, introduced conservatisms, and validation by comparisons with experimental transport results could be useful in the NEI pool-transport guidance. Another more refined approach than the floor-fraction percentages might be to consider debris transport along flow streamlines that exceed the incipient transport velocities.

<u>Response</u>

Detailed flow patterns in the containment pool can be obtained using state-of-the-art 3D computational fluid dynamics (CFD). Several commercially available CFD software applications (FLUENT, FLOW3D) can be used for the flow simulation and analysis, which essentially solve the full set of the conservation of mass and momentum equations (Navier-Stokes equations) as well as turbulence equations for each of the computational elements in the domain of interest. Thus, fully three-dimensional (3D) flow patterns can be obtained, which in turn can be used to predict the various flow paths to the recirculation sump(s), including detailed 3D velocities for the debris transport analysis. The flow velocities and turbulent kinetic energy can be compared to the debris-specific settling velocities, incipient and bulk transport velocities to determine the percentage of debris expected to transport to the sump screen.

Considerations relative to the use of CFD include:

- Defining the containment geometry to be modeled by the CFD code
- Establishment of the water level for these calculations
- Treatment of flow paths to the containment floor
- Treatment of flow paths to and out of the active sump regions
- Treatment of transport restrictions such as curbs and trash racks

- Determination of key transport metrics that include both local velocities (floor transport) and turbulent kinetic energy (debris suspension)
- Comparison of calculated transport metrics to threshold quantities for various debris types, and the resulting determination of overall pool transport fraction for various debris types

As a minimum, the CFD software used for performing 3D flow simulations should have the following features:

- Solves the full set of Navier-Stokes equations
- Turbulence closure options, such the typical k- ε equations with the standard wall function
- Incompressible fluid flow solution
- Modern mesh generator
- Modern preprocessor for specifying fluid property and boundary conditions, such as non-slip walls, inflows, outflows, etc.
- Modern postprocessor or compatibility with independent modern postprocessor for analyzing CFD results

The computer-assisted design (CAD) package used for preparing the 3D geometry of the containment sump shall be capable of performing 3D solid modeling and have a compatible interface with the selected CFD software, i.e., the CAD files shall be imported by the CFD mesh generator. If available, use an existing electronic 3D solid model (file) of the containment as a basis for the geometric model. If a CAD file is unavailable or is not used, the containment geometry and details of obstructions shall be obtained from as built drawings and/or a containment walkdown.

The 3D geometric CAD model is imported into the mesh generator. The geometric model needs to simulate the actual pool water level and break location, thus requiring separate meshes for each of the LOCA break locations and water levels to be analyzed. For better accuracy of the CFD solution, meshes shall be clustered around the break inflow, sump intake(s), and other areas of interest where high velocities and gradients are expected.

The CFD results shall be post-processed to produce meaningful plots that assist in debris transport analysis. Types of useful plots are as follows:

- For a given type and size of debris, plot velocity magnitude contours for the minimum bulk transport velocity at a selected elevation(s) within the containment pool using the CFD software's built-in post-processor or an independent post-processor. Conservative results are obtained if the elevation selected for analysis gives the maximum area under the bulk velocity contour. The area within the velocity magnitude contour connected to the

recirculation sump is determined, and it may be conservatively assumed that debris in this area (of the given type and size being analyzed) will be transported to the sump screen. Refinements based on the flow pattern may be incorporated.

- The effects of turbulence level may be taken into account by assessing whether debris particles or fibers will stay suspended due to the instantaneous vertical velocity component being equal to or greater than the settling velocity of the debris particles. The maximum instantaneous vertical velocity is calculated by adding the fluctuating vertical velocity to the (CFD) computed mean (time average) vertical velocity. The fluctuating velocity is determined from the computed turbulent kinetic energy, k. Contours within which the instantaneous vertical velocity component is equal to or greater than the settling velocities of different type and size of debris being analyzed may be used to assess if this debris may become or stay suspended.
- Velocity vectors and flow streamlines may also be used to assist the analysis of debris transport.

Additional information regarding the use of CFD methods to refine the debris transport analysis is contained in Section 4.2.4.2 of the Evaluation Methodology.

2. The NEI guidance presents the network method for open channel flow as a method of determining flow velocities. The guidance also notes substantial limitations associated with this method including its inability to predict turbulence intensities, flow separations and eddies, three-dimensional velocity profiles, pool formation transients, and the difficulties of simulating complexities such as multiple flow entry locations associated with realistic containment-spray drainage. Appendix C provides a comparison between bulk-flow velocities estimated by the network method and by CFD calculations. (Note that the title to the appendix claims a comparison of transport factors but no transport factors were included). The bulk velocities did compare reasonably well; however, please address whether the network model development used the prior benefit of the CFD-predicted flow patterns (Figure 2 of the appendix) in establishing the network control volumes. Please consider providing a more detailed explanation of the procedure used for the comparison that may dispel this impression. Please also address the need for an independent network model, and more than one flow configuration to be used in the comparison. Please further explain the stated need to check for super critical flow conditions (analogous to sonic flow), which seems out of place in this context. And please address the basis for claims regarding conservatism of results -- i.e., it would be helpful if the claims could be supported either by comparisons to experiment or example calculations.

<u>Response</u>

The method does not attempt to analyze the movement of debris during filling operations but is directed only at debris motion subsequent to initiation of the post-accident recirculation phase. The rationale for focus on the recirculation phase is that this is the time frame when there is a forced and general fluid movement toward the sump screens that overwhelms any debris action during fill (beyond initial debris distribution). Further, if filling action were isolated to a specific and limited location in containment, there could be a general movement from the source to the sump during filling. However, as demonstrated in the volunteer plant input and as would be expected for containments generally, containment filling is driven by break flow and spray flow that would not be a single-source delivery. Therefore, this approach is focused on analysis of debris action upon initiation of recirculation.

The nodal network approach does not calculate turbulent effects or vertical velocities. These are primarily localized effects and are attenuated with the proper levels of conservatism and the subsequent effects of the velocity fields to final destination. The exception to the attenuation is the insulation erosion effects that result from local turbulences. These are minimized, however, with proper attention to debris generation efforts.

An influence of point sources of flow is the increased local horizontal velocities due to major inputs to channel flow. The following is the suggested approach for evaluating these local elevated horizontal velocity regions.

- If the bulk velocity for the channel exceeds the debris transport incipient velocity, the debris is transported and need not be evaluated further.
- If there is a channel between the influx point and the containment sump or a significant area between the influx point and the sump where the bulk velocity is less than the incipient velocity for the debris inventory, the debris may be moved initially but would resettle and need not be considered in the overall debris evaluation. The area required for settling need not be extensive, since most debris will slide or tumble along the floor and settle quickly.
- For those influx source points that do not satisfy either of the above criteria, the debris residing in the area affected by the point sources should be considered in the debris transported to the sump using the approach described in Appendix C of the Evaluation Methodology. The method considers the local velocity boost resulting from the point source.

With regard to prior knowledge of the CFD results, although the CFD results enhanced understanding of containment sump recirculation flow, including definition of channels as well as the refinement of the analysis technique, it must be understood that the guidelines provided for generation of a channel network in subsection 4.2.4.1 of the Evaluation Methodology were developed to alleviate the need for that specific, detailed knowledge. A CFD model of the containment floor is not explicitly required for successful development of a channel flow model, provided that guidelines are implemented and the conservatisms

applied.

Examining the conservatism of the open-channel nodal network method, the results for the volunteer plant compare very favorably with the computational fluid dynamics (CFD) analysis, generally providing calculated flow values with an error of less than 10 percent of the total recirculation flow. A description of the method used to determine the error of the calculations is contained in Appendix C of the Evaluation methodology.

To address inaccuracies of the low-flow regime calculations, uncertainty within the input flow distribution values, and potential errors within the CFD modeling process, it is recommended that 10 percent of the total recirculation flow, as a minimum, should be added to the calculated flow rates and sensitivity calculations should be based on that biased value to identify particular aspects that could significantly influence the results.

Appendix C of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 document has been revised and expanded to provide responses to each of the NRC inquiries. Specifically, the following issues are addressed in the indicated sections.

Item	**RAI Issue**	**Addressed:**
1	"inability to predict turbulence intensities flow separations and eddies, three-dimensional velocity profiles"..	Appendix C section C.2.2. "Turbulent Flow"
2	"pool formation transients"..	Appendix C Section C.2.1 "Filling Operations"
3	"difficulties of simulating complexities such as multiple flow entry locations associated with realistic containment-spray drainage…"	Appendix C Section C.2.2.2 "Horizontal Turbulent Velocity"
4	the title to the appendix claims a comparison of transport factors	Title of Appendix C is presently "COMPARISON OF NODAL NETWORK AND CFD ANALYSIS"
5	"please address whether the network model development used the prior benefit of the CFD-predicted flow patterns (Figure 2 of the appendix) in establishing the network control volumes"	Appendix C Section C.3, "PRIOR KNOWLEDGE OF CFD RESULTS"
6	Please consider providing a more detailed explanation of the procedure	Appendix C Section C.3, "PRIOR KNOWLEDGE OF CFD RESULTS" and

	used for the comparison that may dispel this impression	Appendix C Section C.1 "VELOCITY/FLOW CALCULATION"
7	Please also address the need for an independent network model, and more than one flow configuration to be used in the comparison.	Open channel flow is a well accepted technology for the calculation of flow rates and distributions. The governing equation for the calculation of resistance is confirmed using a second correlation. The approach is relatively direct with explicit guidance (Section 4.2.4.1) and the process is iterative to assure assumed flows and inputs are not incorrect or mislocated. Analysis will comply with 10 CFR 50 Appendix B criteria.
8	Please further explain the stated need to check for super critical flow conditions (analogous to sonic flow), which seems out of place in this context.	Discussion of critical flow conditions removed from Pressurized Water Reactor Sump Performance Evaluation Methodology document
9	And please address the basis for claims regarding conservatism of results	Appendix C, Section C.1 "VELOCITY/FLOW CALCULATION" illustrates the conservative results in the calculation of bulk velocity via the channel flow method. In as much as the Methodology document defines debris size distribution as either small fines (with movement relatively independent of flow velocity) and large pieces which are primarily sensitive to bulk flow velocities, the calculation of conservative bulk flow velocity is considered conservative.

3. Please consider providing more supportive arguments in the NEI guidance regarding the entrapment of debris behind curbs to justify the argument for permanent debris retention. Please consider addressing the interaction of debris loading behind the curb on subsequent debris accumulation. The debris lift velocities measured during the NRC-sponsored separate effects debris transport tests [NUREG/CR-6772] involved a relatively 'clean curb' -- i.e., the tests introduced only small quantities of debris so that each piece encountered a relatively unencumbered curb. Please address the situation where larger quantities of debris could accumulate behind a curb, thereby creating a ramp. Consider that the resulting velocity needed to lift additional debris over the curb could be substantially reduced from that measured for a clean curb.

Response

Any curb will in effect have a finite quantity of debris that it can trap before it becomes "saturated." Beyond that point, the slope of the trapped debris will be such that any subsequent debris will transport similarly along the ramp as it does along the floor. The volume under the ramp should be considered as trapped debris, recognizing that the ramp angle may be difficult to define, likely requiring experiments. The analytical refinements presented in Section 4, "Analytical Refinements," of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004, contain design considerations for debris interceptors such as curbs.

4. The NEI guidance states that debris located in dead-ended compartments will not transport, which is more applicable to debris already settled on the floor in dead-end compartments. However, please consider addressing how suspended debris can transport in the long-term from such a compartment if even a small amount of water flow occurs.

Response

While it is true that a certain amount of transport out of an "inactive" volume within the pool may occur by mixing at the interface with the active pool volumes, it is judged that this impact is dwarfed by the conservatism associated with limiting the quantity of debris in such volumes to that calculated by simple volume ratios. In fact, since these inactive volumes would typically fill early during the pool fill-up phase, they would be expected to contain a higher fraction of the total debris that is preferentially transported there during pool fill-up.

5. Please consider assessing the potential for water-level drop at the recirculation sump screen, if screens in the containment-water drain paths can accumulate enough debris to significantly retard flow. Please also address how lower water levels negatively affect sump-screen failure thresholds.

Response

If such flow restriction were to occur, the impact of a reduced water level in the vicinity of the sump screen

would need to be addressed. Such impacts would include:

- Reduced water level would lead to higher velocities and turbulence levels, and thus greater potential for pool debris transport. This is only important if credit was taken for less than 100% transport in the analysis.
- Lower water level could lead to uncovering a portion of the sump screen, requiring analysis of a partially submerged screen rather than a fully submerged screen. This will typically reduce the effectiveness of the screen significantly.
- Restricted flow to the sump may in fact reduce the available flow to a level insufficient to satisfy the pump requirement, starving the pump.

Note that with proper attention given to drain design, it should be possible to prevent or else minimize holdup in the drain paths.

6. NEI guidance for CFD transport analysis (Page 87) suggests using the minimum bulk transport velocity as a criterion for debris motion. NEI guidance for the network-method transport analysis (Page 90) suggests using the incipient transport velocity. Please consider recommending the same motion-velocity criterion for both methods, unless specific reasons can be provided otherwise. Consider that, if an occasional piece of debris can move, then bulk transport could occur over an extended period of time. Also, pulsation from flow turbulence can facilitate motion of a piece of debris that would not move ordinarily in nonturbulent conditions. Please consider using the lowest incipient velocities measured for specific types and sizes of debris under relevant flow conditions to describe debris motion. Also consider applying this to tumbling and lift velocities.

Response

The methods have been made consistent. If local velocities are less than the incipient transport velocity, then debris is not expected to move, and this is the better criterion for negating any debris motion at all. On the other hand, under steady state conditions, the bulk transport velocity is a meaningful criterion. Use of the incipient velocity is definitely the more conservative approach. The amount of debris that can reach the strainer by occasional pieces of debris is generally considered to be negligible, i.e. trace amounts. The floor pool transport analysis does not consider transient effects and hydrodynamic instabilities.

7. The NEI guidance contains a table of transport velocities, Table 4.4.3.4.5-1, for which the following requests apply. As explained in item "f." below, it is requested that the column labeled "bulk transport velocities" be deleted, thereby presenting only one set of velocity thresholds for debris transport on the floor. Please consider including "insulation density" in the table, which could be useful since there appears to be a possible correlation between incipient transport velocities and material density. Also, for settling velocities, consider citing the range and recommending use of the lower values to ensure conservative transport, instead of citing averages.

Response

The suggested changes have been made to the table, and ac corrected version included in the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004.

Please consider the following additional requests concerning this table.

a. NUKON®. The recommended curb-lift velocities of 0.22 and 0.25 ft/sec for 2- and 6-in curbs, respectively, were based on the minimum test velocities at which debris was observed to lift (test configurations B and C, respectively in Table C.3 of NUREG/CR-6772). Please consider reducing these velocities slightly to 0.19 and 0.22 ft/sec, respectively, to account for test variability that obscures the transition between debris lift and no debris lift. Also, please address how the comment for the NUKON entry refers to Table 4-8 of NUREG/CR-6224, but that NUREG/CR-6224 does not have a Table 4-8.

Response

Results in NUREG/CR-6244 for the B and C Configurations of the flume should only be considered qualitatively, i.e., the quantitative information for these configurations should not be used. This is because flow conditioning at the inlet to the flume was incomplete in Configuration B and nonexistent in Configuration C. Only in Configuration A was flow conditioning complete, i.e., only in Configuration A were the both the flow-straightening vanes and the turbulence-dampening pads in place at the inlet to the flume. (Configuration B had the vanes but not the pads. Configuration C had neither the vanes nor the pads.) So, only in Configuration A was flow conditioning accomplished such that a homogenous one dimensional flow developed in the flume. The observations that debris transported more readily in Configuration B and C are interesting, but no accompanying measurements of turbulence strength (i.e., velocity fluctuations) in the flume were made. Without accompanying turbulence information, the minimum velocities reported for Configurations B and C as necessary to transport debris are meaningful only in a qualitative sense.

Table 4.4.3.4.5-1 has been modified accordingly.

b. Generic Fiberglass. Please provide additional qualification for the use of NUKON® data for generic fiberglass needs. For example, please consider that if the generic fiberglass is heavier than or as heavy as NUKON®, then the NUKON® transport velocities are adequate. But, transport velocities for a lighter variety of generic fiberglass could be lower than those for NUKON®. Consideration for these dependencies could be useful.

Response

The comment is valid. However, transport data for "generic" fiberglass that is lighter than NUKON was not available at the time this response was prepared.

c. Temp-Mat. What is the pertinence of the comment stating that Temp-Mat has a "lower damage pressure" than that for NUKON, in the transport-velocity table? And, how is the reference which cites the debris-generation section of NUREG/CR-6808 (Section 3.2.1.2) relevant to this table?

Response

The "lower damage pressure" comment in the table has been removed.

d. High-Density Fiberglass. Please consider that this type of fiberglass be described by its various material properties including density to ensure that the higher transport velocities recommended for high-density fiber are not used for lighter fiberglass products other than those actually tested. Also consider that the preparation of the fiberglass shreds tested in NUREG/CR-2982, Figure 2.12, tended to create more standardized pieces of debris than have been created recently using a leaf shredder or those that would be created by a LOCA. Hence, the adequacy of representing the finer pieces of LOCA-generated debris (and perhaps less dense materials) using the NUREG/CR-2982 transport velocities, should be considered.

Response

The guidance in question has been clarified. A range of material properties for the HDFG is now listed to differentiate from the LDFG.

e. Thermo Wrap. Please consider either providing the information for Category 'c' (i.e., the incipient transport velocity, the curb lift velocity, and a description of the tested debris), or delete the designation of Category 'c' until more complete information can be provided. Also, why are the cited documents not included in the list of references? Has the referenced data been made available to the NRC?

Response

Category C has been deleted from the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004.

f. Mineral Wool. Again, please consider providing more descriptive information (e.g., density and shred sizes). Please expand in the report on the comment regarding the floatation of mineral wool. For example, if it floats, then transport to the sump would be complete unless dead-end entrapment can be defended. However, the floatation data is not comprehensive because the hottest temperature tested was initially only 120°F and that temperature was not sustained. Hence, mineral wool could readily float to the sump screen first and then subsequently sink later during the accident sequence. Note that test data for mineral wool is very limited in the open literature. Further discussion on the impact floatation would be useful.

Response

The table has been amended to address the comment. Mineral wool has a higher bulk density than Nukon, a lower fiber density and a smaller fiber diameter. In previous testing, significant pre-conditioning has been necessary in order to get mineral wool into a wetted state. The data also indicate that the incipient transport velocity is higher than Nukon.

g. Asbestos and Unibestos. NUREG/CR-6762, Vol. 2, lists asbestos and unibestos as particulate insulations. Therefore, why is NUKON data recommended as a surrogate for asbestos and unibestos, when their transport behaviors are likely to be more similar to those of calcium silicate than those of NUKON? Please consider assessing the physical properties of these materials in comparison with materials of known transport properties. Then, consider adding an extra factor of conservatism to compensate for the complete lack of data.

Response

The recommendation made in the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 is to characterize the Asbestos or Unibestos via SEM analysis, and to use calcium silicate properties if it is determined that the asbestos products are similar to Cal-Sil.

h. Calcium Silicate. Because a large fraction of the LOCA-generated calcium-silicate debris would already be in the dust form (OPG data), and because the remaining damaged pieces tend to disintegrate into silt when transported in hot water, especially when subjected to turbulence, please consider assuming that all of the damaged calcium silicate within the sump pool transports to the sump screen. Please consider and address that claims of limited disintegration of damaged Cal-Sil at higher elevations because of limited-duration containment sprays would require empirical erosion rates.

Response

A transport fraction of 1.0 is certainly a conservative approach and probably realistic once fine debris enters the pool. However, there are some mitigating factors to be considered. Please refer to Item 2.4.5 (b) below for further discussion.

i. Stainless-Steel RMI. Please consider changing the lift velocity over a 6-in curb from ">1.0 ft/sec" to "1.0 ft/sec" so that the guidance is more definitive. What is the intended context of the discussion regarding "approximately 2/3 of RMI remaining suspended"? Why is it included here? Please consider that this comment addresses the suspension of debris by turbulence; a topic that could be usefully addressed in a separate section that explains how to assess the effect of turbulence on all types of debris.

Response

The RMI lift velocities have been expanded in the updated table in the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004.

j. Aluminum RMI. Why is stainless steel-RMI data applied to aluminum-RMI, when the aluminum is lighter and will transport and lift at lower velocities than stainless steel for a given size of fragment?

Response

The application of stainless steel RMI transport metrics to aluminum RMI is inappropriate. The table has been corrected.

k. Fire Barrier 3m Interam & Fiberglass Blanket. Please consider substantiating the assumption that NUKON data can be used, by comparing the material construction, constituents, and densities to formulate a basis for the assumption. Please note that, if either of these materials is less dense than NUKON, then that material could transport at lower velocities than NUKON. Is 3m Interam fibrous?

Response

Available information regarding fire barrier material has been added to the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004.

l. Koolphen. Why is it assumed that NUKON data can be used as a surrogate, when this material (closed-cell phenolic) is not similar to NUKON?

Response

The reference to NUKON has been deleted from the table in the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004.

m. Min-K. This material is a particulate insulation type. So, if its transport behavior is likely to be more similar to that of calcium silicate than to NUKON, then why is NUKON data recommended as a surrogate? Similar to the case of calcium silicate, please consider that 100% transport of damaged Min-K in the pool should be assumed.

Response

The table has been clarified in the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004.

n. Lead Wool. Why does the guidance assume that this material will settle and not transport, when its density is not much higher than that of high-density fiberglass insulation, which was assumed to transport? Please consider that all materials will transport at some velocity, so if lead wool is present in containment, its potential transport cannot be dismissed. Please consider determining its properties by testing or by comparison with other well-characterized materials

Response

The lead component will settle out, as would fabric blankets filled with lead. The guidance in the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 refers to the fabric cover (usually fiberglass cloth or something similar).

o. Dust/Dirt. The NEI suggests using calcium silicate data for dust/dirt. The above review request suggests 100% transport for damaged calcium silicate because of its tendency to disintegrate into fine silt-like particles. Please consider that the transport of dust/dirt will depend on particle size. For example, finer particles and fiber will remain suspended and transport completely, and heavier particles could settle and remain in place. The conservative assumption of 100% transport could be useful as an option, but more refined guidance might be based on NRC-sponsored research into latent debris characterization.

Response

The document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 takes a conservative approach for Dirt/Dust. Generally, small particle sizes and high transport fractions are assumed in absence of other information like a debris size distribution and material properties. Individual plants can certainly utilize the latest NRC research as applicable. They may also use plant-specific data.

p. Sludge (iron oxide). If a plant determines that their containment has iron-oxide sludge, please consider conservatively treating it as dust/dirt since iron particles would be heavier and more prone to settling (if a similar size distribution can be assumed).

Response

Ferrous sludge is unlikely to be found in a PWR. If a plant has sludge, it is considered appropriate to use data from the BWRs (NUREG/CR-6224). Ferrous sludge is known to be very dispersible and transportable in water, as implied by the NRC comment.

p. Coatings. The NEI guidance for coatings is based on the paint sample artificially created for UNM transport tests (NUREG/CR-6772). Please consider expanding the sample, covering a spectrum of sizes, including fine pigment-base particulates, in order for the guidance to consider more than one classification of coating debris.

Response

The document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 provides specific guidance on treatment of coatings. Specifically, Appendix A of that document provides detailed information regarding coatings debris from the postulated high energy line break.

Larger coatings particles, normally associated with blistering or de-lamination failures due to the post-LOCA environment, would exhibit higher settling velocities (or possibly float) having much less affinity for transport. Metrics have been added to the table with regard to coatings.

2.4.5 Debris Disintegration

What is the basis for the NEI guidance on debris disintegration (Section 4.4.4.3, Page 91)? Please consider that at least two test series have shown that fibrous debris disintegrates in a turbulent pool, but the data are currently inadequate to correlate the rate of disintegration with the degree of turbulence. Neither is it known whether other parameters such as pool chemistry would affect the rate of disintegration or whether there is an effective threshold for the level of turbulence that can induce disintegration.

Response

Debris disintegration has not been explicitly addressed within the Baseline Methodology. The "small fines" debris size category adopts the conservative position that all debris less than 4 inches is reduced to its constituent, e.g. individual fibers for fibrous material. For insulation material whose tested destruction pressure is less than that of unjacketed NUKON® or which was not tested at the AJIT CEESI facility, plus Cal-Sil, the NEI Guidance presumes that all the material in the ZOI will become "small fines". For unjacketed NUKON®, Jacketed NUKON®, Knaupf, Temp-Mat/SS wire retainer, and K-wool the NEI Guidance adopts the smallest debris fraction of "large pieces" observed in the AJIT tests for NUKON®. These "large pieces" are considered in the NEI Guidance to be jacketed, and per NUREG/CR-6369, not considered to undergo further erosion. As such, debris disintegration is considered implicitly in the Baseline Methodology.

a. The NEI suggests using engineering judgment to estimate the rate of disintegration using the calculated fluid velocities. It states "If the calculated fluid velocity is less than the incipient transport velocity, fibrous debris is not likely to be subject to disintegration and it may be neglected." What is the basis for this position? Please address turbulence in some detail, and consider that based on observations during the integrated debris transport tests [NUREG/CR-6773], it is possible that debris could remain trapped in eddies at the boundaries of moving water zones and continue to disintegrate at a slow rate. Please also consider that, even a slow rate of disintegration can become important during a long-term cooling scenario. Note that the integrated debris transport tests were limited to a few hours.

Response

Some fraction of debris trapped near the boundaries of moving water zones may be subject to erosion and thus become transportable. This could be handled by slightly reducing the fraction of containment where debris sedimentation would occur. It should be noted that at the present time, the nodal network and CFD

approaches to debris settling do not account for debris transport into a low flow zone from a high flow zone. Thus, they conservatively under-predicts the amount of debris that would settle out in low flow zones. It is expected that this effect would dominate relative to possible erosion in the moving water zone boundaries.

b. Please consider disintegration for all debris types where disintegration is possible. For example, some materials such as RMI will not disintegrate in the pool, but for some materials such as calcium silicate, the disintegration may be complete.

Response

Debris that is destroyed in the ZOI which is assumed to be fine material is not considered subject to further disintegration. Particulate debris that is initially destroyed as large, intact pieces (such as jacketed calcium silicate) may further disintegrate over time. An upper bound estimate would be to assume that all of this material is reduced to fines. However, containment of this material by capsules, cassettes, canvassing, etc. greatly reduces the surface area that is exposed to erosion/disintegration, and these containers should also restrict transport of this material once it is wetted. Therefore, we think that the assumption of 100% disintegration and transport may be too conservative. There may also be some types of calcium silicate that do not disperse in hot, turbulent water, but this would have to be established on a plant-specific basis. For unjacketed materials that are known to be dispersible in water, large disintegration fractions are of course plausible.

c. Without adequate data, please consider basing the rate of disintegration on a conservative physical rationale.

Response

Section 3, "Baseline Methodology," of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004, adopted a very conservative approach to erosion (100% erosion of all materials potentially subject to erosion). Consistent with the analytical refinements presented in Section 4 of the PWR Containment Sump Evaluation Methodology, it is recommended that this conservative approach to erosion is used unless reduction in the conservatism is substantiated through the use of additional material-specific information. Examples of additional information include direct experimental evidence or analogy to similar materials.

2.5 Sump-Screen Head-Loss Evaluation

The NEI guidance proposes using the NUREG/CR-6224 correlation for predicting head loss across fibrous debris beds, but please consider improving some of the guidance regarding debris-specific input parameters. Please note that the proposed correlation is empirically-based, meaning that several coefficients are used to best fit the correlation to observed data. Another way to look at the correlation is that it provides a means of extrapolating from known test data to postulated plant conditions that are not too dissimilar from the known test conditions. The following requests apply to the NEI guidance:

1. The NEI guidance states that the NUREG/CR-6224 correlation has been extensively validated (Page 110). How has it been validated for the insulations and particulates expected in PWR scenarios? Although the form of the correlation is thought to be robust for these applications, please consider citing (in the NEI guidance) the studies that have provided validations for relevant materials. Please also consider and address that, for other materials not previously tested, validation studies should be performed to ensure that appropriate input parameters are used in the correlation.

<u>Response</u>

The NUREG/CR-6224 correlation is applicable to both PWRs and BWRs since the correlation is based on the characteristics of the debris bed material. In NUREG/CR-6224 and in the NEA/CSNI/R (95)11 Report, (the "Green Book"), the correlation has been extensively validated for materials in common use in the BWRs and PWRs. Nukon®, Transco Thermal-Wrap®, and Mineral Wool are three examples of fibrous material. Paint chips, rust, metallic particulates, organic sludge, dirt and concrete dust have also been tested in combination with fiber. Figures A-1 through A-13 of the Green Book illustrate data comparisons to the NUREG/CR-6224 correlation.

The NEA/CSNI/R (95)11 Report depicts generally good agreement of test data and NUREG/CR-6224 predictions for PCI's NUKON®, Transco's Thermal-Wrap®, and mineral wool. (A sample plot from the Green book is shown below). This report concludes that the NUREG/CR-6224 correlation 'can be used "as is" without any modification to predict head loss corresponding to different types of fibrous insulation', by using the appropriate material properties.

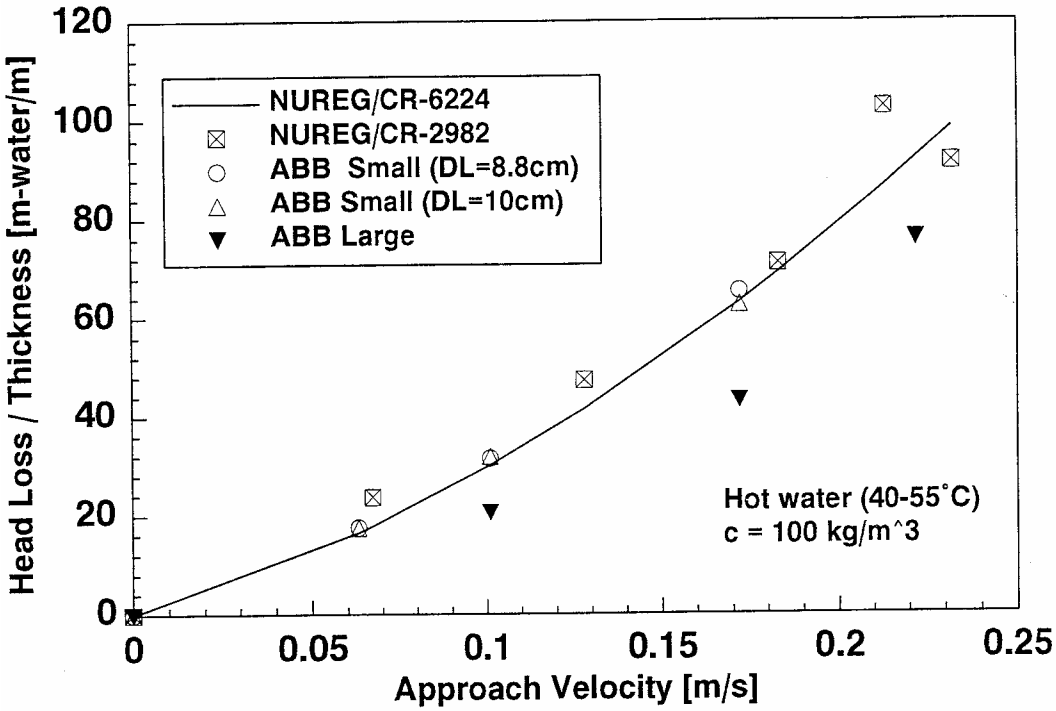

Figure A.8 Comparison of the NUREG/CR-6224 Head Loss Correlation and Selected Experimental Data for Mineral Wool–Hot Water Conditions

In addition to the validation of the NUREG/CR-6224 correlation reported in the NEA/CSNI/R (95)11 Report, head loss testing has been performed for the following debris and used to establish design head loss requirements for replacement strainers at BWRs:

- RMI, Sludge and Paint Particulate
- Min-K
- Min-K, Microtherm, Nukon, and TempMat
- Calcium Silicate and Kaowool
- Aluminum RMI and Fiber
- NUKON® and Sludge
- TempMat and Sludge
- NUKON®, Sludge and Paint Debris
- Knaupf Fiber, Sludge and Paint Debris

- NUKON®, Sludge, IOZ, and Paint Chips

Good agreement between the experimental data and the NUREG/CR-6224 correlation was demonstrated when the correlation was used. Note that all of the database above is privately held and thus is not reflected in either the Draft Guidance or the Baseline Methodology. Refer to Appendix B of the NEI Baseline Methodology for a summary of available test information. (For convenience, this information is also attached as Table HL-1 at the end of this document).

2. The NEI document provides guidance for estimating the specific surface area parameter (ft^2/ft^3) for the correlation by examining the characteristic diameters of particles and fibers. This guidance was adapted from NUREG/CR-6371, written in 1996. However, please consider and address how experience gained since then, has demonstrated that estimating the specific surface area in this manner can underestimate the specific surface area, and hence, the predicted head loss. Then please consider the alternative approach of applying the correlation iteratively to applicable test data -- i.e., by adjusting the specific surface area until the correlation correctly predicts the head loss observed under conditions where all other parameters are reasonably well-controlled. Also, please note the following detailed requests:

Response

The above procedure has in fact been followed in a wide variety of debris-specific analyses, both in the USA and internationally. (Refer to the "Green Book" in this regard). In all cases where the debris bed constituents were well known and did not have a wide variation in characteristic size, the NUREG/CR-6224 correlation bounded the observed experimental data. In cases where a debris bed constituent has as very large variation in debris size, e.g. Cal-Sil, for which less than 5-microns to over 100-microns is observed, use of the smaller debris characteristic may be necessary to ensure that the NUREG/CR-6224 prediction will bound the observed head loss test data.

a. Please consider and address how attempts to estimate the specific surface area by the geometric method of a dirt sample generated for head-loss testing at UNM, underestimated the specific surface area determined through the application of the correlation to test data by a factor of 4.

Response

There is no doubt that values of the specific surface area can be established by experiment for specific and potentially unique species of debris. The information mentioned above appears to be under NRC control. If this is true, please provide the data for our evaluation, and also please provide a detailed characterization of the dirt sample.

b. Please consider and address that, if a specific surface area is estimated for the BWR-URG data for a typical size distribution of corrosion products (see NEI table on Page 5 of Appendix D), the estimated surface area is a factor of 3.8 smaller than the area of 183,000/ft recommended in NUREG/CR-6224. Is the data in the NEI table incorrectly labeled as "% by weight"? Please note that, in the URG, these same percentages were in "% by the number of particles."

Response

This table is correctly labeled in the above regard. It was intended to replicate Table B-4 of NUREG/CR-6224. However, 'MM' in the left column of the table has been changed to 'microns'.

For the BWR-prototypical sludge used in Appendix B of NUREG/CR-6224, S_V = 1.83E+05 is in fact the recommended value, as demonstrated by comparisons to head loss test data for fiber and sludge mixtures. This value is based on assumed spherical particles of sludge with an average minimum diameter of 10-microns.

c. Please consider and address the simple geometric equation used for estimating the specific surface area of a particle assumes perfect spheres. Please note that readily available literature has more advanced formulas that include such terms as the shape factor.

Response

It has been a standard assumption in much of the previous work (e.g. NUREG/CR-6224) to approximate complex particle shapes by simple geometries such as spheres, and then to establish an appropriate average particle size based on the available test data for the material under consideration.

d. In the iterative comparison of the NUREG/CR-6224 correlation to data, uncertainties and variabilities are

subsumed into the specific surface area estimate as the area is adjusted to fit well with the observed data. So, in a sense, the surface area is a bulk parameter that accounts for both deficiencies in the form of the equation and variability in the observed data. Please consider that independent estimates of the surface area (like geometric analysis or direct measurement of surface pores) do not provide the same perspective as a best-fit parameter. In this light, please consider and address how they could be interpreted and applied in the guidance.

Response

Section 3, "Baseline Methodology," of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 provides guidance as to appropriate values of fiber and particulate sizes for use in the NUREG/CR-6224 head loss correlation that have either been shown to be conservative or else are suggested starting values for fine tuning by comparison to experimental data. There is of course no substitute for test data on a given material, this being evaluated in the proper context of the correlation, as implied in Item (d) above.

e. Please consider and address ways in which the current NEI guidance would lead to underestimates of the specific surface areas, and therefore, to underestimates of the associated head loss.

Response

As currently implemented in the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004, the specific surface area (or surface-to-volume ratio) is sensitive to the assumed particle size, and overestimating the average particle size can lead to non-conservative results. Accordingly, the particle size recommendations are biased toward conservatively small numbers. Accurate characterization of the macroscopic debris properties, SEM analysis for the microscopic parameters, and directly applicable test data enhance the accuracy of a spherical-equivalent particle size estimate.

3. The NEI guidance offers an equation for blending specific surface areas for a variety of materials that may co inhabit the debris bed. The guidance references NUREG/CR-6371, however, please address why the presented equation is different from that provided in NUREG/CR-6371. For example, specific surface areas in the NEI guidance are based on the square of the individual areas, whereas in NUREG/CR-6371, the areas are combined

using linear powers of the individual areas. Please discuss the impact of this difference, and justify the NEI equation through the application of the correlation to debris beds consisting of multiple types of debris. Also, please consider and address that while the NEI guidance provides an equation to blend the specific surface areas, it fails to provide guidance for blending various densities for a mixture of debris, such as multiple types of particulates.

Response

The procedure in the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 is derived directly from the head loss equations in Appendix B of NUREG/CR-6224 and effectively uses volume-weighting of the microscopic debris volumes to get an average value for S_V. This makes sense since relevant bulk parameters such as porosity and solidity are themselves volume averaged quantities.

In a homogeneous mixture of one of more debris types, volume weighting of both the macroscopic and microscopic densities is considered appropriate, since the individual species can be reasonably expected to see the same porosity.

If S_V is weighted according to the procedure used for the BLOCKAGE code (NUREG/CR-6371), it is found that the pressure drop across a debris bed may be under predicted when a second component is added, which is counter intuitive. On the other hand, the procedure currently suggested in the NEI Guidance predicts an increase in the pressure drop, which is conservative, compared to BLOCKAGE and is consistent with our expectations. (Refer to Appendix E of the Baseline Methodology for development of the equation used in the Draft NEI Guidance.)

4. The NEI guidance uses a density of 65 lb/ft^3 for a generic debris type called "sludge" regardless of the actual debris material. Please consider identifying this density for iron-oxide sediment, but otherwise, providing debris-specific densities in analyses. Please consider that if a generic sludge density is desired, some assessment of the head-loss correlation be offered to assure that the recommendation conservatively bounds all reasonable particulate types. For example, for dirt or concrete dust, where the particle density is perhaps one-half that of iron oxide, the sludge density will be much less than 65 lb/ft^3. The porosity of a granular particulate bed depends on the ratio of the sludge density to the particle density; hence, it is the assumed ratio of these two densities that is the key issue. [The term "sludge" was applied to the correlation during the BWR resolution because iron-oxide corrosion products represented the dominant particulate. A better name might be the "mud density" or the "granular density." In effect, the sludge density determines the packing limit for a mixed bed

undergoing compression with a high particulate-to-fiber ratio.] Please consider that sludge density is another parameter that could be derived from experimental observations by applying the NUREG/CR-6224 head-loss correlation when multiple types of particulates co-inhabit the bed.

Response

The value 65 lbm/ft^3 is an empirically derived bulk value, and it is appropriate for ferrous corrosion products, sludge or iron oxide sediment found in BWR suppression pools, as determined by the BWROG from testing of industry-supplied samples. Refer to NUREG/CR-6224 in this regard.

A simple ratio of the densities suffices to define porosity for debris beds at very low compaction. As compression increases, particularly to its limit, the porosity of a granular debris bed will depend on the bulk density (the macroscopic density, itself depending on compression), the grain density (solid particle density), and the fluid density. Since different materials exhibit different densities, plant-specific experiments may be required in some cases to determine the appropriate macroscopic density of a granular debris bed as applied to the NUREG/CR-6224 head loss correlation.

With regard to dirt, concrete dust, and calcium silicate, the NEI became aware on April 17, 2004 that the NRC has issued Report No. LA-UR-04-1227. This report documents recently completed experimental work by LANL at UNM. Evaluation of the findings in this test report is a planned near-term activity by NEI.

5. The NEI guidance recommends a condition of solidity based on the sludge density as a limit to debris bed compression (Page 112). The solidity of a debris bed depends on the density of the fibers as well as on the density of the particulates, but the sludge density typically is based on the particulate density alone. Please provide an equation in the guidance that relates the bed solidity to the sludge density. NUREG/CR-6371 and the BLOCKAGE code documentation have provided this relationship, which may be useful.

Response

The implicit, recommended solidity limit in the guidance of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004, is 20 percent, which corresponds to a lower limit porosity of 80 percent. It has been clarified in Section 3, "Baseline Methodology," that this is for a ferrous sludge debris-bed. This is a reasonable computation limit for ferrous sludge debris beds at low

compaction, and it is applicable to a pure sludge bed. For common particulate materials such as dirt, dust, concrete debris, IOZ, rust, etc., as mentioned in the response to RAI #1 above, the 20-percent solidity limit in the Guidance is the current best recommendation.

Based on Appendix B of NUREG/CR-6224, a simple, general relationship is:

Solidity = Bulk Density/Particle Density = 65/324 = 0.20 for ferrous sludge.

The bulk density of a sludge debris bed depends on the porosity as well as the material properties and has to be established experimentally. For materials not yet tested and for which the NUREG/CR-6224 correlation has not been validated, it is recommend that testing be performed, or else similitude arguments made, to determine both the porosity and the bulk density at limiting compaction.

6. The NEI guidance for fiber-bed compression includes an additional coefficient (Page 112) that is not found in NRC-published reports. The new coefficient effectively modifies the correlation's associated compression equation. It is recognized that the compression equation was validated for NUKON but that the coefficient (and the exponent) could be modified for other types of fibers. However, NEI did not provide guidance for selecting values of K other than 1. Please consider and address the need for deduction of appropriate values from test data. Please consider that application of this new coefficient can lead to erroneous head-loss predictions without complete and appropriate guidance.

Response

'K' is a constant that depends on the insulation type. It is 1.0 for Nukon® fiber. Test data or a similitude analysis is required to determine 'K' for fibrous materials that are dissimilar to Nukon. Most fibrous materials are well-behaved and are in fact similar to Nukon, and K = 1 may be used for most commonly encountered fiber. To the best of our knowledge, K-factors for dissimilar materials have not been determined experimentally.

An overall multiplier of 1.3 (i.e. K = 1) in Equation 4.5.3.1.1-4 will significantly over predict compression for thick fiber debris beds in excess of about 6-inches, thus this equation is conservative in these cases.

7. The NEI guidance correctly recommends using a conservatively-low water temperature when estimating head loss because of the higher water viscosity. However, are safety analyses performed to determine the

conservative peak water temperature, suitable for predicting the conservatively-low water temperature? For example, it is conservative to neglect some heat-transport processes and non-safety-related equipment when estimating a conservatively high temperature. But please consider the need for including these same processes and equipment in the low temperature predictions, so that the estimate of water temperature is compatible with a conservative head-loss prediction.

Response

NPSH calculations typically use the maximum water temperature to result in highest vapor pressure, subtracting from available NPSH and thereby being conservative in this regard, taking minimal credit for heat removal. On the other hand, floor water level calculations and head loss calculations generally use the lowest expected post-LOCA water temperature to ensure conservatism.

The use of a single temperature for a given analysis may cause problems, since doing so may be excessively conservative in one case yet non-conservative for other applications. Accordingly, the NEI Baseline Methodology recommends using water temperatures for head loss analysis that are consistent with the NPSH analysis, noting that it may be necessary to evaluate both head loss and NPSH at multiple times throughout the accident progression to ensure that appropriate methods are employed. To simplify, an option is offered to use the peak sump temperature for the NPSH analysis and the minimum expected sump water temperature (over the duration that the ECCS is required to operate) for the head loss analysis, in the event that this level of conservatism can be tolerated. When choosing temperatures for head loss analysis, heat removal mechanisms and their impact should of course be assessed.

8. The NEI head-loss guidance suggests that sheet types of debris (e.g., plastic sheeting and mats) be treated as reducing the effective screen area (Page 99), but the debris-generation guidance (Page 55) suggests that stickers and tape are destroyed into small pieces (presumably to the size of particulates). Please clarify in the guidance, what type and size of debris should be assumed. Perhaps it would be useful for both methods to be evaluated and the one that predicts the higher head loss, be reported. Please consider that, if there is already plenty of particulate in containment, then treating sheet debris as reducing the effective screen area is probably the more conservative approach.

Response

Plastic sheets and mats in the ZOI are expected to be reduced to small pieces, as are stickers, tape, labels,

etc. However, the FME Programs in place at plants should prevent any large sheets of plastic from being present in containment. Experience suggests that debris from stickers and tape is a very small percentage of the total, and BWR test experience further suggests that this debris is a negligible contributor to head loss. The document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004, takes credit for FME Programs and takes no penalty for large sheets of plastic. The methodology of described in this document also considers stickers, tape, paper tags, labels, etc. to be negligible contributors for the reason above.

9. In light of the above comments regarding the proper determination of specific surface areas, please consider that the NEI recommendation to treat unqualified coatings as disintegrating to pigment-base particulates could lead to conservative but unacceptably high head-loss estimates. This is because the appropriate specific surface area for 10-micron particles may be as much as four times higher than NEI-anticipated areas that are based on the geometric diameter alone. Please consider providing a more realistic treatment for plants that cannot tolerate such over conservatism, but note that applicable data are not available.

Response

Data to address this topic adequately have only recently become available. New findings are discussed in Appendix A of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 that indicate that the jet impingement pressure required to defeat qualified coatings systems is relatively high, i.e. > 1000-psid. These findings reduce the size of the coatings ZOI to a realistic level.

Historically, it has been conservatively assumed that all coatings debris in the ZOI is the size of the pigment. Furthermore, to characterize unqualified coatings, the Baseline Methodology currently assumes that all unqualified coatings fail, and that all are of a size equivalent to inorganic zinc (IOZ) primer, which is very conservative. Experiments have been conducted with IOZ and fibers that clearly demonstrate that the NUREG/CR-6224 correlation bounds the data if the IOZ is assumed to be spherical particles 10 microns in diameter and the simple geometric equation of surface-to-volume ratio is used. Reference HL-3 of attached Table HL-1 discusses experiments in which IOZ was used..

10. The NEI head-loss guidance suggests (Page 109) that time-dependent head-loss predictions can be performed in conjunction with time-dependent pool temperature calculations. However, debris transport cannot be modeled in a deterministic manner that reliably predicts time-dependent mobility. For this reason, please address treatment and validation of the quantity of debris assumed in the bed if a partial portion of transportable debris

is presumed. Please consider and address the approach of conservatively presuming that all debris capable of transport to the screen is placed on the screen initially. Please also consider the benefit of time-dependent calculations of water level that directly controls the amount of static head available for water flow across a debris bed.

Response

First, it is agreed that mechanistic, transient debris transport analysis is not viable.

Section 3, "Baseline Methodology," of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 conservatively recommends that the head loss computations be performed for a steady-state condition with the maximum expected quantity of debris on the strainer. Time-dependent calculations of head loss and NPSH can be performed to the extent that the data are available, i.e. containment pressure, sump water temperature, floor water level, debris accumulation on the sump screens, ECCS flow rates, etc. It does not really change the methodology to include time-dependence. This is really more of an extension, in that calculations have to be repeated at multiple points in time.

11. Please expand on the formation of thin-beds and its effect. Please address the following specific considerations.

a. In the scoping evaluation mentioned in the guidance, please address the possibility of establishing a thin bed across the existing screen, as was done in the parametric evaluation. Please expand this scoping evaluation to include (1) estimating the quantity of fiber required to create a ~1/8-in thick debris bed across the screen, (2) estimating how much particulate it would take to establish a head loss sufficient to exceed the NPSH margin, and (3) comparing these quantities to the anticipated quantities of debris in containment.

Response

Section 3, "Baseline Methodology," of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 provides for calculation of the head loss for a thin fibrous debris bed with the full particulate loading, and a sample problem is given in this regard. The approximate fiber quantity necessary to create a thin-bed is easily determined as ~0.01 times the sump screen area. The methodology points out that the particulate quantities can be reduced parametrically to determine the allowable amounts in the event that the calculated thin-bed head loss exceeds the

NPSH margin.

As noted, the theoretical, thin-bed fiber quantity is estimated by straightforward multiplication of the screen surface area times a postulated fiber bed approximately 0.125-inch thick (0.0104-foot). The recommended starting particulate quantity is the amount of latent particulate debris plus other fine particles present, i.e. coatings debris, dirt, concrete dust, etc.

b. Please consider and address that the 1/8-in thickness is an approximate number that could depend upon the type of fibers. For example, if the particulate is calcium silicate and the screen mesh is relatively fine, it does not take 1/8-in of fiber to filter calcium silicate from the flow.

Response

Further quantification depends upon the available data. Currently, there is only a very limited amount of Calcium Silicate test data available. The NRC/LANL/UNM test report (LA-UR-04-1227) has been released. This item is under review.

c. In the guidance, please consider providing an example thin-bed calculation using a comparison to test data.

Response

Section 3, "Baseline Methodology," of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 includes a thin-bed sample calculation that uses some typical plant parameters, and for internal consistency, debris types, quantities and sizes developed elsewhere in the document. Section 3 also addresses latent debris, particulate debris from the ZOI, and any fine particulate debris outside the ZOI. The theoretical, requisite fiber quantity to create a thin-bed is assumed to be present at the strainer.

d. In the guidance, please include a discussion of operationally-created thin-beds (e.g., Perry and Limerick).

Response

Discussions of operability experience are beyond the scope of the current the document, "PWR

Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004. Various NRC Information Notices (e.g. IN 93-34 and IN 95-47) discuss the events at Perry and Limerick. Industry events are also well summarized in the 'Related Generic Communications' section of the recently issued Draft Generic Letter.

Relative to this RAI, the Perry events are reported in detail in CR 93-085. On April 14, 1993, while testing the RHR-B loop at approximately 7800-gpm, a progressive loss of suction pressure was observed, leading to incipient pump cavitation. The RHR-B strainer was small—only about 42 ft^2 of circumscribed area, leading to an apparent approach velocity of ~0.41-fps. However, accounting for the reinforcing structure, the actual approach velocity was much higher since the effective strainer area was significantly less. Less than ~0.44 ft^3 of fiber was required to foul the strainer with a mat of fiber ~0.125-inch thick. Although invisible even in the clear suppression pool water, this amount of fiber was present due to previously unidentified debris from an HVAC filter that had been left in containment and had fallen into the suppression pool. A quantity of ferrous sludge, likely generated by corrosion of carbon steel piping in the RHR loops, was also present on the suppression pool liner, again invisible. Both the sludge and the fiber were easily stirred up and dispersed while circulating the suppression pool with the RHR pump. A thin bed of fiber formed on the strainer, which in turn trapped the ferrous sludge material, leading to high head losses and a loss of NPSH for the RHR pump over a period of several hours. A large passive strainer has since been installed at Perry that, based on design and testing, precludes the thin-bed effect.

12. In the NEI guidance, please develop a section on strainer design that discusses the new technology that was used to resolve the BWR strainer clogging issue. For example, please consider discussing in-detail the reasons why the stacked-disk strainers were successful at defeating thin-bed formation, accommodating large debris volumes and permitting adequate flow. Specifically, the convoluted design forced the approaching flow to sweep parallel across the internal faces of the disks so that debris tended to be pushed along the surface towards the interior debris traps near the center. This passive flow action, a simple result of flow-resistance gradients across the screen, encourages efficient packing of debris without inducing extreme pressures that lead to compaction and high head loss. This concept, in addition to the high surface area per unit volume, is the foundations of advanced strainer design, which could be useful in the PWR sump-screen clogging resolution as well.

Response

We agree that alternate strainer designs exist that preclude the thin-bed effect. However, the design of

"advanced screens" is outside the scope of either the current NEI Guidance or the Baseline Methodology. The document, “PWR Containment Sump Evaluation Methodology,” submitted to NRC on May 28, 2004 does not endorse any specific strainer design. It does, however, provide information regarding several design options that may be considered by licensees.

13. In the NEI guidance, please consider addressing debris beds that contain very little fiber. For example, it is possible to have a debris bed consisting of only calcium silicate, if the screen has a fine enough mesh. In such situations, a granular-bed head-loss correlation may be more applicable than the NUREG/CR-6224 correlation. Such recommendations could be useful.

Response

Section 3.7.2.3.2.3 of the document, “PWR Containment Sump Evaluation Methodology,” submitted to NRC on May 28, 2004 addresses very thin beds of fibrous debris. In the BWR work, it was generally found that very thin fiber beds (less than ~1/8-inch thick, of Nukon® and similar materials) possessed very low particulate filtration efficiencies. For these beds, the head loss is essentially negligible, and the NUREG/CR-6224 correlation gives unrealistically high results. When very little fiber is present, most of the standard types of fine particulate will not form a debris bed on the strainer, instead passing through the strainer mesh.

Now that NRC Test Report LA-UR-04-1227 has been issued, this item is being reviewed with regard to screen size and an appropriate minimum thickness for calcium silicate insulation.

14. The NEI guidance discusses a method of iteratively solving the NUREG/CR-6224 correlation including example solutions. Please consider also mentioning the NRC-sponsored BLOCKAGE code, and presenting the pros and cons associated with its application to PWR sump screens. BLOCKAGE implements the head-loss correlations and can be used to perform screen vulnerability calculations and manual iterations to confirm the appropriate choice of material parameters when data are available for comparison.

Response

The NEI the document, “PWR Containment Sump Evaluation Methodology,” submitted to NRC on May 28, 2004 does not endorse any specific analytical tools, and assessment of the BLOCKAGE computer code

is outside the scope of the current NEI methodology.

With regard to this RAI, we note that the BLOCKAGE code would seem to be a suitable tool for PWR sump screen evaluations. Developed originally for BWR applications, BLOCKAGE makes the assumption that all of the debris that is present in the suppression pool is uniformly distributed. Time-dependent depletion of this debris is modeled, by accumulation of debris onto the strainer, which is a useful feature. Thus, the code can potentially be applied to PWR floor pools.

As noted in Appendix E of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004, the procedure used in BLOCKAGE for determining an average surface-to-volume ratio (S_V) for two or more materials needs to be reviewed and potentially modified. Results from older code versions gave non-conservative answers when particulate was added to fibrous material.

15. In the NEI guidance for RMI debris beds, please consider presenting a complete set of K_t data rather than a single value. The value presented would pertain to stainless steel (mid-size range). Please note that NUREG/CR-6808, contains a more complete set of data that includes values appropriate for aluminum RMI as well.

Response

A more complete set of K_t values based on NUREG/CR-6808 and other available data has been added to the Section 3, "Baseline Methodology," of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004. This table is repeated below.

RMI Foil Type and Bed Type	**K_t (feet)**
2.5-mil SS (NRC large pieces)	0.014
2.5-mil SS (NRC small pieces)	0.010
1.5-mil Al (debris bed)	0.008
1.5-mil Al (debris bed)	0.006
2.5-mil SS (STUK flat pieces)	0.007
2.5-mil SS (1-mm dimple)	0.003

16. The NEI guidance discusses the application of the NUREG/CR-6224 correlation to microporous and fiber debris combinations. It states that the correlation is good up to a particulate-to-fiber mass ratio of 20%. Please consider replacing this guidance with recommendations based on the recent NRC calcium-silicate test report that provides the specific surface area for the calcium silicate product that was tested. Please note that parameters for Min-K are likely to be similar to those for calcium silicate, and perhaps can be used as a surrogate for Min-K if a conservative margin is applied in conjunction with an appropriate rationale.

Response

The NRC calcium silicate test report has recently been released to Industry. This item is currently under review. However, based on this report, it is expected that guidance can be provided for mass ratios of calcium silicate-to-fiber that are larger than 20%.

17. Please add the specific surface area and the debris sludge (granular) density for each type of material in Table 4.5.2.4-1. Is the 40-micron mean particle size reported for calcium silicate too large?

Response

Given in Section 3, "Baseline Methodology" of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 are conservative particle and fiber sizes (or at least starting values) for materials commonly encountered. These are the best recommendations currently available.

The 40-micron size for calcium silicate is a mean value based on manufacturer data sheets and SEM analysis. Based on very limited Cal-Sil data, the Baseline Methodology modified the recommended Cal-Sil mean diameter to 5-microns (2 to 100-micron range). This item will be revisited during Industry review of the NRC Cal-Sil test report, LA-UR-04-1227.

18. Please consider adding a summary of available test data (e.g., provided in URG) that includes NRC-, industry-, and internationally-sponsored tests, and lists the types of materials tested, describes how the tests were executed, and perhaps provides the range of test conditions. This could be useful.

Response

A summary table is provided at the end of these responses. Also refer to Appendix E of the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004 for this information. Pending completion of the review of the recently issued NRC/LANL Cal-Sil test report, no new, publicly available data presently exist to add to this table.

Table HL-1: Overview of Head Loss Experiments and Correlations

Sponsor	Test Facility		Date	Report Reference
BWROG, GE Nuclear Energy	Continuum Dynamics, Inc at EPRI NDE Center, Charlotte		November, 1996	HL-1
Variables Studied	**Ranges**	**Results/Relationships**	**Comments**	
Purpose of Tests: Full-scale tests to obtain pressure loss and performance data on different strainer types as a function of debris type, quantity, flow rate, and time		Qualitatively, this testing showed that passive strainers had been identified which show improved performance over the original strainers. These strainers can collect significant amounts of fibrous insulation and corrosion products with acceptable head loss at the flow rates of interest for BWR ECCS.	An extensive matrix of tests were performed to obtain strainer performance information which does not lend itself to summary. Consultation of the reference is suggested to obtain specific information.	
Materials tested: NUKON, Kaowool, Tempmat, Calcium Silicate, BWR Corrosion Product Sludge, RMI-Various				
Insulation Preparation: See Reference, Per NUREG-6224 recommendations				
Material introduction method: See Reference				
Coverage: Various, see reference				
Approach Velocity: Various, see reference				
Maximum Head Loss 500 ins H2O				
Temperature 60-86 F				
pH 8-10				

Table HL-1: Overview of Head Loss Experiments and Correlations

1

Sponsor	Test Facility		Date	Report Reference
Commonwealth Edison Company	Continuum Dynamics, Inc., Princeton, N. J.		July 1997	HL-2
Variables Studied	**Ranges**	**Results/Relationships**	**Comments**	
Purpose of Tests: Evaluation of the effects of paint chips on sump strainer head loss. Determination of head loss across the sump screen resulting from the buildup of paint chips.		The effect of paint chips by themselves on head loss was minimal.	Most paint chips remained on tank floor and did not reach strainer. When flow was stopped, chips on screen fell off.	
Materials tested: Epoxy paint chips, Ameron/Amercoat 90HS by itself on screens, no other materials.				
Material Preparation Dry paint peeled from plastic sheet, then broken up by hand or in a household blender				
Material introduction method: Chips were presoaked to avoid floating, and added to test tank near diffuser				
Coverage	1000 to 4700 ft^2 paint chips on 28 ft^2 screen, scaled			
Approach Velocity Prototypical, ~0.72ft/sec				
Maximum Head Loss	0.2 inches water			
Temperature	Ambient			
pH	Ambient			

Table HL-1: Overview of Head Loss Experiments and Correlations

1

Sponsor	Test Facility		Date	Report Reference
Northeast Nuclear Energy Company, Millstone Unit 1	Continuum Dynamics, Inc.		February 1999	HL-3
Variables Studied	**Ranges**	**Results/Relationships**	**Comments**	
Purpose of Tests: To evaluate the amount of coating, fibrous, and RMI debris that can be transported to a PWR sump screen during post LOCA recirculation, and to measure the resultant head loss across the debris bed. The effect of boric acid on zinc chips was also evaluated.		Paint chips with boric acid: with pH at 6.0 and 1"to2" bed of paint chips at V=0.25ft/sec, no movement of chips or increase in head loss. Similar results for paint chips by themselves, no boric acid. 0.115 ft^3 NUKON fiber placed ~20 ft from sump screen. Flow started at 0.2 ft/sec, approached to 1.5 ft from screen and stopped. No change in head loss. Ten times amount of fiber placed in tank, 20 ft from screen with velocities up to .25 ft/sec with none on screen, no increase in head loss. Even with fiber moved directly in front of sump, no motion along floor or increase in head loss. Further addition of RMI did not result in debris movement or accumulation on screen. Paint chips added during flow resulted in some transport to screen, but resulted in a head loss of <1.32 inches water.	Paint chips, fiber and RMI on the sump floor at the initiation of flow are unlikely to transport to the sump and generate any measurable head loss. Addition of boric acid does not increase the likelihood of paint chip transport.	
Materials tested: Phenolene 305 epoxy and carbozinc 11 inorganic zinc primer, NUKON® fibrous debris, 2 mil stainless RMI, boric acid	Size of paint: <1/8"-13% 1/8-1/4"-40% ¼"-1/2"-39% ½"-3/4"-7%			
Material Preparation	Paint applied to plastic, sheets, cured and peeled off, shredded into chips. NUKON shredded into small pieces <1/2", classified as NUREG 6224 type 3,4, and 5. RMI cut into 6", 3", 1", and 3/8" squares and then crumpled			
Material introduction method	Wetted debris added to tank (full scale segment of screen) and allowed to settle, pumps then started.			
Coverage	500 ft^2 equiv. Paint, 0.115 ft^3 fiber, 2.5 ft^2 RMI in test matrix			
Approach Velocity	0-0.25 ft/sec			
Maximum Head Loss	1.3 ins H2O			
Temperature	ambient			
pH	> 6.0 with boric acid			

Table HL-1: Overview of Head Loss Experiments and Correlations

1

Sponsor	Test Facility		Date	Report Reference
Detroit Edison/Duke Engineering and Services	ITS Corporation at EPRI NDE Center		October 14, 1997 Preliminary	HL-4
Variables Studied	**Ranges**	**Results/Relationships**	**Comments**	
Purpose of Tests: To characterize the impact of Min-K insulation on prototype ECCS suction strainers		Min-K bed is different than fiberglass. Debris bed was <1/4" thick, uniform. Debris penetrated and plugged suction strainer holes. The debris bed did not resemble long fiber over the holes. Addition of sludge did not produce significantly higher head loss than with Min-K by itself. Head loss seems to continue to increase with time, even after "steady state" was achieved.		
Materials tested: Min-K core material, silica an titanium dioxide, and sludge				
Material Preparation	Min-K core material supplied in loose powder form, and sludge stimulant developed by NRC			
Material introduction method	Flow established, Min-K slurry introduced into tank. If sludge was used it was first introduced, followed by Min-K.			
Coverage	0-96 lb Min-K, 0-17 lb sludge			
Approach Velocity	6350 GPM flow rate			
Maximum Head Loss	158 inches water			
Temperature	Ambient, 78F			
pH	Neutral, tap water			

Table HL-1: Overview of Head Loss Experiments and Correlations

1

Sponsor	Test Facilty		Date	Report Reference
New York Power Authority, James A. Fitzpatrick (JAF) Nuclear Power Plant	ITS at Alden Research Laboratory; 1:2.4 scale model of BWR Mk 1 Suppression Pool		Spring, 1999	HL-5
Variables Studied	**Ranges**	**Results/Relationships**	**Comments**	
Purpose of Tests: Evaluate replacement strainers for JAF; head loss data for micorporous insulation was sparse and suggested higher head losses than for fiber beds		NUREG/CR-6224 conservatively modeled fibrous material. Min-K head loss is greater than that for equivalent amount of microtherm. NUREG/CR-6224 conservatively models head losses for microporous debris microporous to fiber mass ratios <0.2 Cal-Sil head loss characteristics similar to Min-K and Microtherm	Microporous applies to either Min-K or Microtherm	
Materials tested: Fibrous: NUKON, Temp-Mat and Knauf; Min-K; Microtherm				
Material Preparation				
Material introduction method	Debris mixed with water to form slurry, added to test tank; additional debris added in steady state plateaus: Fibrous only, microporous only, microporous and fiber			
Coverage	0-6 lb fiber, 0-1 lb Min-K, 0-1 lb microtherm			
Approach Velocity	~0.096 ft/sec			
Maximum Head Loss	~13 ft H2O			
Temperature	Ambient			
pH	Ambient			

Table HL-1: Overview of Head Loss Experiments and Correlations

1

Sponsor	Test Facilty		Date	Report Reference
USNRC	Alden Research Laboratory		December 1995	HL-6
Variables Studied	**Ranges**	**Results/Relationships**	**Comments**	
Purpose of Tests: Determine the pressure loss characteristics of Thermal Wrap® insulation debris with and without iron oxide particles to simulate BWR suppression pool sludge		No significant differences were found for fibrous insulation head losses between **:** Thermal Wrap®(Knauf-Transco) and NUKON™(Owens Corning-PCI) Head loss increased with bed thickness from 3 ft H2O for 0.25" to 34 ft for 4" without sludge. Head loss also increased for increasing sludge to insulation mass ratios; for 1" bed by a factor of 70 from 0 sludge to 7.5 ratio. Variation in sludge particle size or the addition of paint chips had no measurable effect on head loss.	Higher water temperature reduces head loss because of viscosity effects. This testing was similar to that conducted on NUKON™ insulation debris by Alden Laboratory and reported in June 1995.	
Materials tested: Thermal Wrap® insulation debris, simulated iron oxide sludge, and paint chips				
Material Preparation	Insulating blankets were heat treated and shredded in a leaf shredder			
Material introduction method	Sludge added to test loop, well mixed, then insulation added at once			
Coverage	Fibrous insulation thickness 0.25-4 inches, size class 3 &4; and 0-30 sludge to fiber mass ratios			
Approach Velocity	0.15 ft/sec during bed formation; 0.15-1.5 ft/sec test			
Maximum Head Loss	~55ft			
Temperature	125F			
pH	Not investigated			

Table HL-1: Overview of Head Loss Experiments and Correlations

1

Sponsor	Test Facilty		Date	Report Reference
Fortum Engineering, Ltd			May 20, 1999	HL-7
Variables Studied	**Ranges**	**Results/Relationships**	**Comments**	
Purpose of Tests: To study the strainer differential pressure caused by different insulation types when subjected to the same debris generation, testing, and sump configuration.		Corrected differential pressure for this demonstration 67.5, 10, and 33 kPa for the three insulation types listed under materials. Transportable fractions of debris were 62, 34, and 100%, respectively		
Materials tested: Fine fiber (Al-Si) insulation, coarse glass fiber insulation, and Si-Ca mineral insulation	8 kg 27 kg 5 kg			
Material Preparation	Insulation was heat treated at 300C for 48 hours, and subjected to steam/water jet impingement; resulting debris was collected, examined			
Material introduction method	After examination, the material was introduced into the sump test facility			
Coverage				
Approach Velocity	18-25 mm/sec			
Maximum Head Loss				
Temperature	50C			
pH	H_3BO_3 conc. 12g/kg H_2O			

Table HL-1: Overview of Head Loss Experiments and Correlations

1

Sponsor	Test Facilty		Date	Report Reference
U. S. Nuclear Regulatory Commission	Alden Research Laboratory		May 1996	HL-8
Variables Studied	**Ranges**	**Results/Relationships**	**Comments**	
Purpose of Tests: To provide basic insights into the behavior of RMI debris under LOCA conditions, by itself and in combination with other debris.		Introduction of prototypical RMI debris in the presence of fiber and sludge does not cause significantly different head losses than the head losses observed with only fiber and sludge loadings. During testing, RMI debris, when intermixed with fibrous debris and sludge appeared to decrease head losses compared to similar conditions without RMI debris. Head losses for RMI without any other debris were relatively small, but increased with increasing mass of RMI. RMI debris size had no practical effect on head losses for a given mass/unit area of strainer.		
Materials tested: Diamond Power MIRROR® insulation, NUKON™ insulation.				
Material Preparation:	Prototypical RMI for sedementation and head loss testing was generated by Siemens AG/KWU in Karlstein am Main, Germany			
Material introduction method	Sludge added first, then fibrous insulation and RMI, alternatively.			
Coverage	Variable			
Approach Velocity	0.15-1.5 ft/sec			
Maximum Head Loss	~37 ft H2O			
Temperature	125			
pH	Not Investigated			

Table HL-1: Overview of Head Loss Experiments and Correlations

1

Sponsor	Test Facilty		Date	Report Reference
Commonwealth Edison, LaSalle Station	Duke Engineering and Services at EPRI, Charlotte, N. C.		June 1998	HL-9
Variables Studied	**Ranges**	**Results/Relationships**	**Comments**	
Purpose of Tests: To obtain fiber and Aluminum RMI data with an actual replacement strainer under prototypic conditions		Measured head loss confirmed an approach velocity squared relationship. A synergistic effect of RMI and fibrous debris was observed resulting in head losses greater than adding each constituent's head loss.	Measured head loss for RMI debris was found to be a strong function of the process of debris deposition or accumulation on the strainer. "Shepherding" debris into the strainer suction flow field resulted in higher head losses than more normal processes.	
Materials tested: NUKON™ fibrous debris simulant, 1.5 mil aluminum debris simulant				
Material Preparation	NUKON™ shredded using methodology from NUREG-6224. Al RMI prototypical debris was generated at CEESI. The test debris was developed based on the generation experiments, limited in size (for transport), and crumpled.			
Material introduction method	Incremental RMI addition to operating system, and addition to tank followed by initiating system operation. RMI and fiber added together in tank followed by initiation of system operation.			
Coverage	Limited by test d/p			
Approach Velocity				
Maximum Head Loss	8.17 ft H_2O			
Temperature	Nominal ambient			
pH	Not investigated			

Table HL-1: Overview of Head Loss Experiments and Correlations

1

Sponsor	Test Facilty		Date	Report Reference
Finnish Centre for Radiation and Nuclear Safety (STUK)	STUK		May 1999	HL-10, 11
Variables Studied	**Ranges**	**Results/Relationships**	**Comments**	
Purpose of Tests: To shed light on the physical mechanisms that induce flow resistance in purely metallic insulation debris beds, to quantify the influence of bed structure on flow resistance, and develop an approach to identify and quantify facility related distortions.		Pressure drop caused by pure metallic insulation debris bed is strongly dependent on bed structure. It appears that this factor is more important than the characteristics of the debris. Minimal resistance is found when the debris is aligned with the streamlines, and maximum resistance is found with all debris perpendicular to the streamlines.	The raw data show that: Orderly debris bed behaviour is qualitatively similar on a strainer in a pool and in a test tube section. With debris perpendicular to flow, flow is purely turbulent (as expected); with debris parallel to streamlines, laminar conditions can be achieved. The ratio of maximum to minimum head loss for different configurations (debris bed morphologies) of the same debris can be as high as 160 (not correcting for edge effects).	
Materials tested: DARMET panel insulation				
Material Preparation	Simulated debris, cut DARMET inner foil, 16x2.5cm strips.			
Material introduction method	Strips laid on net into the test section in geometry desired.			
Coverage	12 layers parallel, 5 layers perpendicular, 10 layers perpendicular			
Approach Velocity	Variable			
Maximum Head Loss	Consult reference			
Temperature	50C, 30C, 30C, not controlled			
pH	Not investigated			

Table HL-1: Overview of Head Loss Experiments and Correlations

1

Sponsor	Test Facilty		Date	Report Reference
Swedish Nuclear Power Inspectorate	Studsvik Material Corporation		January 1995	HL-12
Variables Studied	**Ranges**	**Results/Relationships**	**Comments**	
Purpose of Tests: The objective of the project is to ascertain if there is a risk of coagulation of debris particles or fibers which could result in subsequent strainer clogging		pH at the 'isoelectric points', where the particle surface is uncharged is at low value (pH<4) for most materials and some materials (iron oxide, fiberglass, minileit) show a tendency toward coagulation at this pH. SEM investigation of filtered material does not indicate a clear tendency toward coagulation at the isoelectric points. Mineral wool can possibly be a bigger problem for filtration than fiberglass. Small suspended particles are more problematic than large ones. Corrosion products of iron and biological slime can cause rapid pressure drop. Boronic acid can have an effecto by changing the external chemical conditions for filtration of small particles.		
Materials tested: Magnetite, iron oxide hydroxide, fiberglass, mineral wool, caposil, minileit, concrete, primary coloring, and biological slime				
Investigation: Tests and experiments were conducted to determine electrophoretic mobility, coagulation tendency, calculation of ζ-potential, and appearance/size of particles and fibers				

Table HL-1: Overview of Head Loss Experiments and Correlations

Sponsor	Test Facility		Date	Report Reference
CANDU Owners Group/ Ontario Power Generation	Ontario Power Generation		October 1999	HL-13
Variables Studied	**Ranges**	**Results/Relationships**	**Comments**	
Purpose of Tests: Available head loss correlation did not cover parameters of interest; material types, 90-day mission time, pH transient, and velocities		NUREG-6224 underestimates head losses for measured short term pressure drop. Iron oxide and calcium silicate short term results similar on volumetric basis. Calcium silicate beds show a tendency to increase head loss for an extended period of time		
Materials tested: Fiberglass, calcium silicate, paint, dirt, concrete, rust				
Material Preparation				
Material introduction method				
Coverage	1-14 inch thick beds of fiberglass and fiberglass/particulate mixtures			
Approach Velocity	0.025-0.41ft/sec fibrous material; 0.025-0.06ft/sec mixtures			
Maximum Head Loss				
Temperature	40C, 60C			
pH	7 (most), 10,10.7			

Table HL-1: Overview of Head Loss Experiments and Correlations

Sponsor	Test Facility		Date	Report Reference
KAEFER Isoliertechnik, Bremen, Germany	Bremen Polytechnic Department of Naval Architecture and Ocean Engineering – Circulation Water Channel		July 1995	
Variables Studied	**Ranges**	**Results/Relationships**	**Comments**	
Purpose of Tests: Generic tests to quantify head loss of different insulation materials as a function of debris thickness, flow velocity and water conditions (temperature and chemistry)		The experiments with the relevant material types (fibre shreds, mattress debris, foil bulks) showed a pronounced increase of head loss with the loading thickness of the screen and the flow velocity. For a flow velocity of 0.06 m/s and a loading thickness of 300 mm head loss for fibre-type material is typically in the order of 100 kPa. For these materials the head loss tends to increase for higher pH-values. However the opposite was found for glass fibre material. In general the higher temperatures reduced the head loss considerably, i.e. roughly by half. In contrast the metal foil fragments showed very small head loss values.	The results define a general and unique data base for head loss of a variety of insulation materials.	
Materials Tested: Mattress-type insulation material (NGI type 2, mineral wool), cassette-type insulation material (fibre glass, mineral wool, reflective foils)	Bed thickness up to 300 mm in 8 inch circulation pipe with screen			
Material Preparation: See reference				
Material introduction method	Direct loading of a screen (0.25 inch mash size, 1 mm wire thickness)			
Coverage				
Approach Velocity	2-7 cm/s			
Maximum Head Loss	See detailed reports			
Temperature	18 and 49 ^{o}C (64 and 120 deg F)			
pH	Two different water qualities: ph 7.0, boric acid 1800 ppm, sodium 84 ppm ph 9.2, boric acid 1800 ppm, sodium 2400 ppm			

References for Table HL-1:

1 GE Nuclear Energy, "Utility Resolution Guide for ECCS Suction Strainer Blockage", Prepared by BWR Owners' Group, NEDO-32686-A, October 1998

2 Continuum Dynamics, Inc., "Evaluation of Paint Chip head Loss on Vertically Oriented Zion Station Screen: July 1997 Test Phase", July 1997

3 Continuum Dynamics, Inc., "Debris Transport and Head Loss Test report For the Millstone Unit II Sump", February 1999

4 Duke Engineering & Services, "ECCS Strainer Performance Analysis for Min-K", TR-VT5900.01, October 1997

5 New York Power Authority and ITS Corporation, "Characterization of Head Losses Due to Mixed Fibrous and Micorporous Insulation Debris", October 1999

6 Alden Research Laboratory, Inc., "Head Loss of Fibrous Thermal Wrap Insulation Debris and Sludge for BWR Suction Strainers, 265-95/M787F, December 1995

7 Fortum Engineering Ltd., "Comparison of Resulting Differential Pressure Over Sump Screen Using Different Types of Fibrous Debris Generated With High Pressure Water/Steam Impingement, May 1999

8 Science and Engineering Associates, Inc. "Experimental Investigation of Head Loss and Sedimentation Characteristics of Reflective Metallic Insulation Debris", SEA No. 95-970-01-A:2, May 1996

9 Duke Engineering & Services, "Test Evaluation Report for Test TPP-VL0400-005: LaSalle Strainer Fiber and RMI Debris Tests", TPP-VL04000-006, June 1998

10 Finnish Centre for Radiation and Nuclear Safety (STUK), "On the Mechanics of Metallic Insulation Pressure Drop Generation", Juhani Hyv@rinen and Nina Lahtinen, May 1999

11 Finnish Centre for Radiation and Nuclear Safety (STUK), "Metallic Insulation Behaviour in a LOCA", Dr. Juhani Hyv@rinen, October 1999

12 Swedish Nuclear Power Inspectorate, "The Effect of Chemicals on Strainer Filtration, Final Report: Laboratory Tests at Various pH Levels", SKI Report 95:4, January 1995

13 Ontario Power Generation, "Status on Issue of LOCA-Generated Debris", C. Slongo, October 1999

3.0 GUIDANCE TOPICS TARGETED FOR ADDITIONAL INFORMATION

The following topics represent areas where either the current NEI guidance needs to be supplemented or a modest effort could substantially improve the usability of the document.

1. Overall evaluation flow chart
2. Establish level of conservatism expectations
3. Jet-to-sphere mapping
4. Establish destruction pressure extrapolation rationale
5. Complete table of destruction pressures
6. Computerized analysis tools (e.g., CASINOVA, BLOCKAGE)
7. Conservative ZOI debris-size distributions
8. Latent debris characterization and quantities
9. Characterization of coating debris
10. Generalize airborne/washdown guidance for PWRs
11. Spatial debris distribution entering pool
12. Establish transport parameter extrapolation rationale
13. Pool debris-transport model during pool formation
14. Pool debris-transport model in established pool
15. Pool debris-disintegration model
16. Apply NUREG/CR-6224 to test data to deduce suitable input parameters for application of correlation
17. Establish head-loss parameter extrapolation rationale
18. Develop guidance for buoyant debris
19. Prepare computerized comprehensive solution of NUREG/CR-6224 correlation (e.g., PWR Version of BLOCKAGE)
20. Description and treatment of potential chemical effects

<u>Response</u>

It is respectfully suggested that the topics identified above should pertinent to evaluation methodology have been addressed in the document, “PWR Containment Sump Evaluation Methodology,” submitted to NRC on May 28, 2004.. Several items in the list above, such as use of computerized tool (CASINOVA, BLOCKAGE,) are not germane to sump evaluation methodology and are therefore not included in the document referenced submittal.

4.0 DETAILED TEXT-SPECIFIC QUESTIONS

- Please consider adding a list of abbreviations.
- Page 9, Section 1.1, third paragraph. Please explain why the intention is not to replace the plant licensing or design bases, when in fact the design-basis may be replaced.
- Page 18, first paragraph. Please update the reference to a draft RG 1.82 Revision 3, to the final version which was issued November 2003.
- Page 19, Section 1.4, Bullet 2. Please address how specific plants having materials in containment that are not addressed by the NEI guidance would address these materials in their plant-specific analyses.
- Page 28, Section 2.6, second sentence, "The debris volume at the screen should be used to estimate the rate of accumulation of debris on the ECC sump screen." What does this sentence mean? How can a rate be estimated if our debris-transport prediction capabilities are not mature enough to predict the time-dependent accumulation of debris on the screen?
- Page 30, Section 2.8. Please include the advantages of convoluted screen designs (e.g., stacked disk strainers) as means of preventing thin-bed debris accumulations, in this paragraph.
- Page 33, Section 4.1, first paragraph, last sentence. Please include strainer geometry in addition to strainer area (e.g., "changes in strainer area and strainer geometry"). Again, strainer geometry can be useful in the prevention of thin-bed accumulations. In addition, please consider expanding on the scoping process, to directly address the potential of creating a thin-bed accumulation as was done in the parametric evaluation -- i.e., ~1/8" times the screen area provides a rough estimate of the minimum volume of fiber needed to cause the high head losses associated with this type of debris bed. Comparisons of this minimum volume of debris to preliminary estimates of potential debris generation can quickly reveal potential vulnerabilities.
- Page 37, Section 4.2.1.1.1. Please consider including a minimum-pool-level analysis, which has probably been performed at most plants, in the bullet list.
- Page 37, Section 4.2.1.1.3, 4th bullet. Explain why it is necessary to assume loss of offsite power coincident with a LOCA event. How does the loss of offsite power affect sump screen blockage? Why not perform the analyses assuming with and without loss of offsite power and then select the worst case?
- Page 39, Section 4.2.2.4. The abbreviation "HL" presumably means head loss?
- Page 48, Section 4.2.4.2.2. Please address the concern of a break occurring high in the containment, where insulation might be located below the ZOI and underneath the break and could then be damaged by the break-flow outfall.
- Page 48, Section 4.2.4.2.3. 2nd bullet. Please consider and address the presence of small suspended materials in these isolated areas, since even a small rate of flow will eventually transport suspended materials to the sump screen.
- Page 49, Section 4.2.4.2.3, 6th bullet. Should "Section 4.2.4" read "Section 4.2.5"?

- Page 50, Section 4.2.5.1. Please define the term "transportable." All forms of debris are transportable under some flow conditions -- e.g., entire blankets and cassettes will move when subjected to sheet flow during sump-pool formation.
- Page 52, Section 4.2.5.3. Please consider adding a bullet to the first list explaining that the ZOI depends upon the damage pressure of the RMI, which in term depends upon the manufacturer, the attachment method and the material -- i.e., whether it is Al or stainless steel. The last bullet of the second list states "…located within six pipe diameters of the break site." What is the basis for this measurement (six pipe diameters does not relate to a ZOI radius)?
- Page 54, Table 4.2.5.4.2-1. When assessing the transport of flat-plate coating debris, what are the dimensions (other than thickness) of these platelets?
- Page 56, Section 4.2.5.6, 2nd bullet. If Kaowool is the same as K-wool (from the URG) then isn't the destruction pressure known to be 40 psi (substantially higher than that for NUKON)?
- Page 61, Table 4.2.5.6-1. Please consider and address that OPG conducted tests on Marinite board that indicated edge erosion at only 5 pipe diameters, so the destruction pressure for this material is likely to be substantially higher than that for fiberglass.
- Page 64, Section 4.3.2.2. Please note that condensate drainage can also transport fine debris.
- Page 66, Section 4.3.3.2, last paragraph. Please also list "Fines."
- Page 67, Section 4.3.3.4. Please consider adding a bullet to the list that includes "stairwells" and "annular gaps".
- Page 76, Section 4.4.2.2, 2nd paragraph, "……and not at all in dead-ended compartments." Please consider and address that an exception to this statement is suspended materials. Most so-called dead-ended compartments still have some flow passing through or vortices that can transport suspended material from the region given sufficient time.
- Page 77, Section 4.4.2.3. Should "Hydraulic Processes" be a heading?
- Page 93, Table 4.4.3.4.2.5-1. Please list citations ITR-92-03N and ITR-93-02N in the references. Why are they not readily available? Should these sources of information be provided to the NRC for review and to the licensees for their use?
- Page 104, Table 4.5.2.4-1. The material density for NUKON is given as 159 lbm/ft^3, whereas the density used in NUREG/CR-6224 and in the NEI-guidance sample problem on Page 120 uses 175 lbm/ft^3. Please clarify.
- Page 108 mentions Reference 2.24. Why is it not provided in the reference list?
- Page 118, Section 4.5.3.3.2. Please develop this paragraph further, to include a description of the application of the NUREG/CR-6224 correlation to an alternate strainer design (i.e., full screen area for an unloaded strainer vs. the circumscribed area for a fully loaded strainer) instead of just stating, "overly conservative results."
- Appendix C. The title indicates that a comparison of transport factors will be provided, but no transport factors were calculated. Only flow velocities were compared. Some discussion of transport factors would be useful. Please supplement this appendix rather than renaming to reflect the present content.

Response

In light of the NRC comments, the methodology has been significantly revised. Given the text-specific nature of the comments listed above, it is not practical to address each comment individually. All editorial comments have been considered when constructing the document, "PWR Containment Sump Evaluation Methodology," submitted to NRC on May 28, 2004. Non-editorial issues identified above that have been addressed in the most-recent Evaluation methodology include:

- List of abbreviations and acronyms
- The key considerations in selecting alternate strainer designs
- Zone of Influence definition
- Debris transport properties and analysis methods
- Material properties with respect to debris production, debris transport, and head loss
- Head loss calculations, including application of the NUREG/CR-6224 correlation