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U. S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: PWR Containment Sump Evaluation Methodology – Baseline Evaluation

PROJECT NUMBER: 689

Dear Mr. Hannon:

During a March 23, 2004 public meeting to discuss Industry GSI-191 activities, we provided a status of activities to develop an evaluation methodology for use by PWR plants in their evaluation of containment sump performance.

The evaluation methodology presented at the March 23 meeting reflects significant modification of the methodology contained in an October 31, 2003 draft. The revised approach incorporates NRC comments and requests for additional information (RAI) received at the March 23 meeting.

An outline of the evaluation methodology process is shown in Figure 1. The methodology is intended to allow licensees to address and resolve GSI-191 issues in an expeditious manner through a process that starts with a conservative baseline evaluation. The baseline evaluation is expected to guide the analyst and provide a method for quick identification and evaluation of design features and processes that significantly affect the potential for adverse containment sump blockage for a given plant design. The baseline evaluation also facilitates the evaluation of potential modifications that can enhance the capability of the design to address sump debris blockage concerns and uncertainties and supports resolution of GSI-191.

The evaluation methodology currently allows for incorporation of either a deterministic evaluation process (Option A) or a risk-informed evaluation process (Option B). The risk-informed evaluation process, while in an early stage of development, acts upon the willingness of NRC staff, expressed in a March 4, 2004 letter, to utilize current work to risk-inform Title 10, *Code of Federal Regulations*

Section 50.46, “Acceptance criteria for emergency core cooling system for light-water nuclear power reactors,” as a suitable technical basis for defining a spectrum of break sizes for debris generation and containment sump strainer performance. We are currently attempting to arrange a meeting with NRC staff to discuss and hopefully come to agreement on a way to risk-inform GSI-191 evaluation activities that is compatible with the resolution schedule.

At the March 23 public meeting, we committed to provide the revised version of the Baseline Evaluation Methodology for NRC review by April 19, 2004 and the complete Evaluation Methodology and responses to the NRC RAIs by May 28, 2004. In accordance with this schedule, the Baseline Evaluation Methodology is provided as Enclosure 1. An outline of the complete document is provided as Enclosure 2.

Please contact John Butler 202-739-8108, jcb@nei.org, or me if you have any questions on this transmittal.

Sincerely,

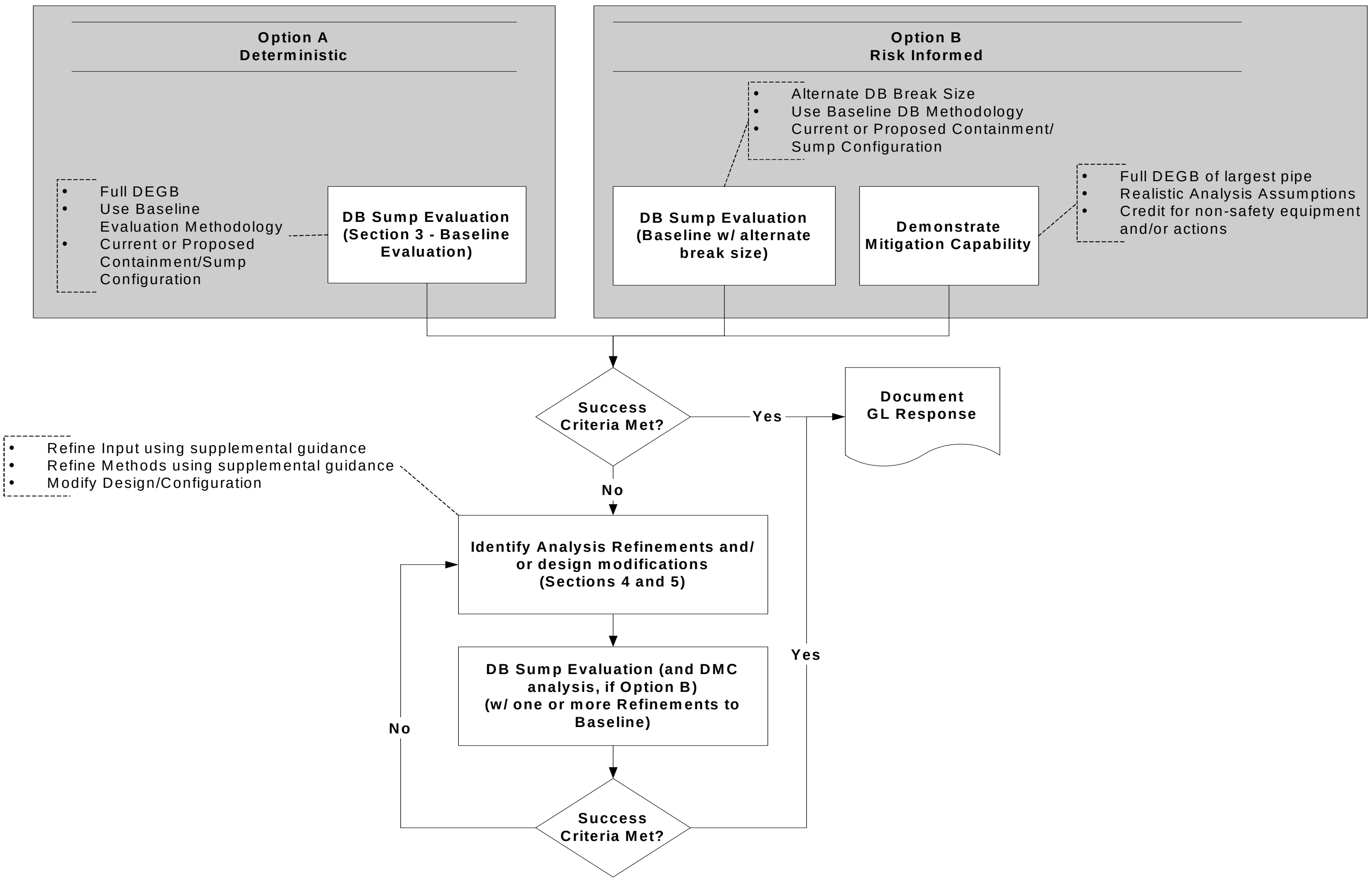
Anthony R. Pietrangelo

Enclosure

c: Mr. Sunil D. Weerakkody, U. S. Nuclear Regulatory Commission
Mr. Ralph E. Architzel, U. S. Nuclear Regulatory Commission
Mr. Michael Marshall, U.S. Nuclear Regulatory Commission`
Mr. John G. Lamb, U. S. Nuclear Regulatory Commission

Figure 1

PWR Containment Recirculation Sump Performance Evaluation Process Overview



Enclosure 2

Outline for PWR Sump Performance Evaluation Methodology

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* - Do not anticipate inclusion of supplemental guidance for this section beyond discussion of potential refinements of baseline analysis that could be developed and supported on a plant-specific basis.

SECTION 3

BASELINE EVALUATION

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3.1 INTRODUCTION

3.1.1 Purpose

The purpose of this baseline evaluation methodology is to provide licensees with a common and consistent approach for doing an initial scoping evaluation to evaluate the post-accident performance of the containment sump screen for a Pressurized Water Reactor (PWR). This common and consistent method is termed the *"Baseline Evaluation Method."*

The Baseline Evaluation Method provides a conservative approach for evaluating the generation and transport of debris to the sump screen, and the resulting head loss across the sump screen. If a plant uses this method and guidance to determine that sufficient head loss margin exists for proper long-term Emergency Core Cooling (ECC) and Containment Spray (CS) function, no additional evaluation for head loss is required.

The same sumps may be used for both long-term ECC for heat removal from the core and long-term CS for heat removal from the containment environment. Revision 3 of Regulatory Guide 1.82 (Reference 3.1-1) as refers to sumps performing this combined or dual function as Emergency Core Cooling (ECC) sumps. This convention of referring to dual-function sumps as ECC sumps will be used here.

3.1.2 Background

The probability of a high-energy line break of PWR piping inside the Reactor Containment Building (containment) is extremely low. However, if the event were to occur, it could result in production of debris that, if transported to and deposited on the containment sump screens, could challenge the function of the ECC sumps. Specifically, debris that would accumulate on the sump screens would result in an increase in the head loss across the resulting debris bed and sump screen. This head loss may be sufficiently large such that the head loss may exceed the available net positive suction head (NPSH) margin of the ECC sumps.

3.1.2.1 General Accident Scenarios of Concern

Postulated accident scenarios of concern are those that require the plant to initiate recirculation flow from the containment sump to mitigate the event. Therefore, the primary design basis accident (DBA) that could present a challenge to the ECC sumps is the Loss-Of-Coolant-Accident (LOCA). However, for some plants, a main steam line break or feedwater break could challenge ECC sump function as well.

3.1.2.2 Accident Phenomena

Three (3) broad phenomena have been identified as governing post accident sump performance:

1. Debris Generation – The destruction of insulation, coatings and erosion of concrete due to the action of the jet resulting from the postulated pipe break.
2. Debris Transport – The movement of debris generated from the jet due to fluid movement associated containment pooling, washdown of containment sprays and from the erosion of submerged material, to the sump when the ECC and CS systems are realigned to draw suction from the containment sump.
3. Head Loss – The development of resistance to flow across the ECC sump screen due to the transport and collection of debris on the sump screen.

The Baseline Evaluation Method provides guidance for licensees to address each of these phenomena and to address post-accident sump screen performance.

3.1.2.3 Limits of Evaluation Method

The guidance presented in the Baseline Evaluation Method only addresses the phenomena and issues up to and including head loss across the sump screen. The application of the Baseline Evaluation Method will provide information which can be used to assess resultant effects on NPSH or pump suction inventory. The calculation of required NPSH of the ECC and CS systems, chemical corrosion effects occurring as a consequence of the postulated event, effects resulting from debris upstream of the sump screen, effects resulting from debris downstream of the sump screen and/or sump screen structural integrity concerns are beyond the scope of the Baseline Evaluation Method and are not addressed in this section.

3.1.2.4 Guidance for Refinements to Baseline Evaluation

The Baseline Evaluation Method presented in this section provides one suggested approach for all utilities to perform an evaluation of the susceptibility of their ECC sumps to failure from debris-induced screen blockage. In addition to the Baseline Evaluation Method and supporting discussion, an example calculation applying the Baseline Method is also provided. The guidance in this section provides a conservative approach for evaluating the generation and transport of debris, and the resulting head loss across the sump screen.

- If a plant uses this Baseline Evaluation Method and determines that head loss margin exists for proper ECC and CS function, no additional evaluation for head loss is required.
- If a plant determines that the results of the baseline approach are not acceptable, or additional design margin is desirable, the refinement guidance provided in subsequent sections may be used to further evaluate the post-accident performance of the ECC sump.

3.1.3 Data Collection to Support Baseline Evaluation

In order to perform the sump performance evaluation according to the guidance in this document, gather the appropriate plant information. The information needed to support the baseline sump performance evaluation is similar to that needed to perform a containment condition assessment walkdown as described in NEI 02-01, “Condition Assessment Guidelines: Debris Sources Inside PWR Containments” (Reference 3.1-2). Therefore, the information primarily documents the configuration of containment and the potential debris sources contained therein.

The information required to perform the assessment can be categorized as follows:

1. General Containment Design Information
    - Topographical containment layout drawings

- Piping isometric drawings
- Process diagrams
- Accident analysis of record and associated licensing basis for post-LOCA recirculation including ECC and CS recirculation flows for various break sizes, spray sequence and flows, time duration, sump water temperature profile, etc.

2. Insulation Details
    - What insulation was used inside containment (insulation specifications),
    - Volume of insulation material installed,
    - Where it was used on equipment, in penetrations, on piping, etc. (drawings),
    - How it was installed; encapsulated, banded, etc. (drawings),
    - Inspection records, if appropriate or available, and
    - Design changes that may have changed insulation used (specifications and drawings).
3. Penetration Details
    - Penetration plan (elevation and azimuth)
    - Drawings of insulation material used in penetrations.
4. Fire Barrier Details
    - What material was used inside containment (material specifications),
    - Where it was used inside containment (drawings),
    - How it was installed (drawings),
    - Inspection records, if appropriate or available, and
    - Design changes that may have changed fire barrier material or location inside containment (specifications and drawings).
5. Protective Coatings Details
    - What coatings were applied,

- Where they were applied,
- QA program requirements,
- Coatings application specification(s),
- Coatings inspection records,
- What coatings were applied to purchased equipment and the coatings program used to apply them, and
- A copy of the “Exempt” or “Unqualified” coatings log, if used at the site.

6. Other Potential Debris Sources
   - Foreign materials exclusion program documentation
   - Latent debris observed to be inside containment
   - Tagging and labeling procedures or technical instructions
   - References for use of cable ties inside containment

The above listing of information is intended to be as complete as possible to support a plant-specific baseline evaluation. However, plant-specific features may suggest that additional information be collected and supporting documents be reviewed in support of performing the baseline evaluation.

3.1.4 References

3.1-1 Regulatory Guide 1.82, Revision 3, “Water Sources for Long-Term Recirculation Cooling Following a Loss-Of-Coolant Accident,” US Nuclear Regulatory Commission, November 2003

3.1-2 NEI 02-01, Revision 1, “Condition Assessment Guidelines: Debris Sources Inside PWR Containments,” September 2002

3.2 METHOD DESCRIPTION

3.2.1 Break Selection

Discussed in this section are the considerations and guidance for selecting an appropriate postulated break size and evaluating the location of the postulated break that presents the greatest challenge to post-accident sump performance.

3.2.1.1 Introduction

The break selection is the first step in assessing post-accident sump screen performance. Break selection consists of two considerations:

1. The size of the break, and,
2. The location of the break.

The objective of the break selection process is to determine the break size and location that results in debris generation that is evaluated to determine the maximum head loss across the sump screen. Since this location is not known prior to performing the evaluation, the term break selection refers to a process of evaluating a number of break locations for a given size break to identify the location that presents the greatest challenge to post-accident sump performance.

3.2.1.2 Discussion

The objective of the break selection process is to evaluate and identify the break locations that provide for the following two results:

1. The maximum amount of debris that is transported to the sump screen, and,
2. The worst combination of debris mixes that are transported to the sump screen.

The locations that provide for these conditions are identified as “limiting break locations” for the purpose of evaluating post-accident sump screen performance.

The criterion used to define the limiting break location is the head loss across the sump screen resulting from deposition of debris on the sump screen; the limiting break location results in the maximum head loss. As noted above, the limiting break location is not known prior to performing the evaluation, but is determined by evaluating a number of postulated break locations. To perform this evaluation, it is necessary to perform the debris generation, debris transport, and head loss calculations for each postulated break location. Therefore, the selection of the limiting break site is an iterative process that requires rigor.

The guidance below documents the process for determining the limiting break location.

3.2.1.3 Postulated Break Size

A double-ended guillotine break (DEGB) of piping, including the primary system piping, may be used as the postulated break size. This approach provides for the prediction of large volumes of debris from insulation and other materials that may be within the region affected by the fluid escaping through the postulated break. NRC has accepted this as an acceptable approach in the resolution of ECCS strainer blockage concerns for Boiling Water Reactor (BWR) plants. This method is applicable to all PWR designs.

Some plant designs require recirculation of containment spray for long term containment cooling after a main feedwater line break or a main steam line break. Either the same considerations as for LOCA or the plant's current licensing basis for those breaks may be used for break selection and size characterization.

3.2.1.4 Identifying Break Locations

Postulation of the break location is somewhat more complex than postulation of the break size. All Reactor Coolant System (RCS) piping, and connected piping, must be considered in the evaluation. Since many break locations are to be considered, a wide range of results is to be expected. Some plant designs require plants to eventually recirculate coolant from the sump for pipe ruptures other than a LOCA. If this is a part of the plant under consideration's licensing basis, then these lines must also be considered for debris generation.

3.2.1.4.1 General Guidance

It is recommended that pipe break locations considered are postulated based on the following criteria:

1. For postulated LOCAs, break exclusion zones are disregarded for this evaluation. In other words, pipe breaks must be postulated in pre-existing break exclusion zones. For main steam and feedwater line breaks, licensees should evaluate the licensing basis and include potential break locations in the evaluation, if necessary.
2. NRC Branch Technical Position MEB 3-1 shall not be used as a basis for determining potential LOCA break locations. The purpose of the analysis is to determine the worst possible break with respect to ECCS sump concerns. Therefore, the location of the pipe break is not chosen based on the stress distribution and or fatigue characteristics of the piping system.
3. For the plants for which main steam line breaks and/or feedwater line breaks must be considered, then the break locations should be consistent with the plant's current licensing basis.
4. Pipe breaks shall be postulated at locations such that each location results in a unique debris source term (i.e. multiple identical locations need not be examined).
5. Pipe break shall be postulated in locations containing high concentrations of problematic insulation (micro-porous insulation, calcium-silicate, fire barrier material, etc.).
6. Pipe breaks shall be postulated with the goal of creating the largest quantity of debris and or the worst-case combination of debris types.
7. Piping attached to the RCS that is small (< 2 inches in diameter) need not be considered. Breaks of this size are sufficiently small (and bounded by the larger breaks) that quantities of debris large enough to challenge the post-accident operability of the containment sump are not generated.

3.2.1.4.2 Piping Runs to Consider

As a minimum, LOCA breaks in the following lines should be considered:

1. Hot leg, cold leg, intermediate (crossover) leg and surge line
2. Piping attached to the reactor coolant system. Examples include, but are not limited to Charging Lines and/or RHR lines.

Some plant designs require plants to eventually recirculate containment coolant from the sump for pipe ruptures other than a LOCA. Two such events are main feedwater breaks and steam line breaks. If this is a part of the licensing design basis for the plant under consideration, then these lines must also be considered for this evaluation.

3.2.1.4.3 Other Considerations for Selecting Break Locations

Section 3.2.1.2, "Discussion," identified the objective of break selection as of identifying a limiting break for post-accident sump performance consideration. Listed below are additional guidelines to use in selecting break locations that support that objective.

1. Identify locations for postulated large breaks that result in the generation of two or more different types of debris. These locations are determined by considering the location of materials (insulation, coatings, etc,) inside containment relative to the break location and Zone of Influence. Specifically, look for locations where problematic insulation (for example, micro-porous insulation) may be combined with particulate debris. Note that the location of materials inside containment should have been identified during the application of NEI-02-01 (Reference 3.2.2-1).
2. Identify locations for which postulated breaks generate an amount of fibrous debris that, after transport to the sump screen, creates a uniform fibrous bed of equal to or greater than 1/8-inch layer to filter particulate debris.
3. If the insulation does not result in the generation of significant particulate debris (for example, the insulation in the ZOI is RMI, there is no micro-porous insulation inside

containment, and fibrous insulation is not affected by the postulated break), particular attention should be given to the characterization of latent debris sources as this source may present the limiting debris loading condition with respect to either fiber, particulates, or both.

3.2.1.4.4 Selecting the Initial Break Location

To start the break selection evaluation, select an initial break location using the guidance given in Sections 3.2.1.4.1 through and including Section 3.2.1.4.3. Multiple breaks will be examined to demonstrate the limiting break location was considered. However, using the guidance identified in these sections, it is possible to identify locations that may be considered to be likely candidates for the limiting location. Thus, it is suggested that an initial postulated break location be chosen with the following characteristics:

1. Pick the initial break location to be near a large quantity of potential debris and/or is near a combination of potential debris types that are known to challenge post-accident sump operation. It is suggested that results from a containment condition assessment, similar to that described in NEI 02-01 (Reference 3.2.2-1) would be useful in assessing such locations.
2. The location is a convenient place to start a sequence of breaks (e.g. at the physical end of a length of pipe when multiple locations on that length of pipe are being evaluated).

Given the above, it is suggested that a candidate location for the initial break location is the junction of the primary piping and the steam generator. Two general industry observations support this suggestion:

1. As a consequence of their size, steam generators have a larger volume of insulation applied to them than does primary system piping.
2. It has been observed that steam generators often have several different types of insulation applied to them.

Therefore, the selection of a break location at the junction of primary piping and the steam generator is a reasonable starting point to address the criteria of evaluating both the maximum amount of debris that is transported to the sump screen, and, the worst combination of debris mixes that are transported to the sump screen.

3.2.1.5 Evaluation of Break Consequences

The evaluation of break consequences is the determination of the head loss across the sump screen as a result of the generation, transport and accumulation of debris on the sump screen that is calculated to occur as a result of the postulated break, and the consequential head loss across the sump screen as emergency core cooling and containment spray recirculation water attempts to pass through the debris bed.

3.2.1.5.1 Purpose of Break Consequence Evaluation

The purpose of evaluating the consequences of a postulated break is to determine the head loss associated with that break and its effect on available NPSH for the recirculation pumps. To accomplish this, the following additional evaluations must be performed for each break location considered:

1. Evaluation of the Zone of Influence (ZOI), the region inside containment that is affected by the fluid escaping from the postulated break location, resulting in the generation of debris. As the ZOI is moved about to different break locations, robust structures (walls) may affect the geometry of the ZOI.
2. Evaluation of the debris source term.
3. Evaluation of debris transport to the sump screen.
4. Evaluation of head loss across the sump screen resulting from debris that has been (transported to and) deposited on the containment sump screen.

Evaluating break consequences in this way provides for the evaluation of sump screen head loss as a function of postulated break size and break location.

3.2.1.5.2 Selection of Intervals for Additional Break Locations

Having evaluated the initial break location, additional locations are evaluated and the results compared to each other. The purpose of this comparison of results is to determine the limiting location for the break size used.

For primary piping, it is suggested that the break location be moved at 3-foot increments along the pipe being considered. This break frequency provides for an acceptable determination of the limiting break location with respect to both:

1. The maximum volume of debris that may be generated and transported to the sump screen, and,
2. The worst combination of debris that may be generated and transported to the sump screen.

It is expected that as the plant specific analysis develops it would be determined and documented by inspection that the number of cases requiring detailed analysis can be limited based on debris inventory, similarity of transport paths and piping physical characteristics.

The same strategies need not be applied when considering main steamline or feedline breaks. A sufficient number of breaks, consistent with the plant-specific design and licensing basis, should be considered to reasonably bound variations in debris generation by the size, quantity, and type of debris. This may result in break intervals as small as 3 feet, depending on plant configuration.

For attached piping, only the length of pipe run up to the flow isolation point need be considered. This approach will account for debris generation from postulated pipe breaks, including single-sided breaks, from attached piping. There is no need to consider pipe breaks in attached piping beyond the isolation points as such breaks, should they occur, will not result in the plant evolving to recirculation from the containment sump to mitigate the event.

3.2.1.6 Break Size for Sample Calculation

For the purposes of the sample calculation presented in this document, the break is taken as ten (10) inches. The break size of 10 inches is based on the assumption that the 10-inch break represents the maximum size of attached piping to the primary system. A single sample debris generation calculation, debris transport evaluation and subsequent head loss is presented. A number of break locations should be identified, as described here, and evaluated to assure that the potential for debris generation, transport and sump screen head loss are adequately evaluated for a given plant.

3.2.1.7 References

3.2.1-1 NEI-02-01, “Condition Assessment Guidelines: Debris Sources Inside PWR Containments,” Revision 1, September 2002.

3.2.1-2 Regulatory Guide 1.82, “Water Sources for Long-Term Recirculation Cooling Following a Loss-Of-Coolant Accident”, Revision 3 November 2003.

3.2.2 DEBRIS GENERATION

3.2.2.1 Introduction

Following identification of postulated break locations, the next step taken in evaluating post-accident sump performance is to determine an appropriate zone of influence (ZOI) within which the resultant break jet would have sufficient energy to generate debris. It is noted that not all debris that is evaluated to be generated is in a form that may be transported to the sump. Thus, evaluation of debris generation from a postulated break is a two-step process:

1. The first step is to evaluate an appropriate ZOI in which debris is generated.
2. The second step is to evaluate the characteristics of the debris generated.

Included in this second step is the identification of transport characteristics of the debris generated by the postulated break. Thus, the evaluation of debris generation for a given break location is an exercise of establishing an appropriate size and shape of the ZOI, mapping that ZOI volume over the spatial layout of insulated piping and calculating the volume of insulation within that ZOI. The final step to evaluating debris generation is the application of a size distribution to the debris generated within the ZOI volume that will be used to evaluate debris transport.

The identification of the ZOI and resulting debris generation for postulated pipe breaks (LOCA, main steamline or feedwater) is both plant- and break-specific. Presented in this section is guidance on establishing the appropriate ZOI and resulting debris characteristics for LOCA.

3.2.2.2 Zone of Influence

The zone of influence is defined as the volume about the break in which the fluid escaping from the break has sufficient energy to generate debris from insulation, coatings, and other materials within the zone. For the baseline calculation, it is recommended that the boundary of the ZOI be assumed to be spherical, with the center of the sphere located at the break site. The use of a spherical ZOI is intended to encompass the effects of jet expansion resulting from impingement on structures and components. Use the guidance in Sections 3.2.2.2.1 and 3.2.2.2.2 to determine the Zone of Influence for a postulated pipe break.

Guidance on the identification of other, more realistic ZOI's is given in the Supplemental Guidance.

3.2.2.2.1 Recommended Size of Zone of Influence

To determine the radius of the spherical ZOI needed to represent the effects of the jet originating from a postulated pipe break, the ANSI/ANS 58.2-1988 standard (Reference 3.2.2-1) was used. Appendices B, C, and D of Reference 3.2.2-1 provide the guidance necessary to determine the geometry of a freely-expanding jet. Guidance is provided for jets originating from a variety of reservoir conditions, including subcooled conditions.

The guidance in Reference 3.2.2-1 was used to determine the geometry of a jet originating from a postulated break in a PWR piping system. A subcooled reservoir and flashing break flow were assumed for the calculations as detailed below. The following steps were followed in performing the calculations:

1. The mass flux from the postulated break was determined using the Henry-Fauske model, as recommended in Appendix B, for subcooled water blowdown through nozzles, based on a homogeneous non-equilibrium flow process. No irreversible losses were considered.
2. The initial and steady-state thrust forces were calculated based on the guidance in Appendix B of Reference 3.2.2-1, and the postulated reservoir conditions detailed below.
3. The jet outer boundary and regions were mapped using the guidance in Appendix C, Section 1.1, of Reference 3.2.2-1 for a circumferential break with full separation. The input to the equations from Appendix C for the thermodynamic conditions at the asymptotic plane was calculated using principles of thermodynamics and the postulated conditions in the reservoir.

4. A spectrum of isobars was mapped using the guidance in Appendix D of Reference 3.2.2-1. Several isobars were considered of interest, including the 10 psi isobar. The 10 psi isobar was of interest as NEDO-32686 (Reference 3.2.2-2) identified 10 psi as the destruction pressure of jacketed Nukon® insulation with standard bands or unjacketed Nukon®.
5. The volume encompassed by the various isobars was calculated using a trapezoidal approximation to the integral. A study was performed to ensure that the results of the volume calculations are not sensitive to the resolution of the trapezoidal approximation. Since the volume result only represents the volume encompassed by the isobars in a free jet, the volume encompassed by results were doubled to represent the Double Ended Guillotine Break (DEGB).
6. The radius of an equivalent sphere was calculated to encompass the same volume as double the volume of a feely expanding jet calculated from Step 5, above.

The radius calculated in Step 6, above, is taken to be the radius of the ZOI that will be used to calculate the volume of debris generated from a postulated break.

The jet expansion calculations were based on the following conditions:

1. A circular break geometry was used for the calculations. This break geometry is representative of both a postulated DEGB of primary piping as well as the DEGB of piping attached to the RCS. The complete breaking of a pipe, either primary piping or piping attached to the RCS, provides for a maximum debris generation volume as there are two ends of the break to release fluid.
2. Fluid reservoir conditions of 2250 psia and 540 ˚F were used for the calculations. The corresponding stagnation enthalpy and subcooling used in the calculations are 547.2 BTU/lbm and 102.7 ˚F, respectively. These conditions are intended to represent a PWR in hot standby conditions and provide for a conservatively large ZOI compared to hot leg conditions at power operations.

3. Ambient pressure of 14.7 psia was used. This is conservative as no credit is taken for containment backpressure (the increase in containment pressure that would result from the release of mass and energy into the containment as a result of the postulated break).

The ZOI is expressed as the ratio of the radius of the equivalent ZOI sphere to break size diameter. This allows the ZOI to be expressed independent of the break size.

The use of a spherical ZOI is conservative compared to jet impingement evaluations previously reviewed and approved by NRC. It is noted that, for a number of plants, a 10 D value is assumed for the limit of jet damage. This is based on NUREG/CR-2913 dated January, 1983. As an example, the acceptability of this approach is documented in the Supplement 6 of the Watts Bar Safety Evaluation Report (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 10D is conservative on volume by a factor of approximately 16 for a single ended rupture and 8 for a double ended rupture as described in the following example;

> Assume a 3 foot diameter pipe. If using a jet with a 10^o half angle, with a damage inducing length of 30 feet (10D). This 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 πr^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. Thus, the use of a spherical representation generally provides a conservatively large approximation to the region affected by a jet.

3.2.2.2.1.1 Insulation

Equivalent spherical ZOI calculations were performed and documented (Reference 3.2.2-3) for values of isobars corresponding to destruction pressures of several types of insulation. Table 3.2.2-1 summarizes these insulation types and the applicable ZOI, expressed as the ratio of the ZOI radius to the break diameter, for which the calculations were performed. The calculations summarized in Table 3.2.2-1 make no changes in insulation destruction pressures based on the differences between dry or saturated steam jets and flashing jets. The reasons for this are as follows:

1. The stagnation pressure of the jet is taken to correspond to the destruction pressure of insulation.
2. It is also noted that there is only anecdotal test data to suggest modification of the destruction pressures of insulation that were determined in support of the BWR strainer blockage resolution.

Therefore, noting that the values for ZOI values listed in Table 3.2.2-1 maximize the ZOI, and the use of a spherical representation generally provides a conservatively large approximation to the region affected by a jet, no addition changes to insulation destruction pressures were made.

3.2.2.2.1.2 Protective Coatings

The criteria for DBA-qualification, or designation as “Acceptable,” of protective coatings (paints) applied to systems, structures and components in PWR containments do not provide data concerning coatings exposed to direct impingement of fluids. As such, the ZOI for DBA-qualified coatings or coatings determined to be “Acceptable,” applied to PWR containment surfaces, which results from fluid impingement from the break jet, has not been clearly defined.

However, an extensive body of data exists related to removal of industrial protective coatings by high-pressure and ultra-high-pressure waterjetting. Examination of this data and associated industry standards, compiled since the mid-1980's, reveals that industrial protective coating systems, identical to the DBA-qualified and "Acceptable" coatings applied to systems, structures and components in Pressurized Water Reactor (PWR) containments, require a water jetting pressure of at least 7,000 psig to initiate destruction of sound coatings. This ability of coatings to withstand high and ultra-high pressure has been reviewed and documented in a paper prepared by a recognized industry coatings expert (Reference 3.2.2-5) and is included as Attachment A.

Based on evaluation presented, a destruction pressure of 1000 psi is chosen for coatings that meet DBA-qualified or "Acceptable" criteria. This is conservative for the following reasons:

1. The value of 1000 psi is seven to eight times lower than the pressures that have been observed in industrial practice to remove coatings using waterjet technology.
2. The initial reactor coolant system pressure of 2250 psi is about ¼ the pressures that have been observed in industrial practice to remove coatings using waterjet technology.
3. Industrial experience with waterjet technology to remove coatings requires application of the high-pressure jet at close proximity of the surface to which the coating is applied (< 12 inches from the jet nozzle discharge) for extended periods of time (> 60 seconds).
4. The blowdown of a PWR RCS due to a large LOCA is in the order of 30 seconds
5. The break discharge pressure decreases over the duration of the blowdown period.

Thus, it is concluded that the use of a value of 1000 psi as the destruction pressure for DBA-qualified and "Acceptable" protective coatings is both appropriate and conservative. The recommended ZOI to be used to evaluate protective coatings debris for the baseline containment sump evaluation is listed in Table 3.2.2-1.

This same industrial experience suggests that the mechanism of coatings removal by waterjets is erosion. The observed coatings debris sizes are in the range of 10 microns to 50 microns, not flakes or chips. Thus, it is recommended that the coatings debris generated within the ZOI representing 1000 psi be treated as fine particulate debris. It is further recommended that these coatings debris be considered highly transportable.

3.2.2.2.2 Selecting a Zone of Influence

For the baseline calculation, the ZOI for insulation is selected based on the insulation inside containment with the minimum destruction pressure. This ZOI is then applied to all insulation types. As discussed in the previous section, this approach provides for the calculation of a conservatively large value for debris generation.

3.2.2.2.3 The ZOI and Robust Barriers

For a given break location, the boundary of the spherical ZOI is drawn about the break. It is possible that this boundary will extend beyond robust barriers such as walls and components. Such barriers will terminate further expansion of the ZOI.

1. In the case of a wall, the sphere will be truncated at the intersection of the sphere and wall.
2. For a component or structural components such as supports, a pressurizer, steam generator, reactor coolant pump or jet shields, the area in the shadow of the component or structure will be free from damage.

There is sufficient conservatism in drawing the sphere that it is not reasonable that a jet reflected off of a wall or structure would extend further than the unrestrained sphere. Furthermore, there is precedence for this conclusion. When evaluating targets for jet impingement, jets were terminated when a robust barrier was encountered. Reflected jets were not considered as they were bounded by the conservatism in the approach taken.

Table 3.2.2-1: ZOI Radii for Common PWR Insulation and Coatings Materials

Insulation Types	Destruction Pressure (psi)	ZOI Radius/Break Diameter	
		Calculated Value	Recommended Value
Protective Coatings (paints)	1000(Ref. 3.2.2-5)	0.29	1.0
Transco RMI Darchem DARMET	190(Ref. 3.2.2-6)	1.20	1.3
Jacketed Nukon® with Sure-hold® bands Mirror® with Sure-hold bands®	150(Ref. 3.2.2-6)	1.59	1.6
Cal-Sil (Al. cladding, SS bands, seam @ 180°)	64(Ref. 3.2.2-7)	2.84	2.9
Cal-Sil (Al. cladding, SS bands, seam @ 0°)	50(Ref. 3.2.2-7)	3.25	3.3
K-wool	40(Ref. 3.2.2-6)	3.69	3.7
Cal-Sil (Al. cladding, SS bands, seam @ 45°)	24(Ref. 3.2.2-7)	5.37	5.4
Temp-Mat with stainless steel wire retainer	17(Ref. 3.2.2-6)	7.6	7.7
Unjacketed Nukon®, Jacketed Nukon® with standard bands Knauf	10(Ref. 3.2.2-6)	11.96	12.0
Koolphen-K	6(Ref. 3.2.2-6)	16.81	16.9
Min-K Mirror® with standard bands	4(Ref. 3.2.2-6)	21.47	21.5

3.2.2.2.4 Simplifying The Determination of the ZOI

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

Once the boundary of the ZOI has been defined, proceed with determining the amount of debris that is generated within the ZOI.

3.2.2.2.5 Evaluating Debris Generation Within the ZOI

Once the ZOI has been determined, calculate the amount of debris generated within the ZOI. Information about the type, location and amount of debris sources within the containment is obtained from plant drawings and the results of a condition assessment walk-down such as described in NEI 02-01 (Reference 3.2.2-4). The characterization of the debris (transport characteristics) is evaluated using the guidance of the following section.

3.2.2.2.6 Sample Calculation

The following is a sample calculation of a ZOI and the debris that would be generated within that ZOI.

1. For the purposes of a sample calculation, a single break size and break location will be assumed and evaluated.
2. The break will be assumed to be at the base of the steam generator.[1] The reason for this choice is that often, more than one type of insulation is applied to steam generators. Figure 3.2.2-1 shows a sample schematic of a reactor coolant system.
3. It will also be assumed that walk-down data for the plant is available and documented in sufficient detail to support this evaluation. For the purposes of this evaluation, it will be assumed that the walk-down was performed by dividing the containment into zones and recording the amount of insulation in each zone. The debris generation zones defined from the walk-down are also shown on Figure 3.2.2-1 and are labeled as Zone A1, Zone

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[1] A 10-inch break is an idealization for the steam generator. It is used here to illustrate the calculation method.

A2, etc. Note that the plant layout and engineering judgment are used to define the zones used to record the location of insulation inside containment.

4. The postulated break will be assumed to occur in Zone A4. For this sample calculation, it is assumed that the walk-down records show the amount of insulation in Zone A4 to be:
   - 300 ft^3 of Nukon insulation
   - 15,000 ft^2 of RMI
5. A 10-inch break of piping attached to the RCS is assumed. The corresponding ZOI is evaluated as follows:

   The diameter of the break is taken as:

   $$D_{BREAK} \quad = \quad 10\, inches$$

   Using the criteria identified above, the minimum destruction pressure for insulation is used to determine the ZOI. From Table 3.2.2-1, the recommended ratio of ZOI radius to break diameter is;

   $$\frac{r_{ZOI}}{D_{BREAK}} \quad = \quad 12$$

   The radius of the spherical ZOI is calculated as:

   $$r_{ZOI} \quad = \quad D_{BREAK} \times \frac{r_{ZOI}}{D_{BREAK}} \quad = \quad 10\, inches \times 12 \quad = \quad 120\, inches \quad = \quad 10\ ft$$

   Thus, the radius of the ZOI is determined to be 10 feet. This ZOI is conservatively applied to all insulations types in the region within the ZOI for the baseline evaluation.
6. A ZOI having a 10 foot radius is superimposed at the base of the steam generator in Zone A4 of Figure 3.2.2-1. From the figure, it is observed that the ZOI includes a substantial portion of the steam generator and associated reactor coolant system piping within Zone A4. Insulation is applied to these components. Therefore, for the purposes of this sample calculation, a ZOI with a radius of 10 ft is conservatively evaluated to result in the destruction of all the insulation within Zone A4. This results in the following volumes of insulation debris:

- 300 ft^3 of Nukon insulation
- 15,000 ft^2 of RMI.

7. Using the recommended ratio of ZOI radius to break diameter for coatings of 1.0 that is given in Table 3.2.2-1, the radius of the coatings ZOI is evaluated as:

$$r_{ZOI} \quad = \quad D_{BREAK} \times \frac{r_{ZOI}}{D_{BREAK}} \quad = \quad 10\,inches \times 1.0 \quad = \quad 10\,inches \quad = \quad 0.833\ ft.$$

From Figure 3.2.2-1, it is clearly observed that the coating ZOI will not be in contact with either walls or floors. Furthermore, with a small ZOI for coatings, coated structures or components may not be within the ZOI. However, a conservative estimate of the square footage of coatings debris is estimated by using the surface area of the sphere of the coatings ZOI:

$$A_{COATINGS\ DEBRIS} \quad = \quad 4\,\pi\,r^2 \quad = \quad 4\,\pi\,(0.833)^2 \quad = \quad 8.72\ sq.\ ft.$$

Thus, the amount of coatings debris generated by the postulated 10-inch break is conservatively estimated to be 8.72 ft^2.

The transport characteristics of the debris volumes calculated above are evaluated using the guidance of the following section. The transport of the debris evaluated using the guidance of Section 3.2.4, and the resulting head loss evaluated using the guidance of Section 3.2.5. The debris generation evaluation is repeated using the guidance of Section 3.2.1 until the limiting head loss is evaluated.

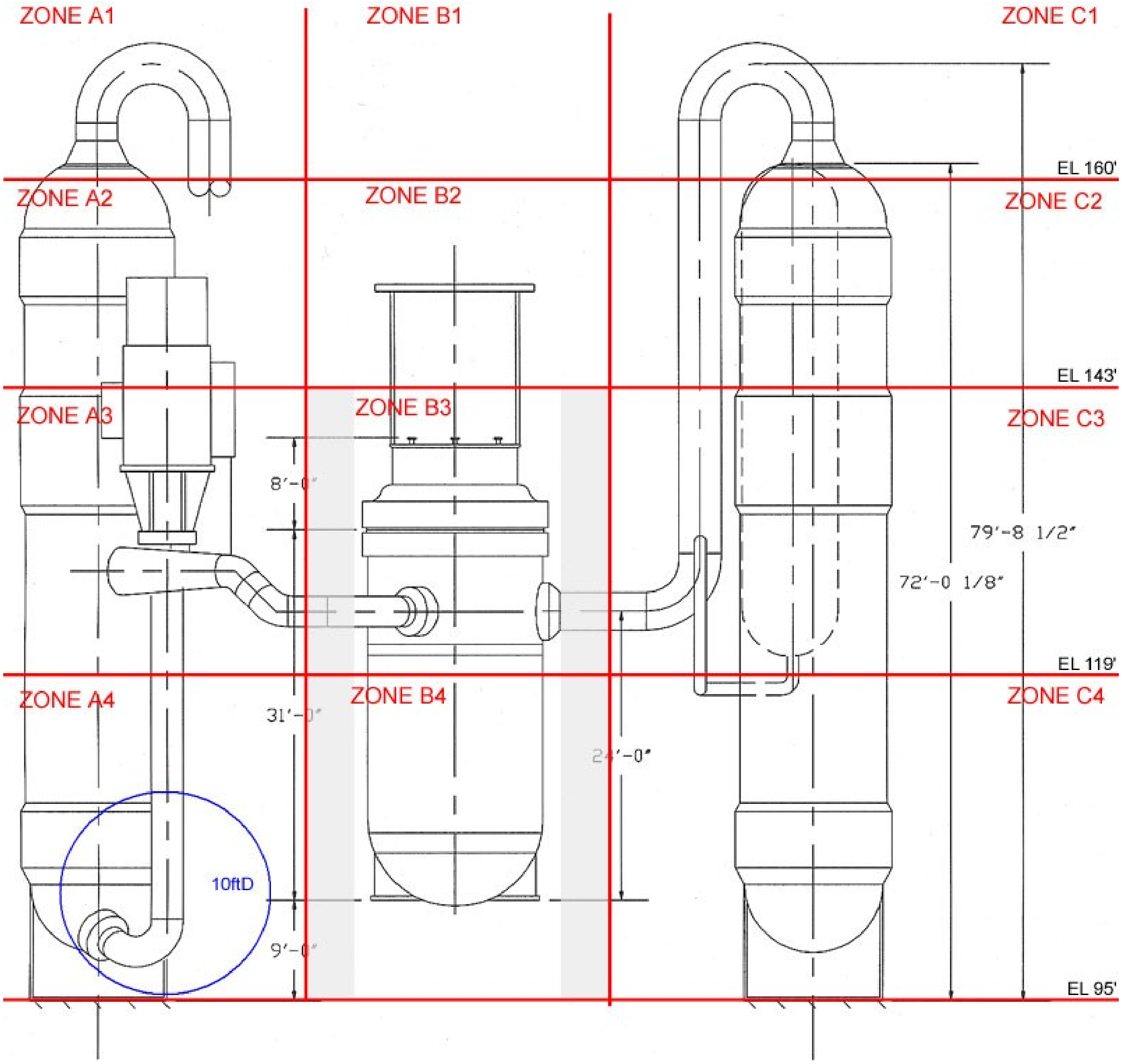

Figure 3.2.2-1: Schematic Showing Reactor Coolant System and Walkdown Zones

3.2.2.3 Quantification of Debris Characteristics

3.2.2.3.1 Definition

Debris characteristics are:

- The post-accident (LOCA and/or secondary pipe breaks where applicable) size distribution size distribution of a material, and
- The debris material size and shape as well as the micro-density (i.e. material density) and macro-density (i.e. as fabricated density).

Debris characteristics are used in transport and head loss calculations. The debris generation section provides the following items as inputs to this section:

- The volume of insulation material in a ZOI
- The surface area of the ZOI for coatings
- The total quantity of indeterminate[2] and unqualified coating inside containment.
- The total quantities of indeterminate and unqualified coating that have been applied to piping that are covered by undamaged insulation.

3.2.2.3.2 Discussion

The first order debris characteristic is the size distribution of the material inside the Zone of Influence (ZOI) of a postulated pipe break. Following a postulated pipe break, all material inside containment may also be subjected to containment spray or immersed in the post-accident pool, and additional debris would be generated, hence the characteristics of the debris generated post-blowdown also need to be identified.

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[2] For definitions of DBA-qualified / acceptable, DBA-unqualified / unacceptable and indeterminate coatings, see ASTM D-5144-00, “Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants.”

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. 3.2.2-8) employed 5 fibrous debris size classification schemes, with 3 to 6 size designations (e.g. large, medium, and small). NUREG/CR-6224 (Ref. 3.2.2-9) 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.

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 (Ref. 3.2.2-6) 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. In the absence of directly applicable experimental data, i.e. tests conducted with prototypical PWR conditions, for a wide variety of material, the NEI Guideline adopts a two size distribution for material inside of the ZOI of a postulated break: 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-accident 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.

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/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 test results.

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 this 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.

The calculation of the quantities for each size category for each of the materials entails multiplying the volume of each material calculated to be in the ZOI by the percentage of the two-size distribution recommended below.

3.2.2.3.3 Size Distribution

3.2.2.3.3.1 Fibrous Material in a ZOI

The fibrous classification of "small fines" adopted in this guideline can be correlated to the combination of "small" and "medium" classification of Table 3-7 of NUREG/CR-6369 Vol. 2, the combination of "small" and "large" classification of Table 2-5 of NUREG/CR-6369 Vol. 1, Classes 1 – 6 of NUREG/CR-6224, and the combination of "Fines" and "Large" classification of the BWROG URG Air Jet Impact Test (AJIT). The classification of "large pieces" adopted in this guideline can be correlated to the "large" category of Table 3-7 of NUREG/CR-6369 Vol. 2, the "large canvassed" of Table 2-5 of NUREG/CR-6369 Vol. 1, Class 7 and "non-transportable" of NUREG/CR-6224, and the combination of "canvas" of the BWROG URG Air Jet Impact Test.

The following are the material-specific size distribution values adopted by this guideline:

a. <u>NUKON® Fiber Blankets.</u> This guideline adopts the value of 60% for small fines and 40% for large pieces as the size distribution of NUKON® (jacketed or unjacketed) inside a pipe break ZOI. As noted previously, these values were selected from the BWROG URG Air Jet Impact Test of NUKON® that generated the largest quantity of small fines and is consider being applicable to PWR conditions based on the Ontario Power Generation test reported in NUREG/CR-6808.

b. <u>Transco Fiber Blankets.</u> This guideline adopts the value of 60% for small fines and 40% for large pieces as the size distribution of NUKON® inside a pipe break ZOI. 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 shows that the Transco blankets tested behaved similar to the NUKON®. Given these experimental data, 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 size distribution adopted for Transco fiberglass blankets in this guideline is conservative since the size distribution adopted for NUKON® fiberglass blankets was the most conservative size distribution of any of the AJIT tests of NUKON® fiberglass blankets.

c. Knauf. Knauf was tested by the BWROG at the CEESI Air Jet Impact test facility and shown to have the same destruction pressure as NUKON® . Since the destruction pressure is the same as NUKON®, engineering judgment suggests that the size distribution should be no worse than NUKON®. Hence this guideline adopts the same size distribution for Knauf as NUKON®: 60% for small fines and 40% for large pieces.

d. Temp-Mat. Temp-Mat was tested by the BWROG at the CEESI Air Jet Impact test facility and shown to have a higher destruction pressure than NUKON®. Since the destruction pressure is higher than NUKON®, engineering judgment suggests that the size distribution should be no worse than NUKON®. Hence this guideline adopts the same size distribution for Knauf as NUKON®: 60% for small fines and 40% for large pieces.

e. K-Wool. K-Wool was tested by the BWROG at the CEESI Air Jet Impact test facility and shown to have a higher destruction pressure than NUKON®. Since the destruction pressure is higher than NUKON®, engineering judgment suggests that the size distribution should be no worse than NUKON®. Hence this guideline adopts the same size distribution for K-Wool as NUKON®: 60% for small fines and 40% for large pieces.

f. Min-K. Absent applicable experimental data, a value of 100% small fines is adopted by this guideline for Min-K in a ZOI.

g. Generic Low-Density Fiberglass. Absent applicable experimental data a value of 100% small fines is adopted by this guideline for generic fiberglass in a ZOI.

h. Generic High-Density Fiberglass. Absent applicable experimental data a value of 100% small fines is adopted by this guideline for generic high-density fiberglass in a ZOI.

i. Generic Mineral Wool. Absent applicable experimental data a value of 100% small fines is adopted by this guideline for any type of mineral wool in a ZOI.

3.2.2.3.3.2 Reflective Metallic Insulation (RMI) in a ZOI

NEI guideline adopts one size distribution classification scheme for all types of RMI insulation after exposure to the conditions within a PWR ZOI, since their ensuing transport and head loss guidelines do not differentiate between different types of RMI (i.e. stainless steel or aluminum).

RMI. The NEI guideline adopts the value of 75% for small fines and 25% for large pieces as the size distribution of any type of RMI inside a pipe break ZOI. These values are based on the size distribution of less than 4 inches as listed in Figure 3-7 of NUREG/CR-6808 based on the two phase testing of a Diamond Power RMI cassette. The size of 4 inches was selected as a conservative upper bound of an RMI debris size that would go through gratings, trash racks, or radiological protection fences by blowdown, containment sprays, or post-accident pool flows. BWROG URG Air Jet Impact Tests (AJIT) of other types of RMI suggests a significantly larger destruction pressure and a consequently smaller quantity of small size debris. Engineering judgment suggests that the 75% adopted for the RMI small-size category in this guideline is conservative in that it is based on the test that resulted in the largest quantity of small RMI debris for a type of RMI that has the lowest AJIT destruction pressure.

3.2.2.3.3.3 Other Material in ZOI

a. Calcium Silicate. There is a wide variety of calcium silicate type insulation installed in PWRs. Some include fiberglass fibers as re-enforcement, some others use organic fibers, and some of the Cal-Sil used up to the late 1950s used asbestos fibers. The Cal-Sil solubility also varies from manufacture to manufacture with some Cal-Sil dissolving promptly in hot water whereas some dissolve at a significantly lower rate. The only publicly available size distribution data on the reaction of an unspecified Cal-Sil to a two-phase jet are found in Table 3-6 of NUREG/CR-6808. Test 5 indicated that the size categories adopted by this guideline would be 50% for small fines and 50% for large Cal-Sil pieces. Given the uncertainties in the subsequent erosion by the post-DBA water this guideline assumes 100% of Cal-Sil in a ZOI is destroyed as small fines.

b. Microtherm. Absent applicable experimental data, a value of 100% small fines is adopted by this guideline for Microtherm in a ZOI.

c. Koolphen. Absent applicable experimental data, a value of 100% small fines is adopted by this guideline for Koolphen in a ZOI.

d. Fire Barrier. Absent applicable experimental data or qualification documentation, a value of 100% small fines is adopted by this guideline for all types of fire barrier material in a ZOI.

e. Lead Wool. Absent applicable experimental data, a value of 100% small fines is adopted by this guideline for all types of lead wool material in a ZOI.

f. Coatings. All coatings within the Coatings ZOI are considered in this guideline to fail when subjected to DBA conditions. Guidance concerning the determination of the

Coatings ZOI is contained in Reference 3.2.2-5. Absent applicable experimental data, a coating debris size value of 100% small fines (10 μm IOZ equivalent) is adopted by this guideline for all types of coating material in the ZOI.

3.2.2.3.3.4 Material Outside the ZOI

Material outside the ZOI can be subjected to containment spray and/or be immersed in the post-DBA pool. Under these circumstances some material could become debris and become subject to transport to the sump screen. Material and components that meet equipment qualification requirements (i.e. material and components on the Environmental Qualification list) have been demonstrated not to degrade in a post-DBA environment so they will not contribute to the post-DBA debris load.

a. Covered (Jacketed) Undamaged Insulation. NUKON® blankets are EQ qualified and as such will not be damaged by the post-DBA environment outside the ZOI. The few publicly available data for reaction of jacketed fibrous insulation material to post-DBA conditions that exist were performed by the NRC. The NRC tests were performed on low density fiber (Transco blankets) and reported in NUREG/CR-6369 Volume 1. Both series of tests were conducted with pieces of blankets that had been subjected to the air jet impact tests at the AJIT facility. No intact blankets were tested. NUREG/CR-6369 concluded that partially torn insulation blankets that retained their cover were unlikely to be eroded by water flow from washdown and spray. Based on these tests and the EQ qualification of NUKON® blankets, this guideline adopts the position that covered (jacketed) undamaged insulation material outside the ZOI will not generate transportable debris (covered or jacketed insulation is any insulation that the raw material , e.g. fiberglass bats, are covered or encapsulated by another material).

b. Other material outside the ZOI.

- 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-accident 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[3] 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.

3.2.2.3.4 Calculate Quantities of Each Size Distribution

The total quantity of each size distribution for each material is the summation of the size distribution for the debris size quantity in the ZOI added to the debris size quantity outside the ZOI. To calculate the quantity of debris size for a material[4] the process is:

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[3] 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.”

[4] Plant specific information size distribution based on qualification testing should be used in lieu of the general recommendation of the NEI Guideline.

1. To obtain the quantity of small fines, multiply the volume of a material in the ZOI computed in the debris generation section by the recommended value of the small size percentage.

2. To obtain the quantity of large fines, multiply the volume of a material in the ZOI computed in the debris generation section by the recommended value of the large size percentage.

3. Recent surveys of US PWR containments per NEI 02-01 have determined that the majority of the coatings on structures, systems and components within containment can be classified into three major categories:

   A. inorganic zinc primers,

   B. epoxy primers and topcoats, and,

   C. epoxy phenolic primers and topcoats.

   Plant specific information should be used to estimate the thickness of the coatings. For those plants that do not have detailed plant specific information, the following guidance is provided. For coatings <u>within the ZOI</u>, multiply the area of the coating ZOI as determined in the debris generation section by the thickness of the coating system: 3 mils inorganic zinc primer plus 6 mils epoxy / epoxy phenolic topcoat[5] to obtain the quantity (volume) of coating debris small fines from a ZOI (Ref. 3.2.2-10). Coatings within the ZOI will be reduced, worst case, post-DBA to small (10 µm[6]), pigment-sized particles (see Table 3.2.2-3).

   To obtain the quantity (volume) of coating debris <u>outside the ZOI</u>, multiply the total area of DBA-unqualified / unacceptable and indeterminate coatings[7] in containment by the worst case of 3 mils inorganic zinc primer (Ref. 3.2.2-10).

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[5] Typical dry film thickness values for inorganic zinc primers and epoxy / epoxy phenolic primers and topcoats are taken from coating manufacturer's product data sheets (for instance, Carboline CZ 11, Carboline Phenoline 305 primer and finish, Ameron D-6, Ameron D-9, Ameron Amercoat 66) for coating products currently installed in US PWR containments.

[6] The 10 micron size is conservative (i.e. more transportable and causes higher head losses) than the larger sizes suggested in Section 3.2.1.3 and Attachment A.

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

Note that epoxy and epoxy phenolic coating failure outside the ZOI will result, in all likelihood, in debris that are relatively larger, highly cohesive, no smaller in the worst case than 25 µm. Unfortunately there are no applicable experimental data as to the size distribution of failed DBA-unqualified / unacceptable and indeterminate coatings when subjected to a post-DBA environment. As such, the assumption that an equivalent volume of inorganic zinc particulate debris (particle size 10 µm) is conservative.

3.2.2.3.5 Sample Calculation

Material in the ZOI:

Total volume of NUKON® blankets in ZOI: 300 cu ft

Quantity of small fines of NUKON® in the ZOI: 300 cu ft * 60% = 180 cu ft

Quantity of large pieces of NUKON® in the ZOI: 300 cu ft * 40% = 120 cu ft

Total area of RMI material in ZOI: 15,000 sq ft

Quantity of small fines of RMI in the ZOI: 15,000 sq ft * 75% = 11,250 sq ft

Quantity of large pieces of RMI in the ZOI: 15,000 sq ft * 25% = 3,750 sq ft

Coatings:

The baseline sample plant has not conducted a detailed containment coating walkdown. From the debris generation, the coating ZOI has a radius of 10 inches. The surface area of a 10 inch sphere is 8.7 sq ft. The total quantity of failed coatings from the ZOI can be calculated as: 8.7 sq ft * 7.5 E-4 ft[8] = 0.007 cu ft of IOZ equivalent debris.

From the plant Appendix R, the total quantity of coatings in containment is 190,000 sq ft. From the plant construction records a total of 160,000 sq ft can be shown to be DBA qualified. Hence

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[8] 9 mills = 7.5 E-04 ft

the total quantity of DBA-unqualified / unacceptable and indeterminate coatings is estimated to be 30,000 sq ft. The total quantity of small fines coating from outside ZOI: (30,000 sq ft of total quantity of unqualified and undetermined coating in containment less the 0 sq ft of unqualified and undetermined coating on piping that is covered by undamaged insulation.) * 2.5E-4 ft[9]= 7.5 cu ft of IOZ equivalent debris.

3.2.2.3.6 Debris Characteristics for Use in Debris Transport and Head Loss

The debris characteristics for the Small Fines size adopted by this guideline are those in the following tables labeled as characteristic size. The next sections describe the characteristics of common fibrous, coatings and particulate debris.

The characteristic sizes listed are the most conservative values that can be associated with debris transport and head loss since they are the size that will have the highest transport factor and cause the highest head loss. Other small debris characteristic sizes can be adopted in lieu of those listed for materials that have applicable transport and head loss experimentally determined characteristic sizes. Plant-specific data can supersede these where necessary and appropriate.

3.2.2.3.6.1 Mass Insulation

This class of insulation includes low-density fiberglass (~2.4 lbm/ft^3), medium-density fiberglass, and preformed fiberglass, as well as fiber felt materials. It also includes microporous insulation such as MinK and Microtherm, as well as Calcium Silicate insulation.

There are three principal types of mass insulation in PWR containments:

- Fibrous Insulation (including Asbestos)
- Granular Insulation (Calcium Silicate & Microporous)
- Cellular Insulation

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[9] 3 mills = 2.5 E-04 ft

The characteristic densities and sizes for thermal insulation materials that have been identified as potential debris in nuclear containments are listed in Table 3.2.2-2. Some are listed by trade names and some by generic names, whereas others are listed as a system and still others as simply an insulation material. For materials not listed the manufacturer should be contacted to obtain the type of information listed in Table 3.2.2.-2.

Fibrous insulation materials include fibrous glass wool such as Performance Contracting's NUKON®, Transco Products' Thermal Wrap®, pre-formed fiberglass pipe (made by Owens-Corning, Knaupf, and Johns-Manville), and fiberglass pipe and tank wrap (from the same three manufacturers).

The NRC refers to the insulation fillers in NUKON®, Thermal Wrap®, and Knaupf-ET as "Low Density Fiber Glass" (LDFG). The LDFG materials are soft, loose and contain minimal binders. There is extensive test data for LDFG. There are also some glass fiber felt mat insulation materials and these include Temp-Mat® and Insulbatte® insulations, both made by JPS Corp., as well as some by other trade names such as AlphaMat® by Alpha Inc. Again, these are relatively soft and loose. Other fibrous materials include ceramic felt mat insulation, two of which are Kaowool® and Cerawool®, both by Thermal Ceramics, Inc.

Finally, there are mineral wool insulation products with a number of different trade names, forms, and densities. Major North American manufacturers are Rock Wool Manufacturing, Roxul, Fibrex, IIG, and Thermafiber. These materials have higher densities and are generally stiffer, having more binder and particulate. While mineral wool has been widely used in Europe, mineral wool has limited use in North American nuclear containments. Mineral wool was the original drywell piping insulation at the Barseback Plant that was blown off by a lifted steam relief valve and which subsequently blocked a couple of ECCS strainers. In general, mineral wool is available in densities that are at least twice those of comparable fibrous glass wool insulations, up to ~10 pcf.

Asbestos insulation may be encountered at some plants. It is typically used as a structural fiber in calcium silicate insulation and sold under the trade name Unibestos.

Granular insulation materials include calcium silicate and microporous insulation. All the calcium silicate insulation in North America has been manufactured without the use of asbestos since about 1972. Produced by various manufacturers over the years, today all calcium silicate is manufactured by IIG, a joint venture between Calsilite Corp. and Johns-Manville Corp., at three factories. The only microporous insulation manufactured in North America is MinK®, manufactured by Thermal Ceramics, Inc. today but by Johns-Manville for many years. Microtherm®, manufactured in the UK, is also available in North America.

The only cellular insulation in Table 3.2.2-2 is cellular glass. Most of what has been installed in US nuclear plants has been manufactured by Pittsburgh Corning Corporation and is known by its trade name, Foamglas®. This is an inorganic, rigid, and brittle cellular insulation typically used in containments on chilled water lines. However, for reference, there are numerous other types of cellular insulations available which are organic compounds. These include melamine, polystyrene, polyisocyanurate, phenolic, polyimide, polyolefin, flexible elastomeric, and polyurethane foams. There are numerous trade names by which these are known. The best known is Dow Chemical’s Styrofoam, which is polystyrene foam insulation.

3.2.2.3.6.2 Failed Coatings

To properly characterize coatings debris for the head loss evaluation, the type, mass, application thickness, particle sizes, and surface area or volume are necessary inputs, and these should be specified to the extent practicable in the debris generation and debris transport calculations. The quantity of a failed coating is adequately specified by the mass of the coating and its density. Alternatively, the surface area of the failed coating, along with its thickness and the density can be used to determine the mass.

Unless replaced by plant-specific information of higher value, Table 3.2.2-3 lists the bulk density and the characteristic size and shape for various types of coatings debris, and these can be used for the evaluation. The actual size distributions of these materials in a post-DBA environment are not known. Thus, the table lists particle sizes that are conservative (i.e. small) for head loss evaluations. Plant-specific data, if available, can supersede these data.

The following types of coatings are commonly found within PWR containments: Inorganic Zinc (IOZ), Epoxy, Epoxy-Phenolic and Alkyd. The densities for the epoxy, epoxy-phenolic and alkyd coatings listed in Table 3.2.2-3 are based on specific gravities presented in the "Performance of Containment Coatings During a Loss of Coolant Accident." (Ref. 3.2.2-11). The density for IOZ is 437 lbm/ft^3 as reported by Carboline for the zinc dust used in the formulation of CarboZinc-11 (Ref. 3.2.2-12).

This guidance assumes complete destruction of coatings within the coating ZOI. In the absence of specific experimental data about the debris particle size distribution for IOZ, alkyds, epoxy and epoxy-phenolic coating debris generated by high pressure water/steam jets in the ZOI, a diameter of 10 μm is assumed as the characteristic size of coating debris generated within the ZOI. The 10 μm characteristic diameter is the nominal diameter of unbound zinc particles and also the alkyd pigment particles of failed coatings. Coatings outside the ZOI that have not been demonstrated to be DBA-qualified or "acceptable," or whose qualification is "indeterminate," are assumed to fail as chips. A typical lower bound for epoxy and epoxy-phenolic coating chip thickness is 1-mil (25.4 μm). A ten-micron (10 μm) diameter is assumed as the characteristic size of debris from IOZ and alkyd coatings outside the ZOI that have not been demonstrated to be DBA-qualified or "acceptable," or whose qualification is "indeterminate."

Table 3.2.2.-2: Mass Insulation Material Debris Characteristics[10]

Debris Name	Insulation Material Description	As-Fabricated Density (lbs/ft^3)	Material Density (lbm/ft^3)	Characteristic Size[11]	
				µm	inch
PCI's NUKON® Blankets	Removable / reusable blankets with woven glass fiber cloth covering fibrous glass insulating board (referred to by the NRC as a "LDFG")	2.4[3.2.2-15, 3.2.2-19]	159[3.2.2-19]	7.0 fiber diameter	28E-05[3.2.2-15,3.2.2-19]
Fiberglass – preformed pipe	Knaupf fibrous glass wool preformed into cylindrical shapes	4.0 +/- 10%[3.2.2-14] or	159[3.2.2-14]	7.5 fiber diameter	30E-05[3.2.2-14]
Fiberglass – preformed pipe	Owens-Corning fibrous glass wool preformed into cylindrical shapes	3.5 to 5.5[3.2.2-19]	159[3.2.2-19]	8.25 fiber diameter	33E-03[3.2.2-19]
Fiberglass – pipe and tank wrap	Fibrous glass wool wrap, using perpendicularly oriented fibers, adhered to an All Service Jacketing (ASJ) facing (made by Knaupf, Owens-Corning, & others)	3.0 +/- 10%	159[3.2.2-14]	6.75 fiber diameter	27E-05[3.2.2-14]
Transco's Thermal Wrap® Blankets	Removable / reusable blankets with woven glass fiber cloth covering fibrous glass insulation)	2.4[3.2.2-14, 3.2.2-25]	159[3.2.2-14]	5.5 fiber diameter	22E-05[3.2.2-14]
Knaupf	Knaupf ET Panel (LDFG similar to Nukon)	2.4	159	5.5 fiber diameter	22E-05
Temp-Mat® and Insulbatte®	Glass fibers needled into a felt mat; these are trade names of insulation products made by JPS Corp.	11.8[3.2.2-16]	162[3.2.2-16, 3.2.2-17]	9.0 fiber diameter	36E-05 max. average[3.2.2-24]
Cellular Glass	Foamglas® is the trade name for this cellular glass product made by Pittsburgh Corning Corporation	6.1 to 9.8 (mean value of 7.5)[3.2.2-26]	156[3.2.2-26]	NA	0.05 to 0.08 pore size[3.2.2-26]; grain size unknown
Kaowool®	Needled insulation mat made from ceramic fibers; Kaowool is a trade name for a family of ceramic fiber products made by Thermal Ceramics, Inc.	3 to 12[3.2.2-18]	160 to 161[3.2.2-27]	2.7 to 3.0 fiber diameter	10.8 to 12.0 E-05
Cerawool®	Needled insulation mat made from ceramic fibers; Cerawool is a trade name for a family of ceramic fiber products made by Thermal Ceramics, Inc.	3 to 12[3.2.2-18]	156 to 158[3.2.2-27]	3.2 to 3.5[3.2.2-27] fiber diameter	12.8 to 14.0E-05
Mineral Wool	Generic name for families of products made by Rock Wool Mfg., Roxul, Fibrex, IIG, and others	4, 6, 8, 10[3.2.2-20] pcf are standard	90[3.2.2-20]	5 to 7[3.2.2-20] fiber diameter	20 to 28 E-05
K®	Trade name of microporous insulation products made by Thermal Ceramics, Inc. from fumed silica, glass fibers, and quartz fibers	8 to 16 pcf[3.2.2-28]	NA	< 0.1[3.2.2-29]	< 4E-06
Calcium Silicate	Manufactured by IIG in three locations (2 use diatomaceous earth, 1 uses expanded perlite)	14.5[3.2.2-21]	144[3.2.2-22]	5 µm mean particle size (2 to 100 µm range)[3.2.2-22]	20E-05
Microtherm	Microporous Insulation	5 to 12 pcf [3.2.2-23]	NA	<0.2	<4.0E-06
Asbestos	Structural fiber used in Cal-Sil type ins.	7 to 10	153	1 to 8	4 to 32E-05

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[10] For materials not listed the manufacturer should be contacted to obtain the type of information listed in Table 3.3.6-1.

[11] The sizes listed are to be used in the NUREG/CR-6224 head loss correlation as an initial value absent applicable experimental data.

Table 3.2.2-3: Coating Debris Characteristics

Generic Coating Material	Material Density (lbs/ft^3)	Characteristic Size (µm)	Characteristic Size (Ft)
Inorganic Zinc (IOZ)	457	10$^{(1)}$	3.28E-05$^{(1)}$
Epoxy and Epoxy Phenolic Coating Chip (outside ZOI)	94	25$^{(2)}$	8.20E-05$^{(2)}$
Epoxy and Epoxy Phenolic Coating Particles (in ZOI)	94	10$^{(1)}$	3.28E-05$^{(1)}$
Alkyd Coating	98	10$^{(1)}$	3.28E-05$^{(1)}$
Aluminum	90	10$^{(2)}$	3.28E-05$^{(2)}$

Note 1: Spherical Particle Diameter

Note 2: Flat Plate Thickness

3.2.2.4 References

3.2.2-1 ANSI/ANS 58.2-1988, “American National Standard Design Basis for Protection of Light Water Nuclear Power Plants Against the Effects of Postulated Pipe Rupture,” 1988

3.2.2-2 NEDO-32686, “Utility Resolution Guidance for ECCS Suction Strainer Blockage,” Revision 0, Boiling Water Reactor Owner’s Group, November 1996

3.2.2-3 Calculation Note CN-CRA-04-12, “Jet Expansion Calculation Using ANSI/ANS 58.2-1988, Performed in Support of GSI-191 Methodology Development,” Westinghouse Electric Co, LLC, April 2004 (Proprietary)

3.2.2-4 NEI-02-01, “Condition Assessment Guidelines: Debris Sources Inside PWR Containments,” Revision 1, September 2002

3.2.2-5 White Paper, “Defining the Zone of Influence (ZOI) and Minimum Coating Debris Size for DBA-Qualified and Acceptable Coatings in Pressurized Water Reactor (PWR) Containments,” J. R. Cavallo, April 2, 2004, included as Attachment A.

3.2.2-6 NUREG/CR-6808, “Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance,” US Nuclear Regulatory Commission, February 2003

3.2.2-7 N-REP-34320-10000-R00, “Jet Impact Tests – Preliminary Results and Their Applications,” Ontario Power Generation, April 2001

3.2.2-8 D.V. Rao et al, NUREG/CR-6369, Vol 1: Drywall Debris Transport Study-Final Report; Vol 2: Drywell Debrsi Transport Study: Experimental Work-Final Report, February 1998

3.2.2-9 G. Zigler et al, NUREG/CR-6224; Parametric Study of the Potential for BWR ECCS Strainer Blockage due to LOCA Generated Debris, September 1995

3.2.2-10 E-Mail, John Cavallo to Gil Zigler, March 16, 2004

3.2.2-11 Aldinger, T.I., White, R.A., and Manley, R.A., Performance of Containment Coatings During a Loss of Coolant Accident, Bechtel Power Corporation, November 10, 1994

(In Volume III of the Utility Resolution Guidance (URG) for ECCS Suction Strainer Blockage, BWROG, November 1996)

3.2.2-12 E-mail, Jon Cavallo to Gilbert Zigler, Subject: Specific Gravity of Metallic Dust Used in Inorganic Zinc Coatings, October 23, 2002.

3.2.2-13 Thermal Insulation Handbook, by William C. Turner and John F. Malloy, Robert E. Krieger Publishing Company, Inc., 1981

3.2.2-14 Phone conversation with Scott Miller, Knaupf Fiberglass on July 7, 2003

3.2.2-15 Telephone conversation with Gregg Hunter, Performance Contracting, Inc., July 9, 2003

3.2.2-16 Product literature provided by JPS Glass Fabrics on Insulbatte® and Tempmat@ insulation products (www.jpsglass.com)

3.2.2-17 Phone conversation with Joan Kirby, JPS Glass Fabrics on July 7, 2003

3.2.2-18 Product literature provided by Thermal Ceramics, Inc. on Kaowool Blanket Products (www.thermalceramics.com)

3.2.2-19 E-mail from Chris Crall, Owens Corning Corporation, July 7, 2003

3.2.2-20 Telephone conversation with Chris Bullock, Rock Wool Manufacturing, July 7, 2003

3.2.2-21 Telephone conversation with Jeremy Haslam of IIG, Inc., July 7, 2003

3.2.2-22 Certificate of Analysis from Tech-Flo, supplier of Perlite Filteraids, provided by IIG, Inc.

3.2.2-23 Product literature provided by Microtherm, Ltd. (http://www.microtherm.uk.com)

3.2.2-24 Military Specification MIL-I-16411F, Section 3.3

3.2.2-25 Telephone conversation with Mike Sollie, Transco Products, Inc., July 9, 2003

3.2.2-26 Telephone conversation with Tim Bovard, Pittsburgh Corning Corp., July 10, 2003

3.2.2-27 E-mail from Garrick Ackart, Thermal Ceramics, Inc., July 10, 2003

3.2.2-28 Telephone conversation with Frank Duchon, Thermal Ceramics, Inc., July 10, 2003

3.2.2-29 Microporous Theory, Technical Notes on MinK, Document Number TN01301, provided by Thermal Ceramics, Inc

3.2.3 LATENT DEBRIS

3.2.3.1 Definition

Latent debris is defined as dirt, dust, paint chips, fibers, pieces of paper (shredded or intact), plastic, tape, or adhesive labels, and fines or shards of thermal insulation, fireproof barrier, or other materials that are present in the containment prior to a postulated break in a high-energy line inside containment. Dust and dirt includes miscellaneous particulates that are present in the containment. Potential origins for this material include activities performed during outages and foreign particulates brought into containment during outages.

3.2.3.2 Discussion

The potential for latent debris in containment during plant operation which may impact head loss across the Emergency Core Cooling sump screens should be considered. Therefore, it is necessary to determine the types, quantities, and locations of latent debris sources.

Due to the variations in containment design and size from unit to unit, many miscellaneous sources should be evaluated on a plant-specific basis. It is not appropriate for the licensees to say that their Foreign Materials Exclusion (FME) programs can entirely eliminate sources of miscellaneous debris unless plant-specific walkdowns verify this. Plant-specific walkdown results can be used to determine a conservative amount of dust and dirt to be included in the debris source term. The walkdown will not be able to directly measure this type of debris. However, it is possible to quantify the amount of debris with additional steps.

It is recommended that the following activities are performed to quantify the amount of latent debris inside containment:

- Calculate the horizontal and vertical surface areas inside containment. 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 below.

3.2.3.3 Baseline Approach

Latent debris is a contributor to head loss across the sump screen and should be evaluated accordingly. Information is provided in the guidance below to evaluate the quantity of latent debris with sufficient rigor to eliminate excessive conservatism. Note, however, that in many cases the contribution to head loss by latent debris will be small in comparison to that caused by debris from other sources such as insulation materials. In these cases, latent debris will not determine the course of action for mitigating ECCS sump strainer issues.

The impact on the results of the sump performance evaluation as a whole should be considered before performing an extremely rigorous analysis of latent debris loading. While it is possible to evaluate the effects of latent debris to a high degree of detail, use of conservative strategies is recommended. Furthermore, the use of conservative strategies in the evaluation of latent debris effects can provide for more head loss analysis margin and can improve operational flexibility if sump modifications are made.

3.2.3.3.1 Calculate horizontal and vertical surface area inside containment.

Horizontal and vertical surfaces are considered in this calculation. Vertical surfaces such as walls and sides of equipment are considered although a significant amount of debris does not typically collect on vertical surfaces in the absence of things that promote adhesion of solids to the surface.

The following surfaces are included in the calculations:

- Floor area
- Walls
- Cable trays
- Equipment (such as valve operators, air handlers, etc.)
- Other surfaces, as appropriate (junction boxes, etc.).

Use the following guidance in the calculations:

1. Flat surfaces are considered to be floors, cable trays, AOV diaphragms, and other flat or nearly-flat surfaces. The bases for this are:
    - Unless the surface is highly convoluted (e.g., a heat exchanger or similar device), assuming a flat surface will not have a significant effect on the surface area calculation. Furthermore, the area projected onto the horizontal plane by the surface would be the key determining factor for the settling and accumulation of debris. For example, while a series of heat exchanger fins may have a large surface area, a significant percentage of that area could be vertical which would preclude accumulation of debris on much of the surface area.
    - The surface area calculations are greatly simplified if the intricacies of surfaces are not explicitly accounted for.
2. Half of the surface area of round surfaces such as conduits and ladder rungs is used. The basis for this assumption is that the lower half of the surface area is either inverted or tangent to the vertical plane, so accumulation of debris in this area does not occur. In reality it is likely that the percentage of surface area susceptible to debris accumulation is less than half, because it is unlikely that debris would remain on the regions of the surface that are nearly vertical.

3. Ten percent of the vertical surfaces inside containment is used. The basis for this assumption is that accumulation of debris on vertical surfaces will typically not occur, but is considered for conservatism. Although walls are considered, the containment dome itself is not considered. Debris accumulation on this surface is precluded because it is inverted or tangent to the vertical plane.
4. Perform thorough calculations to determine the surface area to be considered for each area of containment. The information needed to perform the calculations can be obtained through plant drawings (plans) and photographic evidence obtained during containment walkdowns.
5. If exact dimensions are unavailable, use estimated dimensions. Acceptable sources of estimated dimensions are plant drawings (plans) that do not include explicit dimensions for the component in question (i.e., a representation of the component is shown but not detailed) and photographic evidence. Conservatively large values shall be used when dimensions are estimated and bases for the values used shall be provided.

3.2.3.3.2 Evaluate resident debris buildup.

Although recent sampling of surfaces inside containment at a number of plants indicated that it is likely that the maximum mass of latent debris inside containment is less than 200 pounds, it is recommended that a survey of containment is performed, with the objective of determining the quantity of latent debris.

Surveying the containment for latent debris will ensure that higher-than-average debris loads are accounted for and will allow plants to take advantage of smaller latent debris loading if lower quantities are present.

Note that it will be necessary to perform periodic surveys (as part of outage efforts) to validate that there has been no significant change in the latent debris load inside containment. This evaluation of the presence of foreign material is described in NEI-02-01 (Reference 3.2.3-3). The necessary rigor of these surveys is dependent on the effectiveness of the licensee’s FME and housekeeping programs with respect to containment cleanliness. If the licensee has rigorous programs in place to control the cleanliness of containment and documents the condition of containment following an outage, it is adequate to perform inspections and limited sampling of surfaces. If the cleanliness of containment is not controlled through rigorous programs, or if the programs in place do not address all areas of containment, it is necessary to perform more comprehensive surveys.

3.2.3.3.2.1 Evaluate the resident debris buildup on surfaces.

To quantify the amount of latent debris on horizontal surfaces in containment, determine the thickness of the debris layer on a surface and the surface area the layer covers. This information can be used with the macroscopic debris density (with respect to volume) to determine the mass of debris present.

Use the following steps to evaluate the resident debris buildup on horizontal surfaces:

1. Divide containment into areas based on the presence of robust barriers. This will allow differing (from section to section) latent debris concentrations and compositions to be adequately represented and will facilitate subsequent debris transport calculations. Examples of appropriate areas include:
   - Accumulator rooms
   - In-core instrumentation room
   - Loop subcompartments
   - Steam generator or pressurizer subcompartments
2. Determine representative surfaces for each section of containment. For each section this involves defining survey areas of known dimensions. The number of sampling areas examined per section of containment must be determined on a plant-specific basis. Use the following guidance to select representative surfaces:
   - If the worst surface in a given section can be readily identified, it is acceptable to use that surface to represent the entire section. For example, if little or no debris is

present on the surfaces in a section except for one, that one surface can be used to represent the debris accumulation in the entire section.

- If multiple surfaces have debris accumulation with different compositions and thicknesses, it is necessary to sample each of the surfaces to adequately represent the latent debris load for that section.
- If the area has a uniform and homogeneous latent debris load, a convenient surface can be chosen as the representative surface.

3. Survey the representative surfaces in each section to measure the debris quantity. Take care to ensure all health physics procedures are followed for any samples collected. Two strategies are recommended.

   - Collect the debris using equipment that will allow measurement of the quantity of debris at a later time. The volume of debris collected is then divided by the surface area to determine the thickness of the debris layer.

     The collection method should allow estimation of the debris layer thickness and not change the macroscopic density of the debris that is collected. An acceptable method for collection is the use of swipes to remove the debris from the area in question. Since there is the potential to damage samples during the collection process, take care to not destroy or otherwise change the physical properties of the debris.

   - Measure or estimate the thickness of the debris layer directly. Since it is unlikely that a measurement device (such as calipers) can determine the layer thickness directly, it is recommended that the layer thickness be determined by comparison to an object of known or measurable thickness. Since the debris layers are expected to be quite thin (mils or fractions of mils), comparison to objects like sheets of paper or very thin sheets of metal is recommended.

     While it is possible to determine the thickness of the debris layer to an acceptable degree of accuracy, it may be difficult to accomplish, even if the debris layer is of uniform thickness and homogeneous composition. Therefore, care should be taken in the measuring process to achieve the most accurate results possible.

4. Calculate the thickness of the debris layer, based on the quantity of debris collected and the surface area of the sampling area.

3.2.3.3.2.2 Evaluate the quantity of other miscellaneous debris.

In addition to determining the amount of latent debris accumulation on surfaces, other miscellaneous debris sources are to be accounted for in the debris source term. The survey of containment for these materials is to be performed consistent with the guidance in NEI 02-01 (Reference 3.2.3-3). Use the following guidance for each source to be considered:

- Equipment tags: Determine the number and location of equipment tags of each material type (paper, plastic, metal) within containment. Evaluate the transport of tags to the sump screen when performing the Debris Transport analysis (Section 3.2.4). Although paper tags may dissolve in the post-accident containment environment, it is conservative to assume that they remain intact and available for transport to the sump screen. This assumption shall be used unless there is information that indicates the tags will not remain intact.
- Tape: Determine the amount and location of each type of tape within containment. Evaluate the transport of tape to the sump screen when performing the Debris Transport analysis (Section 3.2.4). Although FME and housekeeping programs will remove most of the tape used during outage and construction activities, there may still be quantities present in containment. These pieces of tape could be in inaccessible areas or attached to components in plain view. Pieces of tape that have partially disintegrated from being in containment during plant operation should be considered in the latent debris source term. Additionally, tape affixed to surfaces such as ladder rungs in order to improve grip shall be assumed to fail and become transportable debris.
- Stickers or placards affixed by adhesives: Include items such as stickers and signs that are not mechanically attached to a structure or component in the latent debris source term. Evaluate the transport of these materials to the sump screen when performing the Debris Transport analysis (Section 3.2.4). It is likely that adhesives would fail in post-accident

conditions. Assume that all stickers and placards affixed by adhesives fail and become transportable debris.

3.2.3.3.3 Define debris characteristics.

Debris characteristics can be defined using two methods:

- Analyze debris samples to determine composition and physical properties.
- Assume composition and physical properties of the debris, using conservative values.

Because of the additional rigor and complexity as well as the additional time required to perform detailed analysis of the samples, it is recommended that conservative characteristics (with respect to head loss, as documented in Section 3.2.5) are assumed for the latent debris. The following debris characteristics should be used:

- Use a fiber/particulate mix that will cause the thin-bed effect to occur.

  Use the guidance for calculation of head loss to evaluate the required fiber quantity for the thin bed effect to occur. Assign the fiber/particulate mix such that just enough fiber is available to cause thin-bed formation, and classify the remaining debris as particulates. This approach is conservative with respect to head loss and provides potential for the thin bed effect to occur, even if no fibrous insulation is present in containment.

- Fiber Density = 62.4 lbm/ft^3

  The basis for this value is that it effectively makes the fiber neutrally buoyant, which results in maximum transport to the sump screen.

- Particle Density = 100 lbm/ft^3

  The basis for this value is that most particulate material can be categorized as “dirt”. A representative material would likely be soil or sand, brought into containment during outage activities or construction. According to Reference 3.2.3-1, the densities of “Earth” and “Sand” are both 95 lbm/ft^3. Therefore, 100 lbm/ft^3 is recommended.

- Particle Diameter = 10 µm

Based on typical diameter of dust particles [Reference 3.2.3-2], a diameter of 10 μm is suggested. This diameter is conservatively small with respect to transport to the sump screen, since the diameter of “dirt” particles such as earth or sand is larger than that of dust. Furthermore, the diameter of 10 μm is consistent with the size of particles of failed coatings (Reference 3.2.3-4).

Note that ongoing research efforts by NRC and Los Alamos National Labs may provide additional information regarding the physical characteristics of latent debris.

If it is decided to analyze the debris samples to determine the composition and physical properties, the work should be performed by a laboratory experienced in material identification, analysis of the macroscopic and microscopic properties of material samples, and handling of radioactive materials. Note that there are challenges to effectively determining the debris characteristics by analysis:

- It is likely that thorough analysis of samples would be extremely expensive, possibly with little benefit.
- It is potentially impractical or impossible to separate the debris from the media or device used to capture it.
- It is possible that the macroscopic density of the debris as well as other characteristics will be changed during the sampling process or transportation to the analysis facility. These changes in characteristics would result because it is likely that the debris is not a homogenous solid; therefore it is possible for the debris to be compacted, damaged, or otherwise manipulated.

3.2.3.3.4 Determine fraction of surface area susceptible to debris accumulation.

Not all areas are susceptible to accumulation of debris. For example, housekeeping activities at some plants may involve cleaning floors with special wipes, vacuum cleaners, or other methods. In these cases, the areas that are within the scope of the cleaning program could have essentially no debris accumulation, whereas inaccessible areas of the same surface could have an accumulation of debris. A single debris layer thickness would not accurately represent the entire surface.

It is appropriate to conservatively assume that the entire surface area is susceptible to debris accumulation. If it is unreasonable to use this assumption, in addition to determining the total horizontal surface area inside containment (per Section 3.2.3.3.1) it is necessary to determine the fraction of the surface area of each component and surface that is susceptible to debris accumulation. To accomplish this, evaluate the fraction of the surface area susceptible to debris accumulation a component-by-component or surface-by-surface basis using the results from Sections 3.2.3.3.1 and 3.2.3.3.2 as input. Use the following guidance:

1. Assume 100% of the surface area is susceptible to debris accumulation for inaccessible areas as well as accessible areas that are not thoroughly cleaned and documented as clean per plant procedures prior to restart (e.g., cable trays, junction boxes, and valve operators), and floors with gratings sitting on flat surfaces.
2. Evaluate the fractional area susceptible to debris accumulation for smooth floor areas and other surfaces cleaned per plant procedures prior to restart on a case-by-case basis. Considerations include the method of cleaning (e.g. pressure washing vs. vacuuming) and accessibility of areas. Because of wide variations in containment design and effectiveness of housekeeping and FME programs, evaluations must be performed on a plant-specific basis.

   For all cases in which the area susceptible to debris accumulation is reduced, a conservatively large fractional area susceptible to accumulation must be determined, and bases must be provided for the fractions used. Use the following guidance:

   - Calculate the total surface area of the surface being considered.
   - Calculate the area of the surface that is clean. Use simplifying assumptions that will result in a conservatively small clean area.
   - Calculate the ratio of potentially dirty area to the total area.

3.2.3.3.5 Calculate total quantity and composition of debris.

The final step in determining the quantity of latent debris located inside containment is to compute the total quantity of latent debris using the results from Sections 3.2.3.3.1, 3.2.3.3.2, and 3.2.3.3.3 as input.

Use the following guidance when performing the final calculations:

1. The calculations should be performed on an area-by-area basis (consistent with Sections 3.2.3.3.1, 3.2.3.3.2, and 3.2.3.3.3). Performing the calculations in this way will facilitate adequate representation of the debris densities and characteristics in the different areas inside containment.
2. Compute the total quantity of debris for each area by multiplying the total surface area susceptible to debris accumulation by the debris layer thickness for the area of containment being considered.
3. Include quantities of other types of latent debris such as tape, equipment tags, and stickers.
4. Categorize and catalog the results for input to the debris transport analysis.

3.2.3.4 Sample Calculation

The sample calculation considers the bottom level of containment. Equipment tags, tape, and stickers have been excluded from this example since minimal calculations are required for these items and guidance is included in Reference 3.2.3-3. The following surfaces are included in the calculation:

- Floor areas
- Cable trays
- Sump drain pumps

For an actual calculation, more detail and rigor are required to document all the surface area on a given level of containment. Since this is a sample calculation, only representative examples were used.

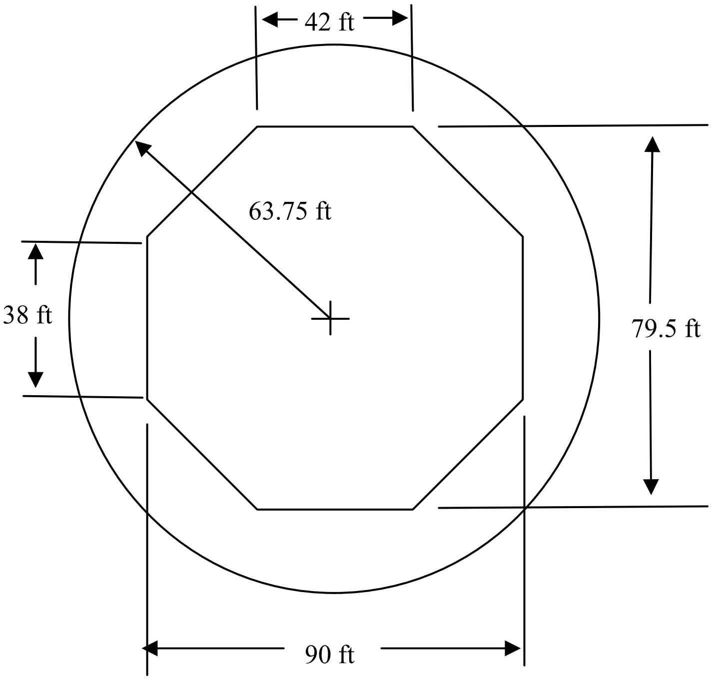
Section 3.2.3.4.1 documents the calculation of the horizontal areas for complex rooms and cable trays. Section 3.2.3.4.2 documents the calculation of the amount of debris present in the area being considered.

3.2.3.4.1 Calculate horizontal surface area

The examples below show the calculation of a number of complex floor areas. Rooms of simpler geometry are calculated with less effort and therefore examples of those calculations have not been shown.

1. Calculate area between containment shell and Steam Generator (SG) compartments

   The floor area between the containment shell and SG compartments roughly looks like the region between the octagon and circle in the figure below:



   Therefore the area of the octagon is calculated as:

   $A = (90 \text{ ft}) (75 \text{ ft}) – (4) (0.5) [(0.5) (79.5\text{-}38)]*[(0.5) (90\text{-}42)]$

   $A = 5754 \text{ ft}^2$

Subtract area of octagonal region from round region:

$A = \pi\,(63.75\text{ ft})^2 - 5754\text{ ft}^2$

$A = 7014\text{ ft}^2$

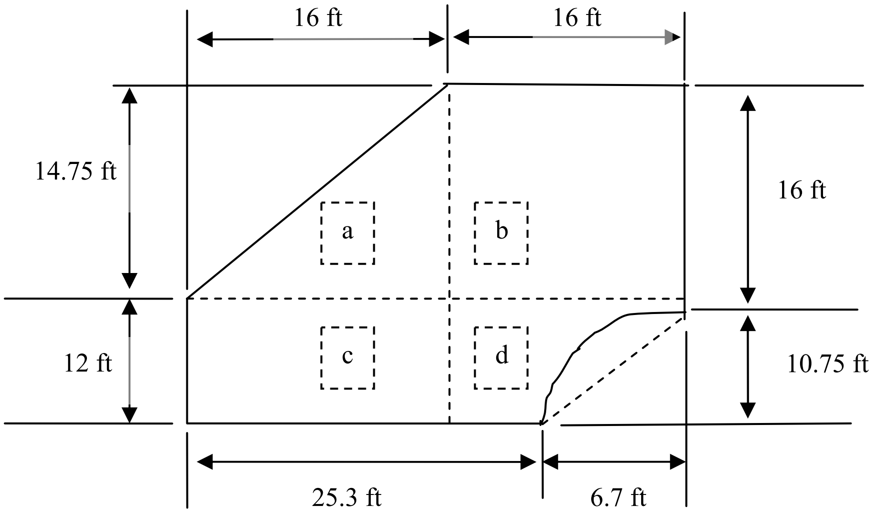
Subtract area of the Reactor Coolant Drain Tank (RCDT) room and Excess Letdown Heat Exchanger room (these areas protrude from the rough octagonal shape):

$A = 7014\text{ ft}^2 - 56\text{ ft}^2 - 94.6\text{ ft}^2$

$A = 6914\text{ ft}^2$

2. Calculate area inside SG compartments

Each SG compartment has a shape and dimensions roughly like the shape with the solid border below. To simplify the calculations, the room was divided into four regions and the round wall was assumed to be straight:



$A = a + b + c + d$

$a = 0.5(16\text{ ft})\,(14.75\text{ ft}) = 118\text{ ft}^2$

$b = (16\text{ ft})\,(14.75\text{ ft}) = 236\text{ ft}^2$

$c = (12\text{ ft})\,(16\text{ ft}) = 192\text{ ft}^2$

$d = (16\text{ ft})\,(12\text{ ft}) - (0.5)\,(10.75\text{ ft})\,(6.7\text{ft}) = 156\text{ ft}^2$

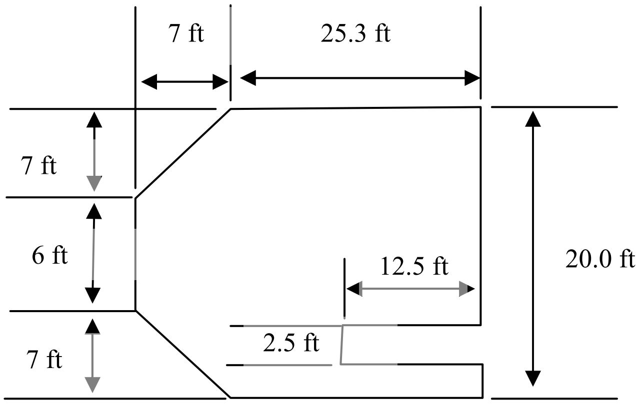
$A = 466\text{ ft}^2$

A_{total} = 4(A) (since there are 4 steam generators)

= 1864 ft^2

3. Calculate area inside seal table room

The geometry of the seal table room is as shown in the figure below. One simplifying assumption was with regard to the six foot long wall. It is actually curved and protrudes into the room, but was assumed to be straight. This assumption results in prediction of a conservatively large floor area.



A = (32.3 ft) (20 ft) – (2) (0.5) (7.0 ft) (7.0 ft) – (2.5 ft) (12.5 ft)

A = 563.8 ft^2

4. Calculate area of cable trays and other components.

For this sample calculation, 300 linear feet of cable trays was assumed. It was also assumed that the trays were 1 foot wide, resulting in a total surface area of 300 ft^2. For all cable trays, the length and width should be documented and used to calculate the horizontal surface area.

The other example of component surface area in this sample calculation is the rectangular cover on the sump drain pumps, as shown in the spreadsheet below. It is noteworthy that the covers over the sump were documented as part of the floor area, since there is no floor area considered below them.

Other components were not examined in detail for this sample calculation. Components that should be examined include, but are not limited to:

- RCS piping and other piping
- Pressurizer relief tank
- Excess letdown heat exchanger (depending on location)
- Air handling units
- RCS draindown tank and associated heat exchanger
- Junction boxes

3.2.3.4.2 Calculate quantity of debris

This section documents sample calculations of the quantity of debris in the area considered. The calculations are relatively straightforward. To calculate the mass of debris in a given area:

Volume = (Debris Layer Thickness) * (Surface Area)

Mass = (Volume) * (Density)

Example results are presented in Table 3.2.3-1. It is noteworthy that the results are for demonstration only and are based on hypothetical debris survey results.

3.2.3.5 References

3.2.3-1 "ASHRAE Handbook of Fundamentals," American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1972

3.2.3-2 Strok & Koral, "Handbook of Air-Conditioning, Heating, and Ventilation," Second Edition, Industrial Press, 1965

3.2.3-3 NEI-02-01, "Condition Assessment Guidelines: Debris Sources Inside PWR Containments," Revision 1, September 2002

3.2.3-4 Bostelman, Jan and Zigler, Gilbert, "Failed Coatings Debris Characterization," BWRG Containment Coatings Committee, July 10, 1998

Table 3.2.3-1: Sample Calculation of Debris Quantity

								Fiber			Particulates		
Description	Length ft	Width ft	Surface Area ft^2	Layer Thickness in	Percent Clean %	Debris Volume ft^3	Fiber by Volume %	Volume ft^3	Density lb/ft^3	Mass lb	Volume ft^3	Density lb/ft^3	Mass lb
Floor Areas													
1 Area between SG rooms and cont. shell			6914.0	1.00E-03	25.0	0.43	50.0	0.22	62.40	13.48	0.22	100.00	21.61
2 SG rooms (4 rooms)			1864.0	1.00E-03	25.0	0.12	50.0	0.06	62.40	3.63	0.06	100.00	5.83
3 RCDT room	24.00	8.00	192.0	1.00E-03	0.0	0.02	50.0	0.01	62.40	0.50	0.01	100.00	0.80
4 RCDT HX room	20.00	6.75	135.0	1.00E-03	0.0	0.01	50.0	0.01	62.40	0.35	0.01	100.00	0.56
5 RCDT HX room anteroom	13.30	11.25	149.6	1.00E-03	0.0	0.01	50.0	0.01	62.40	0.39	0.01	100.00	0.62
6 Excess letdown HX rm	22.25	4.25	94.6	1.00E-03	0.0	0.01	50.0	0.00	62.40	0.25	0.00	100.00	0.39
7 Seal table room			563.8	1.00E-03	0.0	0.05	50.0	0.02	62.40	1.47	0.02	100.00	2.35
Equipment													
1 Sump drain pump cover	6.00	4.00	24.0	1.00E-03	0.0	0.00	50.0	0.00	62.40	0.06	0.00	100.00	0.10
2 Cable trays	300.00	1.00	300.0	1.00E-03	0.0	0.03	50.0	0.01	62.40	0.78	0.01	100.00	1.25
Totals						0.67		0.34		20.91	0.34		33.51

Notes:
Sump top plate surface area included in Floor Area #1
Calculations for floor areas #1, 2, 7 documented separately
Debris layer thicknesses are hypothetical, not based on actual survey data.

3.2.4 DEBRIS TRANSPORT

3.2.4.1 Definition

Debris transport is the estimation of the fraction of debris that is transported from debris sources (break location) to the sump screen. The four major debris transport modes considered in the NEI Guidance are:

- Blowdown Transport – the transport of debris by the break jet
- Washdown Spray Transport – the vertical transport by the containment sprays/break flow
- Pool Fill-up Transport – the horizontal transport of the debris by break and containment spray flows to active and inactive areas of basement pool
- Recirculation Transport – the horizontal transport of the debris in the active portions of the basement pool by the recirculation flow through the ECCS system

3.2.4.2 Discussion

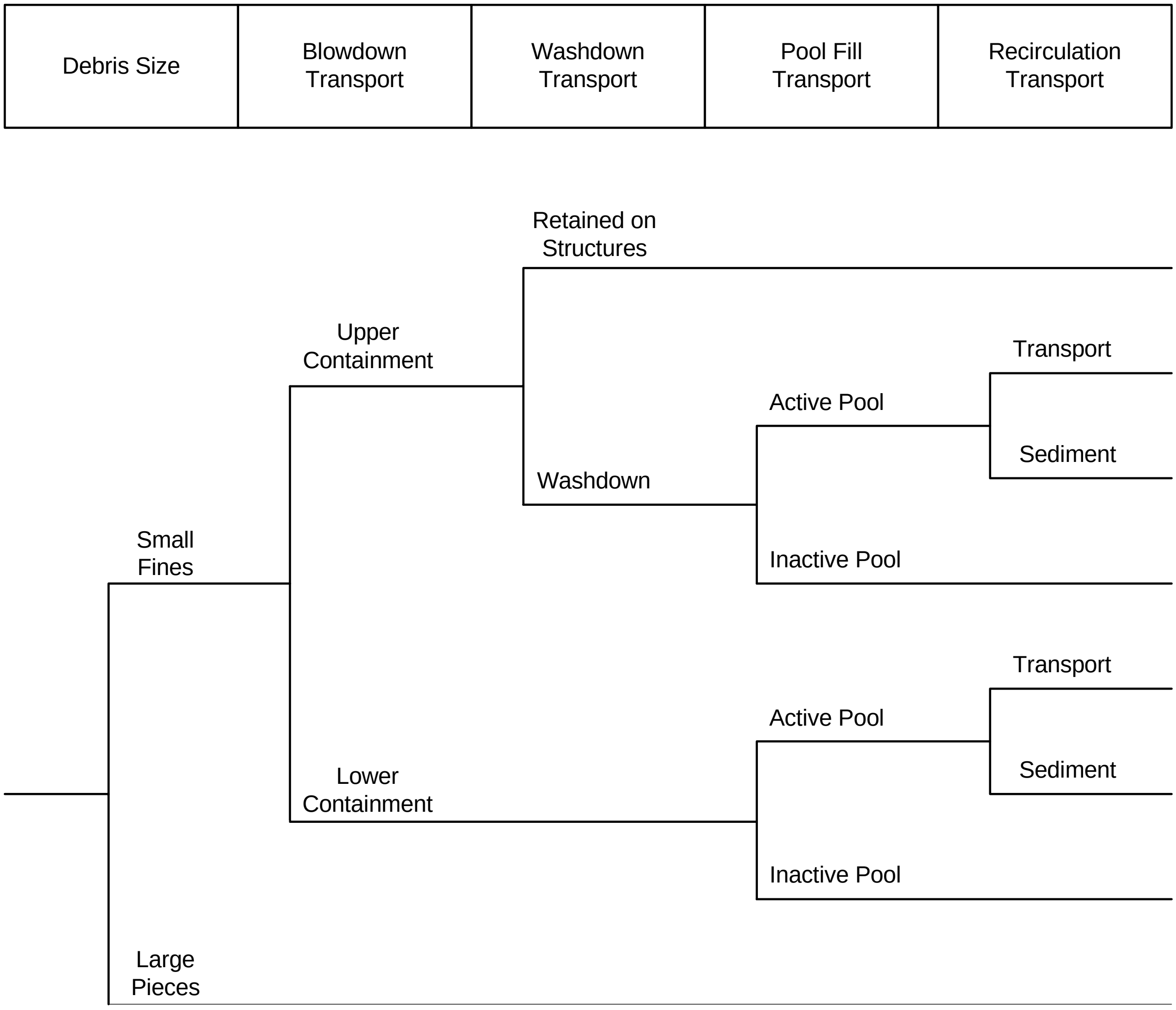
For the NEI Guidance the methodology used to determine the amount of debris transported is based on the methodology reported in Section 4.2 of NUREG/CR-6762 Vol. 4 (Reference 3.2.4-1). Figure 3.2.4-1 depicts the generic transport logic tree for use in the NEI Guidance.

Transport fractions for each branch are provided for debris from the ZOI as well as debris outside the ZOI. These transport fractions are provided for three general types of containments:

- Highly compartmentalized containments
- Mostly un-compartmentalized containments
- Ice condenser containments

Highly compartmentalized containments are those that have distinct robust structures/compartments totally surrounding the major components of the RCS, e.g. steam generator and pressurizer. Typical examples of these containments are Westinghouse 3 loop plants and earlier CE plants with dry ambient atmosphere containments. Mostly un-compartmentalized containments are those that have partial robust structures surrounding the steam generators. Typical examples are the B&W dry ambient atmosphere plants. All of the 7 ice condenser plants are 4 loop Westinghouse plants with no compartmentalization in the lower containment. For breaks that are not inside a defined compartment the transport fractions of the mostly un-compartmentalized containments should be used.

Figure 3.2.4-1: Unquantified NEI Guidance Logic Tree



3.2.4.3 Debris Transport

Guidance is provided to calculate the debris transport values for each of the three major types of containments, for the major categories of debris: fibrous insulation in the break ZOI, RMI insulation in the break ZOI, other material in the ZOI, and debris outside the ZOI. The type of material found in each classification is provided in the debris characteristic section and the latent debris section.

The debris characteristic terminologies employed herein are those from the debris characteristics section. 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. 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 fibrous insulation material, the large pieces are assumed to be jacketed/canvassed, hence not subjected to further erosion.

The Baseline Evaluation guidance considers two transport modes for the containment bottom 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 bottom floor elevation. All plants have a calculation determining the water level in containment following a DBA. This calculation provides estimates of the volume of each compartment that are considered to be flooded by the DBA. Using this calculation and a layout of the containment elevation an analyst can determine which of the volumes are below the containment bottom floor. The analyst then needs to review all the lower compartments to ensure that those volumes do not have drains from the upper part of the containment (e.g. refueling pool) that may cause them to participate in the active volumes. This guideline considers that all volumes at the containment bottom floor elevation will participate in the recirculation flow path from the containment sprays and break flow to the sump.

All the debris that is on the containment bottom 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 bottom floor begin to increase and the pool turbulence decrease. During this fill process of the containment bottom floor pool, as depicted in Figure 1-4 and 1-5 of NUREG/CR-6808 (Reference 3.2.4-2), 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, this NEI guidance considers that all debris in the containment bottom floor is uniformly distributed throughout the entire volume of water in containment. This guidance 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 bottom floor to the inactive sumps by the thin sheets of high velocity water. To add to the conservatism, the NEI guidance then considers that all debris classified as “small fines” or “small RMI pieces” are transported to the sump during recirculation. Plants can deviate from the Baseline Evaluation guidelines to account for plant specific features. Such deviations from the Baseline Evaluation guidance are considered refinements to the baseline methodology. Additionally, plants may consider implementing refinements identified in Sections 4 and 5 of this guide.

3.2.4.3.1 Highly Compartmentalized Containment

This guidance assumes that the pipe break in a highly compartmentalized containment occurs at the bottom of the compartment. For breaks that are not located in the bottom of the compartment or on upper portion of a compartment, e.g. a main steam line break, the mostly un-compartmentalized containment values should be used.

Fibrous Insulation in the ZOI:

The following guidance is provided for all types of fibrous debris in the ZOI.

Blowdown Transport:

Debris transport during blowdown is assumed to cause the small fines debris from the compartment where the break is postulated to occur to be distributed to all horizontal surfaces outside the compartments and the dome. Most of the break locations in a compartment are located in the bottom of the compartment. For conservatism it is assumed that only 25% of the small fines debris is ejected upward, the rest going to the containment bottom floor. This fraction is derived as a conservative estimate of the free volume in a compartment above the lower portion of the compartment not occupied by components such as steam generators. The large debris pieces from the ZOI are assumed to fall to the compartment floor and not be transported.

Washdown Transport:

Debris transport by the containment spray is assumed to cause all the small fines to be transported to the containment bottom floor and be evenly distributed on the floor. No transport of the large pieces is assumed to occur by containment spray.

Pool Fill Transport:

Debris transport in the containment bottom floor pool during fill up will transport all 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, i.e. the cavity under the reactor vessel. 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 the large pieces is assumed to occur during pool fill up.

Recirculation Transport:

Debris transport in the containment bottom floor pool during recirculation is assumed to transport 100% of the small fines in the active volumes of the pool to the sump. No transport of the large pieces is assumed to occur during recirculation.

RMI Insulation in the ZOI:

The following guidance is provided for all types of RMI debris in the ZOI.

Blowdown Transport:

Debris transport during blowdown is assumed to cause the small RMI debris pieces from the compartment where the break is postulated to occur to be distributed to all horizontal surfaces outside the compartment. For conservatism it is assumed that only 25% of the small RMI debris is ejected upward, the rest going to the containment floor. This fraction is derived as a conservative estimate of the free volume in a compartment above the lower portion of the compartment not occupied by components such as steam generators. The large RMI debris pieces from the ZOI are assumed to fall to the compartment floor and not be transported.

Washdown Transport:

Debris transport by the containment spray is assumed to cause none of the small RMI debris that are not on the containment bottom floor and are in containment spray pathway to be transported to the containment bottom floor. The flow velocities and the very shallow pool depths are not conducive to transport of small RMI debris. No transport of the large pieces is assumed to occur by containment spray.

Pool Fill Transport:

Debris transport in the containment bottom floor pool during fill up will transport all the small RMI debris. Some of the small fines will be transported to the inactive volumes of the pool that will not participate in the recirculation flow, i.e. the cavity under the reactor vessel. 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 the large RMI pieces is assumed to occur during pool fill up.

Recirculation Transport:

Debris transport in the containment bottom floor pool during recirculation is assumed to transport 100% of the small RMI debris in the active volumes of the pool to the sump. No transport of the large RMI pieces is assumed to occur during recirculation.

Other Material in the ZOI:

All other material in the ZOI, including coatings within the Coatings ZOI will be assumed to transport similar to the small fines of fibrous material.

Debris from Materials Outside the ZOI:

All debris from materials outside the ZOI is considered to be in the active volumes of the pool at the start of recirculation and 100% transported by the active volumes of the pool to the sump. Latent debris is also considered to be to be in the active volumes of the pool at the start of recirculation and 100% transported by the active volumes of the pool to the sump. This is conservative since debris from outside the ZOI is not considered to be transported to the inactive sump.

3.2.4.3.2 Mostly Un-compartmentalized Containment

The following guidance is provided for all types of fibrous debris in the ZOI.

Fibrous Insulation in the ZOI:

Blowdown Transport:

Debris transport during blowdown is assumed to cause the small fines debris from the compartment where the break is postulated to occur to be distributed to evenly to all horizontal surfaces outside the compartments and the dome. The large debris pieces from the ZOI are assumed to fall to the containment bottom floor and not be transported.

Washdown Transport:

Debris transport by the containment spray is assumed to cause all the small fines to be transported to the containment bottom floor and be evenly distributed on the floor. No transport of the large pieces is assumed to occur by containment spray.

Pool Fill Transport:

Debris transport in the containment bottom floor pool during fill up will transport all 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, i.e. the cavity under the reactor vessel. 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 the large pieces is assumed to occur during pool fill up.

Recirculation Transport:

Debris transport in the containment bottom floor pool during recirculation is assumed to transport 100% of the small fines in the active volumes of the pool to the sump. No transport of the large pieces is assumed to occur during recirculation.

RMI Insulation in the ZOI:

The following guidance is provided for all types of RMI debris in the ZOI.

Blowdown Transport:

Debris transport during blowdown is assumed to cause the small RMI debris pieces from the compartment where the break is postulated to occur to be distributed to all horizontal surfaces outside the compartments. For conservatism it is assumed that all the small RMI debris is deposited on the containment bottom floor. The large RMI debris pieces from the ZOI are assumed to fall to the containment bottom floor and not be transported.

Washdown Transport:

There is no debris transport by the containment spray of the small RMI pieces since all small RMI debris is assumed to be transported by the blowdown to the containment bottom floor. Also, no transport of the large pieces is assumed to occur by containment spray.

Pool Fill Transport:

Debris transport in the containment bottom floor pool during fill up will transport all the small RMI debris. 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. 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 the large RMI pieces is assumed to occur during pool fill up.

Recirculation Transport:

Debris transport in the containment bottom floor pool during recirculation is assumed to transport 100% of the small RMI debris in the active volumes of the pool to the sump. No transport of the large RMI pieces is assumed to occur during recirculation.

Other Material in the ZOI:

All other material in the ZOI, including coatings within the Coatings ZOI will be assumed to transport similar to the small fines of fibrous material.

Debris from Materials Outside the ZOI:

100% of debris from materials outside the ZOI is considered to be in the active volumes of the pool at the start of recirculation and 100% transported by the active volumes of the pool to the sump. Latent debris is also considered to be to be in the active volumes of the pool at the start of recirculation and 100% transported by the active volumes of the pool to the sump. This is conservative since debris from outside the ZOI is not considered to be transported to the inactive sump.

3.2.4.3.3 Ice Condenser Containment

Fibrous Insulation in the ZOI:

The following guidance is provided for all types of fibrous debris in the ZOI.

Blowdown Transport:

Debris transport during blowdown is assumed to cause most of the small fines debris from the lower containment where the break is postulated to occur to be transported to the upper compartment and the dome through the ice condenser baskets. Ten percent of the small fines debris is retained in the upper compartment and the ice condensers, the rest returning back to the lower containment floor by the melting ice. Steam and water with entrained debris will all go through the ice condenser cavities. Some of the debris will be entrained in the baskets. At the end of blowdown at least 50% of the ice will have melted. Ten percent is a conservative average value of the open area in the ice condenser. The large debris pieces from the ZOI are assumed to fall to the lower containment floor and not be transported.

Washdown Transport:

All the small fines that were transported to the upper containment by the blowdown will be conservatively assumed to be all transported by the containment sprays from the upper containment to the lower containment bottom floor and be evenly distributed on the lower containment bottom floor. No transport of the large pieces is assumed to occur by containment spray.

Pool Fill Transport:

Debris transport in the lower containment bottom floor pool during fill up will transport all 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, i.g. the cavity under the reactor vessel. 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 the large pieces is assumed to occur during pool fill up.

Recirculation Transport:

Debris transport in the containment bottom floor pool during recirculation is assumed to transport 100% of the small fines in the active volumes of the pool to the sump. No transport of the large pieces is assumed to occur during recirculation.

RMI Insulation in the ZOI:

The following guidance is provided for all types of RMI debris in the ZOI.

Blowdown Transport:

Debris transport during blowdown is assumed to cause most of the small RMI debris from the lower containment where the break is postulated to occur to be transported to the upper compartment and the dome through the ice condenser baskets. For conservatism it is assumed that only 10% of the small RMI debris is transported to the upper compartment, the rest returning back to the lower containment bottom floor by the melting ice. Steam and water with entrained debris will all go through the ice condenser cavities. Some of the debris will be entrained in the baskets. At the end of blowdown at least 50% of the ice will have melted. Ten per cent is a conservative average value of the open area in the ice condenser. The large debris pieces from the ZOI are assumed to fall to the lower containment bottom floor and not be transported.

Washdown Transport:

Debris transport by the containment spray is assumed to cause none of the small RMI debris that are on the upper containment bottom floor and are in containment spray pathway to be transported to the containment bottom floor. The flow velocities and the very shallow pool depths in the upper containment floor are not conducive to transport of small RMI debris. No transport of the large pieces is assumed to occur by containment spray.

Pool Fill Transport:

Debris transport in the lower containment bottom floor pool during fill up will transport all the small RMI debris. 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. 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 the large RMI pieces is assumed to occur during pool fill up.

Recirculation Transport:

Debris transport in the containment bottom floor pool during recirculation is assumed to transport 100% of the small RMI debris in the active volumes of the pool to the sump. No transport of the large RMI pieces is assumed to occur during recirculation.

Other Material in the ZOI:

All other material in the ZOI, including coatings within the Coatings ZOI will be assumed to transport similar to the small fines of fibrous material.

Debris from Materials Outside the ZOI:

All of debris from materials outside the ZOI is considered to be in the active volumes of the pool at the start of recirculation and 100% transported by the active volumes of the pool to the sump. Latent debris is also considered to be in the active volumes of the pool at the start of recirculation and 100% transported by the active volumes of the pool to the sump. This is conservative since debris from outside the ZOI is not considered to be transported to the inactive sump.

3.2.4.4 Calculate Transport Factors

The calculation of the transport factors for each type of debris is done by using the unquantified logic tree as a guide. A logic tree should be developed for each of the debris types and using the previously discussed values for the appropriate containment type. The summation of the two "Transport" branches is the cumulative transport fraction for the debris type.

3.2.4.4.1 Sample Calculation

The baseline sample plant is classified as a highly compartmentalized containment. From the post-DBA water level calculations we have that the inactive pools account for 30% of the total post-DBA water volume in containment.

From the debris classification section there are two types of debris from the ZOI for the baseline sample plant: NUKON® and RMI. Using the recommended transport fractions we have:

NUKON®

The following is a quantified logic tree for NUKON®:

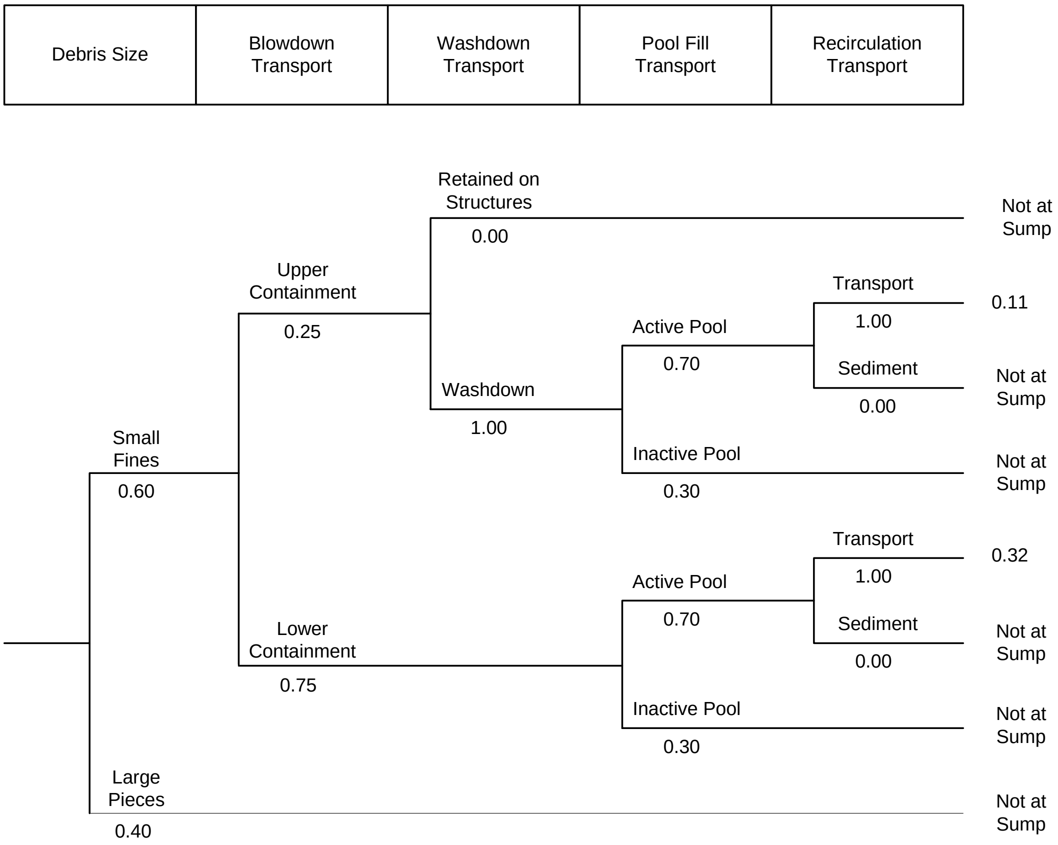


Figure 3.2.4-2: NUKON® Transport Logic Tree

(Sample Problem)

Adding the two paths that reach the sump, the total cumulative transport factor for NUKON® fines reaching the sum is the 0.11 + 0.32 = 0.43. As such 43% of the volume of NUKON® in the ZOI reaches the sump in the form of small fines. No large pieces of NUKON® will be transported to the sump.

RMI:

The following is a quantified logic tree for the RMI:

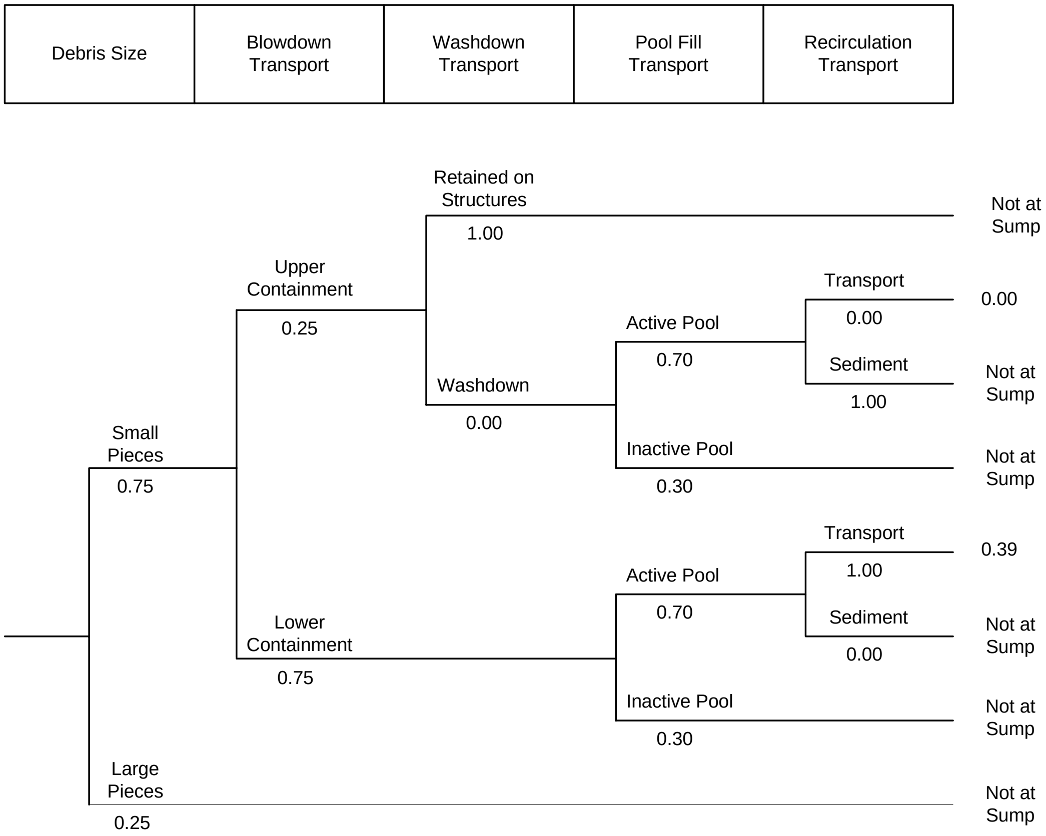


Figure 3.2.4-3: RMI Transport Logic Tree

(Sample Problem)

From inspection of the logic tree 0.39 is the transport factor for RMI. As such 39 % of the volume of RMI in the ZOI reaches the sump in the form of small pieces. No large RMI pieces will be transported to the sump.

Coating debris material from both from within the coatings ZOI and from outside the coatings ZOI will all be transported to the sump. All debris material outside the ZOI, including latent debris, will also be transported to the sump.

From the debris generation sample calculations we have:

Total volume of NUKON® blankets in ZOI:	300 cu ft
Total quantity of RMI material in ZOI:	15,000 sq ft

From the debris characterization section we have:

Total Quantity of small fines coating:

0.007 cu ft from the ZOI + 7.5 cu ft from outside the ZOI = 7.5 cu ft

From the latent debris section we have:

Latent fiber:	20.91 lbs @ 62.4 lbs/cu ft	=	0.34 cu ft
Latent particulates:	33.51 lbs @ 100 lbs/cu ft	=	0.34 cu ft

Using the transport fractions derived above, the following quantities of debris are transported to the sump:

Fibers: small fines:	300 * 0.43 + 0.34	= 129.34 cu ft
RMI small pieces:	15,000 * 0.39	= 5,850 sq ft
Coating small fines (IOZ equivalent):		= 7.5 cu ft
Latent Particulates:		= 0.34 cu ft

3.2.4.5 References

3.2.4-1 NUREG/CR-6762, "GSI-191 Technical Assessment," U.S. Nuclear Regulatory Commission (2002)

Volume 1: D. V. Rao, B. Letellier, C. Shaffer, S. Ashbaugh, and L. Bartlein, "GSI-191 Technical Assessment: Parametric Evaluation for Pressurized Water Reactor Recirculation Sump Performance," LA-UR-01-4083, 2002

Volume 2: D. V. Rao, B. Letellier, K. W. Ross, L. Bartlein, and M. T. Leonard, "GSI-191 Technical Assessment: Summary and Analysis of U.S. Pressurized Water Reactor Industry Survey Responses and Responses to GL 97-04," LA-UR-01-1800, 2002

Volume 3: C. J. Shaffer, D. V. Rao, and S. G. Ashbaugh, "GSI-191 Technical Assessment: Development of Debris-Generation Quantities in Support of the Parametric Evaluation," LA-UR-01-6640, 2002

Volume 4: S. G. Ashbaugh, and D. V. Rao, "GSI-191 Technical Assessment: Development of Debris Transport Fractions in Support of the Parametric Evaluation," LA-UR-01-5965, 2002

3.2.4-2 NUREG/CR-6808, LA-UR-03-0880, D.V. Rao, Clinton J. Shaffer, M.T. Leonard, "Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance," U.S. Nuclear Regulatory Commission, February 2003

3.2.5 HEAD LOSS

3.2.5.1 Introduction/Scope

The methodology presented within this chapter details how to calculate the head loss from a debris bed that could be formed on the ECCS sump screen(s). The sump screen parameters and the thermal/hydraulic conditions required for this analysis will first be discussed. The types, total quantities and characteristics of debris that are generated in the containment and transported to the sump screen are also primary design inputs for this methodology.

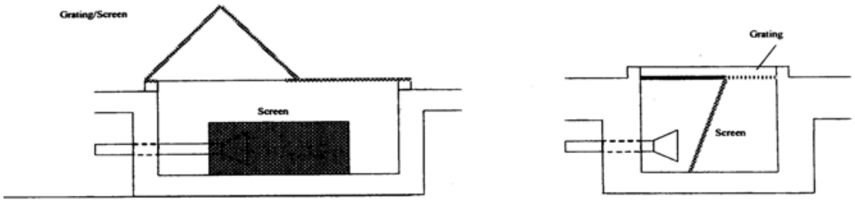
The methodology will provide the user with the head loss (feet-of-water) for the debris bed on the sump screen. The user then has to add the estimated clean sump screen head loss to obtain the total head loss across the sump screen. The ability to sustain this head loss is then assessed by comparison to the NPSH Margin. Sample problems are provided to illustrate the methodology.

3.2.5.2 Inputs for Head Loss Evaluation

3.2.5.2.1 Sump Screen Design

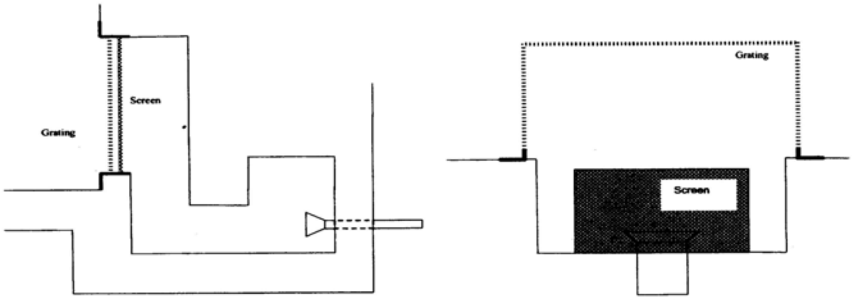
The sump screen design is an important consideration in the evaluation of debris head loss. Plant drawings should provide details as to the screen construction, the orientation and the mesh size (or hole-size and pitch for perforated plates). Typical PWR sump screen configurations are illustrated in Figure 3.2.5-1. Newer designs, such as those installed in the BWRs, typically have more surface area and different geometries.

Figure 3.2.5-1: Typical PWR Sump Screen Configurations



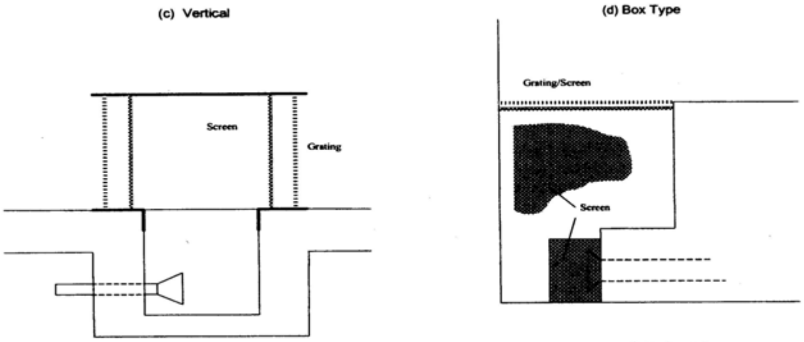
(a) A Frame

(b) Inverted Lean To



(c) Vertical

(d) Box Type



(e) Box Type

(f) Horizontal

Derived from plant drawings, the sump screen area (A) is the total area of the sump screen (without any correction for the solid area of the mesh or wire screen) over which debris accumulates. Curbs are ignored when determining the screen area. For flat screens, the sump screen is simply the total circumscribed area of the screen or perforated plate. Framing and/or significant structures that block flow through the screen should be subtracted from the total area to get a net screen area. For alternate geometries, particularly in the case of star or stacked disc designs, the initial strainer surface area available for debris deposition is the total perforated plate surface area, decreasing to the circumscribed area as debris fills in the voids and gaps between the ridges and disks.

If the screen is completely submerged, the net screen area is used. If the screen is partially submerged, the wetted area should be determined based on the height of the containment floor water pool at the time the head loss is calculated.

The sump screen opening size (or hole-size and pitch for perforated plate screens) is obtained from plant drawings. The opening size is usually the size needed to keep out debris of a size greater than the minimum size of openings in the ECCS (e.g. spray nozzles, valve throats and pump cooling lines). The sump screen opening size is used in determining the clean strainer head loss. The debris-bed head loss calculation methodology adopted in this chapter is largely independent of the sump screen opening size.

The Clean Strainer Head Loss (CSHL) is the head loss of the sump screen assembly in a clean, unfouled condition. The CSHL is a required input for the overall head loss evaluation and is highly dependent on plant-specific sump screen construction details and thermal hydraulic conditions. Calculating the head loss of the sump screen assembly in a clean condition involves calculating the head loss across the screen itself taking submergence of the screen into consideration. The CSHL will mainly depend on the screen mesh size (or hole size and pitch for perforated plates), the flow through the screen, and the water temperature using standard methods of fluid mechanics. This baseline methodology does not provide details on how to calculate clean strainer head loss as this information is available from other sources. Clean sump screen head loss information is typically available from the manufacturer of the raw screen material itself. Note that existing plant calculations often document CSHL. In some cases the head losses due to the attendant support structures, mechanical configuration of the bracing and other structures in the sump (such as vortex suppressors) cannot be neglected, and these losses should normally be included in the CSHL calculation.

3.2.5.2.2 Thermal-Hydraulic Conditions

3.2.5.2.2.1 Recirculation Pool Water Level

For conservatism, the minimum water level of the recirculation pool should be used to estimate the head loss across the debris bed accumulated on a screen. The minimum level will yield the smallest surface area (thus potentially greater head loss) for those screens that are not completely submerged in the pool as well as the lowest available NPSH to the ECCS pumps.

3.2.5.2.2.2 ECCS Flow Rate

For conservatism, the highest flow rate (Q) should be used in calculating the head loss across a screen. In this regard, the Baseline Methodology recommends that maximum pump flows, as identified in current NPSH calculations, be used for the ECCS flow rates. For multiple sump screens, the flow rate for the head loss calculation is the flow through each of the screens.

3.2.5.2.2.3 Temperature

The recirculation sump water temperature should be documented in the plant design basis calculations and is an important parameter in the head loss calculation.

The Baseline Evaluation Methodology recommends the following:

1. The temperature at which the head loss is evaluated should be consistent with the temperature used for the NPSH evaluation.
2. However, it is not clear which temperature is limiting overall, therefore, multiple times, temperatures and flows during the accident may need to be evaluated. (For example, use of 250˚F gives a head loss of 8.8-feet for the sample problem of this section, whereas using 120˚F gives 33.9-feet).

3. As a conservative simplification, the maximum expected sump temperature may be used for the NPSH analysis, whereas the lowest expected temperature during ECCS operation may be taken for the head loss analysis

3.2.5.2.2.4 Debris Types, Quantities and Characteristics

Fibrous insulation debris, RMI debris, coatings debris, and miscellaneous debris such as concrete debris, dust, dirt, other latent debris, rust, etc. all have to be considered if they are present inside the containment. Therefore, the types, quantities (mass or volume) and characteristics of all potential debris materials need to be specified in the design input for a sump screen head loss evaluation. For fibrous materials, the insulation volume is the main parameter needed. For particulate materials, the mass and the density are the main parameters required. For RMI, the main parameter needed is the total foil area of the damaged RMI.

The composition and characteristics of the debris bed on the sump screen are important inputs into the head loss model. The debris types, quantities (i.e. mass or volume), and characteristics (e.g. shape and thickness) reaching the sump screen are needed to calculate the pressure drop across the debris bed. The debris types and potential quantities at the sump screen are determined by the debris generation and transport calculations.

3.2.5.2.3 Head Loss Methodology

The head loss model assumes that the screen is initially clean and that the floor pool contains a homogenous mixture and concentration of debris (i.e., fibrous, particulate, etc.). Upon switchover of suction from the refueling water storage tank (RWST) to the recirculation sump, debris begins to be transported to the sump and accumulates on the sump screen. Initially, some portion of the debris whose size is smaller than the screen mesh size (or hole-size of the perforated plate) passes through the sump screen. Fibers will quickly start to form a fiber mat in the cases where there is no RMI debris transported to the sump screen. (If RMI is present at the screen, refer to Section 3.2.5.2.3.1.3). As the fiber mat forms it will start trapping particulate debris reaching the sump screen. With sufficient fibers reaching the screen, a uniform fiber mat bed will be formed at which time the head loss across the debris will start increasing. The head loss across the debris bed will continue to rise as more debris is deposited on the screen, reaching steady state when all of the available debris is deposited on the screen.

Most analysts are interested in the head loss across the sump screen when all debris reaching the sump screen accumulates on the screen. The head loss methodology herein provides the ability to compute the sump screen head loss given the total quantity and type of debris over a specified surface area at a given ECCS pump flow.

3.2.5.2.3.1 General Theoretical/Empirical Formulas

3.2.5.2.3.1.1 Fibrous Debris Beds with Particulate

For general use with fiber and particulate debris beds, the NUREG/CR-6224 correlation is recommended for determination of the head loss. The refinement guidance of Section 4 provides a discussion of factors associated with estimating debris head losses and presents several debris head loss correlations developed over the last few years.

The NUREG/CR-6224 head loss correlation is described and validated in detail in Appendix B of that report and is a semi-theoretical head loss model. The correlation is based on the theoretical and experimental research for the head loss across a variety of porous and fibrous media carried out since the 1940s. The NUREG/CR-6224 head loss correlation has been thoroughly validated for fibrous debris and ferrous sludge found in BWRs for a variety of flow conditions, water temperatures, and in different experimental facilities. The types of fibrous insulation material tested include NUKON™ and Temp-Mat®. The particulate matter debris tested includes iron oxide particles from 1 to 300 μm in characteristic size, plus inorganic zinc and paint chips. In these cases, with the appropriate selection of particle sizes as described in Tables 3.3.2.3.6-1 and 3.3.2.3.6-2 of this document, the NUREG/CR-6224 head loss correlation bounds the experimental results.

US NRC Regulatory Guide 1.82 Revision 3 states that estimates of head loss caused by debris blockage should be developed from empirical data based on the sump screen design (e.g., surface area and geometry), postulated combinations of debris (i.e., amount, size distribution, type), and approach velocity. Therefore, there may be materials and combinations of materials for which the empirical head loss data does not exist. In theses cases, the following options are available:

- Characterization of the material with Scanning Electron Microscopy (SEM) analysis, and establishing a size distribution;
- Choosing an alternative material that conservatively represents the material in question, via similitude arguments;
- Head loss testing of the particular material to establish a correlation or else validate an existing correlation for that material; or
- Utilize other data which may exist to establish head loss for the material in question. (The refinement guidance presented in Section 4 summarizes some of the industry test data. More data are possibly available, some of which are currently the property of individual utilities.)

The NUREG/CR-6224 head loss correlation, applicable for laminar, transient and turbulent flow regimes through mixed debris beds (i.e., debris beds composed of fibrous and particulate matter) is given by:

$$\Delta H = \Lambda \left[3.5\, S_v^2\, \alpha_m^{1.5} (1+57\, \alpha_m^3)\, \mu\, U + 0.66\, S_v\, \alpha_m/(1-\alpha_m)\, \rho\, U^2 \right] \Delta L_m \qquad (3.2.5\text{-}1)$$

where:

ΔH is the head loss (feet-of-water)

S_v is the surface-to-volume ratio of the debris (ft^2/ft^3)

μ is the dynamic viscosity of water (lbm/ft/sec)

U is the fluid approach velocity (fps)

ρ is the density of water (lbm/ft^3)

α_m is the mixed debris bed solidity (one minus the porosity)

ΔL_m is the actual mixed debris bed thickness (inches)

Λ is a conversion factor –

$\Lambda = 1$ for SI units, and

$\Lambda = 4.1528\text{x}10^{-5}$ (ft-water/inch)/(lbm/ft^2/sec^2) for English units.

The fluid approach velocity, U, is given simply in terms of the volumetric flow rate and the effective screen surface area as:

$$U = \frac{Q}{A}$$

where:

Q is the total volumetric flow rate through the screen, (ft^3/sec) and

A is the effective screen surface area (ft^2).

The screen surface area, A, is the submerged (wetted) effective surface area of the screen as described in Section 3.2.5.2.1 above. As noted previously, the available surface area may change with time, particularly in the case of star or stacked disc designs. For these particular alternate geometry screens, given sufficient debris reaching the screen, the effective surface area may eventually decrease to the circumscribed area. At the limit, the head loss for alternate geometry screens may be calculated using the circumscribed area and the debris load equal to the total debris load transported to the screen less the quantity of debris required to fill in the volumes/gaps of the alternate geometry screen.

The mixed debris bed solidity (α_m) is given by:

$$\alpha_m = \left(1 + \frac{\rho_f}{\rho_p} \eta \right) \alpha_o c \qquad (3.2.5\text{-}2)$$

where:

α_o = is the solidity of the original fiber blanket (i.e. the "as fabricated" solidity)

η = m_p/m_f, the particulate-to-fiber mass ratio in the debris bed

m_p = $\Sigma\, m_i$ is the total particulate mass, (lbm)

ρ_f = the fiber density (lbm/ft^3)

ρ_p = the average particulate material density (lbm/ft^3) = $\Sigma\, \rho_i V_i \,/\, \Sigma\, V_i$

c = the head-loss-induced volumetric compression of the debris (inches/inch)

For debris deposition on a flat surface of a constant size, the compression (c) relates the actual debris bed thickness, ΔL_m, and the theoretical fibrous debris bed thickness, ΔL_o, (inches), via the relation:

$$c = \frac{\Delta L_o}{\Delta L_m} \tag{3.2.5-3}$$

Compression of the fibrous bed due to the pressure gradient across the bed is also accounted. The relation that accounts for this effect, which must be satisfied in parallel to the previous equation for the head loss, is given by (valid for ratios of $\Delta H/\Delta L_o > 0.5$ ft-water/inch-insulation):

$$c = 1.3 * K * (\Delta H / \Delta L_o)^{0.38} \tag{3.2.5-4}$$

Here, '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. It should be noted that this formulation for debris bed compression may over predict compression significantly in the case of very thick debris layers, roughly 6-inches or more. Thus, in these cases, it is conservative.

For very large pressure gradients and for cases where very little fiber is present, the compression has to be limited such that a maximum solidity is not exceeded. In NUREG/CR-6224, this maximum solidity is defined to be:

$$\alpha_m = 65\ \text{lbm/ft}^3/\rho_p \qquad (3.2.5\text{-}5)$$

which is equivalent to having a granular debris layer with a bulk density of 65 lbm/ft^3. Note that 65 lbm/ft^3 is the macroscopic, or bulk density of a granular media such as sand or gravel and clay (Reference 3.2.5-1). Based on NUREG/CR-6224 (Reference 3.2.5-2), the above value is also appropriate for ferrous sludge. For a sludge particle density of ~324 lbm/ft^3, the maximum solidity is ~20%, and this value has been determined from test data to yield acceptable results with the NUREG/CR-6224 head loss correlation. In general, solidity is defined as:

$$\alpha_m = \rho_b / \rho_p \qquad (3.2.5\text{-}5a)$$

where ρ_b is the bulk, or macroscopic density, and ρ_p is the particle, or grain density. Since the solidity depends on the material properties, different materials may require testing to establish appropriate values. In practice, however, the limiting value of solidity specified above works well for many particulate mixtures.

Each constituent of debris has a surface-to-volume ratio associated with it based on the characteristic shape of that debris type. For typical debris types, we have:

Cylindrically-shaped debris:	$S_v = 4/\text{diam}$;
Spherically-shaped debris:	$S_v = 6/\text{diam}$;
Flakes (flat-plates):	$S_v = 2/\text{thick}$;

where ‘diam’ is the diameter in feet of the fiber or spherical particle, and ‘thick’ is the thickness in feet of the flake/chip. Other debris not listed above would have its surface-to-volume ratio calculated similarly based on one of the above characteristic shapes. Clearly, the above relations are simplified approximations. Generally, what is done is to select a characteristic size, for example, small spheres to represent irregularly shaped particulate debris, small cylinders to represent fiber, etc. Whatever modeling approach is used, a comparison to test data then has to be made to assess the validity of the approximation for that particular material, with the characteristic sizes adjusted as required for the head loss correlation to conservatively match the data. For debris not yet tested and for which similitude arguments cannot be made, SEM analysis and/or plant-specific testing may be required.

The following is a method for calculating the average surface to volume ratio for two different types of debris constituents (Reference 3.2.5-3).

$$S_v = \mathrm{SQRT}\,[(S_{V1}^2 * v_1 + S_{V2}^2 * v_2)/(v_1 + v_2)], \qquad (3.2.5\text{-}6)$$

where v_1 and v_2 are the microscopic volumes of constituents '1' and '2,' respectively.

Clearly, this result can be extended to more than two such fiber species as follows:

$$S_v = \mathrm{SQRT}\,[\Sigma(S_{Vn}^2 * v_n)/\Sigma(v_n)], \qquad (3.2.5\text{-}7)$$

where the subscript 'n' refers to the nth constituent.

The above procedure is developed in detail in Attachment C of this document. Averaging in the above manner will yield a higher pressure drop as more than one type of debris is added to the mixture.

Tables 3.2.2-2 and 3.2.2-3 list recommended values of fiber and particle sizes based on the data currently available, from which values of S_V may be derived. Where values are not given or where uncertainty otherwise exists, it is best to err on the small side for conservative values of S_V. In some cases, further measurements to establish debris sizes, SEM analysis, and comparisons to head loss correlations and test data may be required to establish appropriate values.

To obtain an aggregate density for both particulate and fibrous debris, a simple volume averaging procedure is appropriate, as indicated in association with Equation 3.2.5-2, since, for a well-mixed debris bed, the individual species can reasonably be expected to see the same porosity.

Summarizing the computation process:

- Fiber and particulate debris are handled with the general form of the NUREG/CR-6224 correlation, Equation 3.2.5-1.
- Material properties are necessary – see Section 3.2.2.3 (Debris Characteristics) for material properties of material commonly encountered in PWRs.
- Knowing the debris quantities that are calculated to reach the sump screen, the mass ratio of particulates-to-fiber (η), the fiber density (ρ_f), and the average particulate density (ρ_p), and the theoretical bed thickness (ΔL_o) are determined.
- A compression factor [c] must be specified. This is an iterative process, with a value of 2.0 being a reasonable first approximation. (Adjust ‘c’ thereafter in the direction of convergence. Alternatively, the bed thickness may be assumed and ‘c’ derived from this.)
- The mixed bed solidity (α_m) is next calculated from Equation 3.2.5-2.
- An overall, average value of S_v must be determined for the fibrous materials, each of the particulates and then an average for the overall debris mixture by Equation 3.2.5-7. If multiple fiber types are present, then each type should be included in the averaging process.
- The water properties (ρ and μ) are specified at the sump temperature at the time the head loss across the debris bed is calculated. Alternatively a conservative approach would be to calculate the head loss using the lowest sump water temperature calculated over the entire time frame that the ECCS needs to function.
- The approach velocity will be known from the sump screen area and the ECCS flows through the screen.

- Substitution of all of the above information into Equation 3.2.5-1, in combination with iterative solution of Equations 3.2.5-3 and 3.2.5-4, yields the sump screen head loss and the actual debris-bed thickness, ΔL_m.

The head loss across a debris bed consisting of fibrous debris (no particulates) can be calculated with the general form of the NUREG/CR-6224 correlation, Equation 3.2.5-1, where the mass ratio of particulates-to-fiber (η) is set to zero. Given the presence of particulates from dirt/dust and possibly unqualified coatings, it would be unusual to have to analyze pure fiber bed head loss for a PWR. However, this case has application when interpreting experimental results, so it is mentioned for completeness.

3.2.5.2.3.1.2 RMI Debris Beds

The head loss for a RMI debris bed on the sump screen surface depends mainly on the accumulation at the sump screen and the type and size distribution of RMI debris. The key parameter needed to evaluate pure RMI head loss is the surface area of the RMI bed on the screen. The commonly accepted empirical correlation for RMI (Reference 3.2.5-1) is:

$$\Delta H = [1.56\text{E-}05/(K_t)^2]\ U^2\ A_{foil}/A_c \qquad (3.2.5\text{-}8)$$

where:

K_t is the interfoil gap thickness (ft)
ΔH is the head loss, (feet-of-water)
U is the sump screen approach velocity, (ft/sec)
A_{foil} is the RMI foil surface area, (ft^2)
A_c is the sump screen surface area, (ft^2).

Extracted from Table 7-2 of NUREG/CR-6808, some values of K_t are listed below. Other values of K_t are listed in Appendix K of the SER to the URG.

Table 3.2.5-1: Values of K_t from NUREG/CR-6808

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

In Appendix K of the NRC SER to the BWROG URG, the NRC concluded that a value of K_t of 0.012 in the above general equation bounds the head loss data reasonably well for 2.5-mil SS RMI. Substituting this value of K_t into Equation 3.2.5-8, one obtains:

$$\Delta H = 0.108\ U^2\ A_{foil}/A_c \qquad (3.2.5\text{-}9)$$

Equation 3.2.5-9 accounts for experimental uncertainties, test repeatability variations, and debris size and material types. As such, for 2.5-mil, SS foil, Equation 3.2.5-9 predicts the head loss across a pure RMI debris bed for PWR sump screens. The refinement guidance given in Section 4 will provide further discussion of RMI head loss correlations.

3.2.5.2.3.1.3 Mixed Debris Beds (RMI, Fiber and Particulates)

A mixed debris bed of RMI, fiber and particulates is handled by superposition (Reference 3.2.5-1). First, the fiber-and-particulate head loss is determined using the methodology of Section 3.2.5.2.3.1.1. Next, the RMI head loss is determined using the methodology of Section 3.2.5.2.3.1.2. These two head losses are then added together to estimate the total head loss of a RMI, fiber, and particulate bed. This procedure is conservative, and the user need not be concerned with how the debris bed is formed.

The superposition of RMI and fiber may be overly conservative for cases where relatively large amounts of RMI and trace amounts of fiber (e.g. latent fiber) are estimated to be transported to the sump screen. Experiments have shown that fiber can become caught either within the voids of the RMI bed or at the surface of the RMI bed (which can have a significantly larger surface area and a lower approach velocity than the sump screen itself). For plants that are essentially all RMI, a relatively small amount of latent fiber could provide the quantity necessary to develop a thin bed, causing unacceptable or unrealistic results when added algebraically to the RMI head loss. More realistic methods for trace amounts of either RMI or fiber will be addressed in the refinement guidance of Section 4.

3.2.5.2.3.1.4 Calcium Silicate Insulation

Calcium silicate (Cal-Sil) is a granular insulation. It consists of fine particulate material that is chemically bonded and is also held together by a fine fibrous matrix. Experiments thus far indicate that it is best treated as a particulate material for head loss calculations. Test data will be required for specification of the appropriate particle sizes and surface-to-volume ratios to use in head loss analysis. At present, most of the head loss test data for Cal-Sil are privately held, the exception being the NRC/LANL/UNM Cal-Sil Test Report whose issuance is pending. Based on current information, the NUREG/CR-6224 correlation can be used according to the methods of Section 3.2.5.2.3.1.1 if the application is limited to particulate mixtures containing up to about 20% Cal-Sil by mass. Additional head loss data for Cal-Sil is anticipated to be released by the NRC in the near future. The Supplemental Guidance will provide additional background regarding the insights gained in the very limited series of head loss experiments available for review through April 2004.

Cal-Sil is used in many of the PWRs and has different compositions. For example, it may contain diatomaceous earths, perlite and/or asbestos fibers, and plant-specific characterization (via SEM analysis, at a minimum) is warranted to identify the specific composition, particle size range, and source of this material.

3.2.5.2.3.1.5 Microporous Insulation

Microporous insulation (e.g. MinK and Microtherm) is also a granular insulation and has been used in PWRs. The analyst is cautioned to ensure that the applicable material properties are used, since there may be significant variations in material properties from those suggested in the Debris Characteristics section. The Supplemental Guidance will provide additional background regarding the insights gained in the very limited series of head loss experiments available for review through April 2004.

Microporous and Fiber Debris

A limited series of head loss tests was performed with microporous debris in the presence of fibrous debris. These tests showed that the NUREG/CR-6224 correlation bounded the experimental data for all cases where the microporous-to-fiber mass ratio was less than about 20 percent. For mass ratios higher than about 20 percent, the NUREG/CR-6224 correlation was found to be potentially non-conservative.

The computation of the head loss of mixed microporous and fiber debris beds (where the microporous to fiber mass ratio is less than 20 percent) is the same as described for a fiber and particulate bed (Section 3.2.5.2.3.1.1). The currently available experimental database does not support a correlation for estimating the head loss across a debris bed composed of micro-porous and fibrous insulation where the microporous to fiber mass ratio is more than 20 percent.

In the event that a debris bed composed of microporous and fibrous insulation (or calcium silicate and fiber, where the microporous-to-fiber (or the Cal-Sil-to-fiber) mass ratio is more than 20 percent), is calculated to form on the screens, the alternatives currently available for improving the sump screen performance include:

- Removal of microporous or calcium silicate insulation until the debris generation and transport analysis yields a debris mixture in which the particulate-to-fiber mass ratio is less than 20 percent;
- Use of a head loss correlation other than NUREG/CR-6224 (See the refinement guidance of Section 4 for potentially applicable head loss correlations.); or

- Conduct of head loss experiments using plant-specific debris mixtures, sump screen configuration, and thermal hydraulic conditions.

Microporous or Calcium Silicate Debris Only

Based on results from a very limited series of experiments, microporous insulation debris or calcium silicate debris by itself has been shown to induce significant head losses. Tests have determined that the NUREG/CR-6224 correlation is unreliable for predicting the head loss of microporous insulation debris alone. The currently available experimental database does not support a correlation for estimating the head loss across a debris bed composed solely of microporous insulation debris.

Calcium silicate by itself has also been shown to induce high head losses (Ref. 3.2.5-4). Preliminary indications are that the NUREG/CR-6224 correlation may fit the data if appropriate physical parameters are used in the correlation. Further instruction in this regard is deferred to the Supplemental Guidance and pending the release of the NRC/LANL/UNM Cal-Sil test report.

The alternatives currently available for improving sump screen performance for a debris bed on the screen composed of only microporous or calcium silicate insulation include:

- Removal of all granular insulation (e.g. Cal-Sil, MinK, Microtherm, etc.);
- Use of a head loss correlation other than NUREG/CR-6224 (The guidance on refinements given in Section 4 will address potentially applicable head loss correlations);
- Conduct of head loss experiments using plant specific debris mixtures, sump screen configuration, and thermal hydraulic conditions.

Granular Insulation and RMI Debris

Reference 3.2.5-4 suggests that the head loss for an RMI and calcium silicate debris bed will be relatively low, with increased head loss as the quantity of Cal-Sil debris quantities increases.

The expectation is that the same would also occur for all types of granular insulation (Min-K, Microtherm and calcium silicate) and RMI debris beds. Mixtures of granular insulation, RMI, fiber, and other debris should be treated the same as mixed debris bed treatment of 3.2.5.2.3.1.3 with the limitations noted in 3.2.5.2.3.1.4 and 3.2.5.2.1.3.5 above.

3.2.5.2.3.2 Methodology Application Considerations

3.2.5.2.3.2.1 Total Sump Screen Head loss

The total strainer head loss (TSHL) is the sum of the debris-bed head loss (DBHL) and the clean strainer head loss (CSHL).

$$\text{TSHL} = \text{CSHL} + \text{DBHL}$$

3.2.5.2.3.2.2 Evaluation of Breaks with Different Combinations of Debris

It is important to identify the break location that produces the highest debris bed head loss, i.e., the limiting break. The limiting break is not necessarily the break that generates the largest total quantity of debris. For example, a break that generates enough fiber that, after the transport considerations, deposits enough fiber on the screen to cause a thin bed may yield higher head losses in the presence of particulate than the break that generates more fiber (for the same quantity of particulate). As such, the analyst needs to evaluate a spectrum of breaks with different combinations of debris types to ensure that the mixture of debris on the screen that causes the highest head loss is identified.

3.2.5.2.3.2.3 Thin Fibrous Beds

For the reasons discussed in Section 3.2.5.2.3.2.2 and as suggested in Revision 3 of RG 1.82, this methodology recommends that the head loss for a one-eighth-inch-thick fiber debris-bed (including particulates) be evaluated for existing PWR sump screens.

For conditions of fiber and particulate present in the post-LOCA containment floor pool, as the fiber-bed is deposited on the screen, particulate material will be trapped by the fiber, increasingly so as the fiber bed thickens. Once a fiber bed of approximately one-eighth-inch thickness is formed, if there is sufficient particulate debris, a low permeability granular layer of debris on top of the fiber bed will be formed. The head loss associated with the accumulation of mostly particulate debris on thin fibrous beds can be quite high, and surprisingly enough, greater than the head losses associated with much larger quantities of fiber and much thicker beds of debris. This apparently counter-intuitive head loss phenomenon is known as the Thin Bed Effect (TBE). The Supplemental Guidance will provide further discussions on the TBE.

It only takes a small quantity of fiber to facilitate TBE occurrence, and since it is difficult to make a defensible case that no fibers whatsoever are present in the containment, the possibility of forming a thin fibrous bed generally has to be evaluated for existing PWR screens. Additionally, given the uncertainties of debris generation and transport calculations, the total quantities of fiber calculated to reach the sump screens may be on the high side, hence the impact of a smaller quantity of fiber reaching the sump screen should be examined, i.e. the transport of only the fiber necessary to form a thin bed potentially being the limiting case. This methodology recommends that the head losses given a one-eighth-inch fiber bed (plus particulate) be calculated as a sensitivity analysis.

To analyze a thin fiber bed, a fiber quantity sufficient to form a bed one-eighth-inch thick should be determined to be available and if present could be deposited on the sump screen. The requisite quantity is easily calculated as 0.010-foot times the sump screen net area. The head loss computations are the same as described for fiber and particulate beds (Section 3.2.5.2.3.1.1) using the full value of particulate matter transported to the sump screen. (This would include latent debris such as dirt and concrete dust. It would also include any other fine particulate debris such as rust, inorganic zinc, epoxy fine material, etc.) It should be noted that the particulate layer is characterized by a very high sludge-to-fiber ratio; hence a limiting value for the compression is used. If under these conditions, the thin-bed head loss should exceed the

NPSH Margin, then the allowable particulate loading can be evaluated by reducing the particulate quantity until the calculated head loss is within the NPSH margin.

3.2.5.2.3.2.4 Sump Screen Submergence

For submerged screen sumps the head loss computation methods presented herein are directly applicable. Submerged screens are characterized by having the ambient pressure on one side of the screen, and the flow is driven by the pump. The limiting criterion for submerged screens occurs when the combined clean sump and debris bed head loss exceeds the NPSH Margin.

For partially submerged screen sumps the head loss computation methods presented herein are also directly applicable. Partially submerged screens are characterized by having the ambient pressure on both sides of the screen. In this case the flow driver is the difference in fluid elevation between the two sides of the screen. As debris accumulates on the screen, the water level behind the screen falls in order to generate a pressure drop to allow the flow rate to be achieved. The limiting criterion for a partially submerged screen is when the debris bed accumulation on the screen reduces the flow to less than the flow requirements for the sump. Numerical simulations confirm that an effective head loss across a debris bed approximately equal to one-half of the pool height is sufficient to prevent adequate water flow. As such, for partially submerged sump screens the methodology described herein should be used to estimate the pressure drop due to debris across the submerged sump screen area. The partially submerged sump screen will operate properly if the estimated head loss (in feet-of-water across the debris bed, when added to the clean screen head loss) is less than one-half the pool height.

3.2.5.2.3.2.5 Buoyant Debris

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.

3.2.5.2.3.3 Methodology Limitations and Other Considerations

3.2.5.2.3.3.1 Flat Screen Assumption

The NUREG/CR-6224 correlation adopted in this methodology was developed mainly using data obtained in a closed loop that contained a vertical pipe section which housed a horizontally mounted flat screen. The flat screens yielded conservative data for the development of the NUREG/CR-6224 correlation because all debris was forced onto a very small screen in a small-scale test apparatus. In the case of alternate design screens (stacked disc, star, large-passive, etc.) direct application of the NUREG/CR-6224 correlation may yield overly conservative results (Reference 3.2.5-2). For these alternate geometry screens, independent head loss correlations should be developed based on actual design configurations, debris loads, and test data to reduce conservatism.

3.2.5.2.3.3.2 Non-Uniform Deposition on Sump Screen Surfaces

PWR sump screens can have vertical and inclined orientation. On a vertical screen, there is greater chance for non-uniform deposition of debris, which will usually lead to lower head losses because of thin spots in the debris bed. Body forces also tend to shear the bed from the screen, also a mitigating factor. For these reasons, using the uniform deposition assumption for vertical screens is a conservative approach. Similar statements can be made for curved surfaces such as horizontally oriented, cylindrical strainer designs, since body forces in the debris bed essentially act in the opposite direction to the suction forces over a significant portion of the strainer area.

An inclined, flat surface is less limiting than a horizontal surface, therefore, the uniform deposition assumption again should be conservative.

3.2.5.2.3.3.3 Very Thin Fiber Beds

This section pertains to the regime where fiber loading is less than that required to form a thin-bed. The NUREG/CR-6224 head loss correlation was developed and validated for debris that is uniformly distributed on the screen surface. However, experiments have shown that very thin fibrous beds (with a thickness of less than one-eighth inch) are characterized by large scale non-uniformities on the screen and negligible head losses. For fibrous debris bed less than one-eighth inch thick, the NUREG/CR-6224 head loss correlation significantly over predicts the experimentally determined head loss and should not be used. Instead, it is appropriate to consider the head loss across fibrous debris beds less than one-eighth inch to be negligible.

3.2.5.2.4 Sample Calculation

The following examples demonstrate the use of the head loss equations with the debris sources specified in Section 3.2.2.3 of this document and typical plant conditions. These calculations assume steady-state conditions at final debris loading with steady ECCS flows and a simple, flat-plate strainer geometry.

3.2.5.2.4.1 Fiber and Particulate Debris Bed

<u>Flow Conditions:</u>

These are obtained from plant design documents and NPSH calculations.

ECCS Flow Rate (Q) = 9000 gpm

Temperature (T) = 170 °F

Fluid Density (ρ) = 60.80 lbm/ft^3

Fluid Viscosity (μ) = 2.51E-04 lbm/ft/sec

Screen Parameters:

These are obtained from screen design drawings and ECCS flow rate.

Effective Surface Area (A) = 300 ft^2
Screen Approach Velocity (U) = 0.067 ft/s

Debris Types/Quantities at Screen:

These are obtained from Debris Characteristics (Section 3.2.2), Latent Debris (Table 3.2.3-1) and the Transport Analysis (Section 3.2.4).

NUKON Fiber = 129 ft^3
Latent Fiber = 8.84 ft^3 ⇐ 62.4/2.4 * 0.34 ft^3
Latent Dirt-Dust = 33.51 lbm
Qual-Epoxy = 329 lbm
Unqual. Coatings = 2625 lbm

Debris Characteristics:

- NUKON

Theoretical Packing Density (ρ_f) = 2.4 lbm/ft^3
Fiber Diameter (D) = $2.33 * 10^{-5}$ ft (use LDFG)
Surface to Volume Ratio (S_v) = $1.717 * 10^5$ ft^{-1} ⇐ 4 / $2.33 * 10^{-5}$ ft^3
Mass of Fiber (m_f) = 309.6 lbm ⇐ 129 ft^3 * 2.4 lbm/ft^3
Fiber Density = 175 lbm/ft^3
Fiber Volume = 1.77 ft^3 ⇐ 309.6 lbm / 175 lbm/ft^3

- Latent Fiber

Theoretical Packing Density (ρ_f) = 2.4 lbm/ft^3 (assume same as LDFG)
Fiber Diameter (D) = $2.33 * 10^{-5}$ ft
Surface to Volume Ratio (S_v) = $1.717 * 10^5$ ft^{-1} ⇐ $4 / 2.33 * 10^{-5}$ ft^3
Mass of Fiber (m_f) = 21.22 lbm ⇐ 8.84 ft^3 * 2.4 lbm/ft^3
Fiber Density = 62.4 lbm/ft^3 (Table 3.2.3.4.2-1)
Fiber Volume = 0.34 ft^3 ⇐ 21.22 lbm / 62.4 lbm/ft^3

- Latent Dirt/Dust

Particle Density = 100 lbm/ft^3
Particle Diameter (D) = $3.28 * 10^{-5}$ ft
Surface to Volume Ratio (S_v) = $1.829 * 10^5$ ft^{-1} ⇐ $6 / 3.28 * 10^{-5}$ ft^3
Particle Volume = 0.335 ft^3 ⇐ 33.51 lbm / 100 lbm/ft^3

With respect to qualified coatings in the ZOI, a relatively high damage pressure has been justified in earlier sections of this document. However, the demonstration calculations will use a spherical ZOI with radius of 10-feet, for a surface area of 1256.6 ft^2. The qualified coatings thickness is taken to be 0.009″. For unqualified coatings, a thickness of 0.003″ is used, and 30,000 ft^2 is the assumed coverage. In both cases, the coatings particles are conservatively assumed to be spherical with diameter equal to 10 μm. The coatings material is assumed to be inorganic zinc (IOZ) in both cases.

- Qualified Epoxy

Particle Density = 350 lbm/ft^3 (IOZ-equivalent)
Particle Diameter (D) = $3.28 * 10^{-5}$ ft
Surface to Volume Ratio (S_v) = $1.829 * 10^5$ ft^{-1} ⇐ $6 / 3.28 * 10^{-5}$ ft^3
Particle Volume = 0.94 ft^3 ⇐ 329 lbm / 350 lbm/ft^3

- Unqualified Epoxy

Particle Density = 350 lbm/ft^3 (IOZ-equivalent)
Particle Diameter (D) = $3.28 * 10^{-5}$ ft
Surface to Volume Ratio (S_v) = $1.829 * 10^5$ ft^{-1} ⇐ 6 / $3.28 * 10^{-5}$ ft^3
Particle Volume = 7.50 ft^3 ⇐ 2625 lbm / 350 lbm/ft^3

- Average Fiber

Total Fiber Volume = 2.11 ft^3
Total Fiber Mass = 330.82 lbm
Ave Fiber Density = 156.86 lbm/ft^3
Ave Surface to Volume Ratio (S_v) = $1.717 * 10^5$ ft^{-1}

- Average Particulate

Total Particle Volume = 8.775 ft^3
Total Particle Mass = 2987.5 lbm
Ave Particle Density = 340.46 lbm/ft^3
Ave Surface to Volume Ratio (S_v) = $1.829 * 10^5$ ft^{-1}

- Average Debris

Total Particle Volume = 8.775 ft^3
Ave Surface to Volume Ratio (S_v) = $1.829 * 10^5$ ft^{-1}

Total Fiber Volume = 2.11 ft^3
Surface to Volume Ratio (S_v) = $1.717 * 10^5$ ft^{-1}

Ave Debris Surface to Volume Ratio (S_v) = $1.8078*10^5$ ft^{-1}

Debris Bed Equations:

- Theoretical Debris Bed Thickness (ΔL_o)

  Total Volume of Fiber divided by Screen Area = 5.51 inches

- Particulate to Fiber Mass Ratio (η)

  Mass of Particles divided by Mass of Fiber = 9.03

- Actual Bed Thickness (ΔL_m) = 2.72 inches

Assume a value for the bed thickness and iterate until Equations 3.2.5-3 and 3.2.5-4 converge on approximately the same number. Computer solution may be required.

Eq. 3.2.5-1: Head Loss Across Debris Bed (ΔH) = 17.80 feet H_2O

Eq. 3.2.5-2: Mixed Debris Bed Solidity (α_m) = 0.16

Eq. 3.2.5-3: Head Loss Volumetric Compression (c) ≈ 2.03

Eq. 3.2.5-4: Head Loss Volumetric Compression (c) ≈ 2.03

Equations 3.2.5-3 and 3.2.5-4 have converged within <1% of each other, which is considered and acceptable convergence. Therefore, the head loss is calculated as 17.80 feet-of-water.

The mixed debris bed solidity should be less than or equal to 0.20, therefore OK.

3.2.5.2.4.2 Fiber Debris Bed

No sample calculation is provided since a pure fiber debris bed would be unusual, given the coatings particulate debris in the ZOI, latent debris, the presence of dirt/dust and other possible sources of particulates such as ablated concrete. However, should a fiber-only debris-bed head loss need to be calculated, the process would be the same as for fiber and particulate except that the particulate quantities would be set to zero.

3.2.5.2.4.3 RMI Debris Bed

Flow Conditions:

These are obtained from plant design documents and NPSH calculations.

ECCS Flow Rate (Q) = 9000 gpm

Temperature (T) = 170 °F

Fluid Density (ρ) = 60.80 lbm/ft^3

Fluid Viscosity (μ) = 2.51E-04 lbm/ft/sec

Screen Parameters:

These are obtained from screen design drawings and ECCS flow rates.

Effective Surface Area (A) = 300 ft^2

Screen Approach Velocity (U)` = 0.067 ft/s

Debris Types/Quantities:

These are obtained from the Debris Characteristics (Section 3.2.2) and Debris Transport Analysis (Section 3.2.4).

2.5-mil SS RMI = 4387.5 $\text{ft}^2 \Leftarrow 11{,}250\ \text{ft}^2 * 0.39$ T.F.

Debris Bed Equations:

The head loss correlation for RMI is taken from Section 3.2.5.2.3.1.2

$$\Delta H = 0.108\, U^2\, (A_{foil} / A_c)$$

where,

ΔH = the head loss across the RMI bed (ft-water),

U = the approach velocity to the screen (ft/s),

A_{foil} = the surface area of the RMI foils (ft^2 – nominal), and

A_c = the strainer circumscribed area (ft^2).

Substituting the above plant specific parameters,

$$\Delta H = 0.108\, (0.067)^2\, (4387.5 / 300)$$

$$= 0.007 \text{ ft-water} \cong 0.01 \text{ ft-}H_2O$$

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

The head loss of a mixed fiber, particulate, and RMI debris bed is the addition of the fiber-and-particulate head loss to the RMI head loss. For example, if the quantities of debris were as in the totals of Sections 3.2.5.2.4.1 and 3.2.5.2.4.2, then the total mixed RMI and fibrous debris bed head loss would be:

ΔH_{RMI} = 0.01 ft-water

$\Delta H_{Fiber + Particulate}$ = 17.80 ft-water

hence,

$\Delta H_{RMI+ Fiber + Particulate}$ = 17.81 ft-water. (We can neglect the RMI in this case).

3.2.5.2.4.5 Thin-Bed of Fiber and Particulate Debris

Flow Conditions:

These are obtained from plant design documents and NPSH calculations.

ECCS Flow Rate (Q) = 9000 gpm
Temperature (T) = 170 °F
Fluid Density (ρ) = 60.80 lb/ft^3
Fluid Viscosity (μ) = 2.51E-04 lb/ft/sec

Screen Parameters:

These are obtained from screen design drawings and ECCS flow rate.

Effective Surface Area (A) = 300 ft^2
Screen Approach Velocity (U)` = 0.067 ft/s

Debris Types/Quantities:

As a starting point, use plant-specific quantities of fine particulate and latent debris. Provided that sufficient fiber is available, the fiber quantity is specifically selected to create a Thin-Bed. Nukon® is assumed for this example, although latent fiber could just as well be used if a sufficient amount is present.

NUKON Fiber = 3.125 ft^3 ⇐ 0.125″/12 * 300 ft^2
Dirt-Dust = 33.51 lbm
Qual-Epoxy = 329 lbm
Unqualified Coatings = 2625 lbm

Debris Characteristics:

- NUKON

Theoretical Packing Density (ρ_f) = 2.4 lbm/ft^3
Fiber Diameter (D) = $2.33 * 10^{-5}$ ft
Surface to Volume Ratio (S_v) = $1.717 * 10^{5}$ ft^{-1} ⇐ $4 / 2.33 * 10^{-5}$ ft^3
Mass of Fiber (m_f) = 7.5 lbm ⇐ 3.125 ft^3 * 2.4 pcf
Fiber Density = 175 lbm/ft^3
Fiber Volume = 0.043 ft^3 ⇐ 7.5 lbm / 175 lbm/ft^3

- Latent Dirt/Dust

Particle Density = 100 lbm/ft^3
Particle Diameter (D) = $3.28 * 10^{-5}$ ft
Surface to Volume Ratio (S_v) = $1.829 * 10^{5}$ ft^{-1} ⇐ $6 / 3.28 * 10^{-5}$ ft^3
Particle Volume = 0.335 ft^3 ⇐ 33.51 lbm / 100 lbm/ft^3

- Qualified Epoxy

Particle Density = 350 lbm/ft^3 (IOZ-equivalent)
Particle Diameter (D) = $3.28 * 10^{-5}$ ft
Surface to Volume Ratio (S_v) = $1.829 * 10^{5}$ ft^{-1} ⇐ $6 / 3.28 * 10^{-5}$ ft
Particle Volume = 0.94 ft^3 ⇐ 329 lbm / 350 lbm/ft^3

- Unqualified Coatings

Particle Density = 350 lbm/ft^3 (IOZ-equivalent)
Particle Diameter (D) = $3.28 * 10^{-5}$ ft
Surface to Volume Ratio (S_v) = $1.829 * 10^{5}$ ft^{-1} ⇐ $6 / 3.28 * 10^{-5}$ ft
Particle Volume = 7.5 ft^3 ⇐ 2625 lbm / 350 lbm/ft^3

- Average Particulate

Total Particle Volume = 8.775 ft^3

Total Particle Mass = 2987.5 lbm

Ave Particle Density = 340.46 lbm/ft^3

Ave Surface to Volume Ratio (S_v) = $1.829 * 10^5$ ft^{-1}

- Average Debris

Total Particle Volume = 8.775 ft^3

Ave Surface to Volume Ratio (S_v) = $1.829 * 10^5$ ft^{-1}

Total Fiber Volume = 0.043 ft^3

Surface to Volume Ratio (S_v) = $1.717 * 10^5$ ft^{-1}

Ave Debris Surface to Volume Ratio (S_v) = $1.82847 * 10^5$ ft^{-1}

Debris Bed Equations:

- Theoretical Debris Bed Thickness (ΔL_o)

  Total Volume of Fiber divided by Screen Area = 0.125-inch

- Particulate to Fiber Mass Ratio (η)

  Mass of Particles divided by Mass of Fiber = 398.34

- Actual Bed Thickness (ΔL_m) = 1.764-inches

  Sum the fiber and particulate volumes. Multiply by 12 and divide by the product of the (Solidity * Screen Net Area) Limiting solidity value of 0.20 is recommended.

Eq. 3.2.5-1: Head Loss Across Debris Bed (ΔH) = 19.27 ft-H_2O

Eq. 3.2.5-2: Mixed Debris Bed Solidity (α_m) = 0.20

The calculated head loss is 19.27 feet of water via iterative solution. Computational tools may be required. Since the calculated head loss of the thin-bed exceeds the NPSH Margin at most plants, parametric calculations can be performed to determine the allowable particulate quantities at the sump screen(s).

3.2.5.2.4.6 Microporous Insulation

As noted in 3.2.5.2.3.1.5 above, the currently available experimental data can only support the head loss calculations of microporous insulation debris in the presence of fibrous debris provided the mass ratio of microporous insulation-to-fiber is less than 20 percent. In these cases the microporous insulation debris is treated as a particulate and the equations and methods for fibrous and particulate head loss are used (see example of Section 3.2.5.2.4.1 above).

3.2.5.2.4.7 Determination of Requisite Sump Screen Size

If, through the evaluation of the debris head loss, the existing screen does not provide sufficient surface area, the calculations provided within this methodology can be utilized with little or no modification to determine the amount of surface area required.

The key assumption in the head loss correlations provided is homogeneous debris accumulation on a flat plate. As noted in Section 3.2.5.2.3.3.1, different screen orientations and configurations can provide different debris accumulation profiles and take advantage of uneven debris distribution and flow redistribution. In these cases, the head loss correlations provided in this methodology may yield overly conservative results. As such, adjustments to the head loss correlation could be made based on experimental test data applicable to the actual sump screen orientation and configuration. Some test data exist for vertical screens; (see Ref. 3.2.5-6), but applicability of the test data always has to be assessed. In some cases, plant-specific testing may be required to reduce conservatism. Suggested refinements are further outlined in the Supplemental Guidance.

3.2.5.2.5 Calcium Silicate

Informal results on the NRC/LANL calcium silicate testing at UNM were presented in February 2003 (Reference 3.2.5-4). This presentation did not provide any quantitative guidance with respect to use of the NUREG/CR-6224 correlation with Cal-Sil debris mixtures. A recent LANL/NRC/UNM paper [Reference 3.2.5-5] has provided more detailed test results. The formal NRC test report on this program is not yet available.

Reference 3.2.5-5 has been reviewed, and some observations are provided. With respect to the calcium silicate tests with Nukon fiber, the principal comment is that these results will have to be applied very carefully on a plant-specific basis. For example, the researchers operated their test apparatus at very high flow rates, which induced high approach velocities that compressed the debris beds to the compression limit of the granular debris. When the flow was reduced, the compressed bed did not relax, nor did it release the trapped particles. Hysteretic effects were observed, for which head losses were actually greater at lower flows. Then, the surface-to-volume ratio was adjusted such that the NUREG/CR-6224 correlation conservatively predicted the hysteretic effects. For some plants, this testing does not represent prototypical behavior, and it is excessively conservative. It also suggests the troubling conclusion that there is no benefit to throttling the ECCS flows to reduce sump screen head loss with Cal-Sil, which for some plants again may not be true.

Based on the research procedures described above, Reference 3.2.5-5 concludes that S_V = 550,000 ft^{-1} is an appropriate value for the specific type of Cal-Sil that was tested. The researchers further recommend that this value be conservatively enhanced for safety analyses. Our observation is that this procedure will be excessively conservative for many plants, depending on the type(s) of Cal-Sil present in these plants and on the sump screen approach velocities. Therefore, the results of Reference 3.2.5-5 should be applied with extreme caution.

The researchers applied similar techniques to the test with fiber, dirt and concrete dust in Reference 3.2.5-5. Therefore, the recommended value of $S_V = 190{,}000\ ft^{-1}$ is also considered too conservative.

Reference 3.2.5-5 itself mentions that the LANL Test Report, LA-UR-03-0471, should be consulted for final recommendations once it is issued. On April 17, 2004, the PWR Industry became aware that Los Alamos published LA-UR-04-1227, "GSI-191: Experimental Studies of Loss-of-Coolant-Accident-Generated Debris Accumulation and Head Loss with Emphasis on the Effects of Calcium Silicate Insulation". A review of that document has been initiated for the purpose of assessing what, if any, further guidance regarding treatment of Calcium Silicate might be supported by the tests reported.

3.2.5.3 References

3.2.5-1 NUREG/CR-6808, LA-UR-03-0880, D.V. Rao, Clinton J. Shaffer, M.T. Leonard, "Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance," U.S. Nuclear Regulatory Commission, February 2003

3.2.5-2 NUREG/CR-6224, G. Zigler, J. Bridaeu, D. V. Rao, C. Shaffer, F. Souto, W. Thomas, "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris," Final Report, U.S. Nuclear Regulatory Commission, October 1995

3.2.5-3 C.J Shaffer, et al., "BLOCKAGE 2.5 Reference Manual," NUREG/CR-6371, December 1996

3.2.5-4 Leonard, M. T., Arup Maji, et. al., "Debris Accumulation & CalSil Head Loss Testing—Findings & Preliminary Conclusions," Presentation at GSI-191 Public Meeting, Albuquerque, NM, March 5, 2003

3.2.5-5 Shaffer, C. J. et. al., "Debris Accumulation and Head-Loss Data for Evaluating the Performance of Vertical Pressurized-Water-Reactor Recirculation Sump Screens", presented at the NEA/NRC Workshop on Debris Impact on Emergency Coolant Recirculation, Albuquerque, NM, February 25-27, 2004

3.2.5-6 NEA/CSNI/R (95) 11, “Knowledge Base for Emergency Core Cooling System Recirculation Reliability,” Prepared by U.S. Nuclear Regulatory Commission for the Principal Working Group 1 (PWG-1), International Task Group, Committee on the Safety of Nuclear Installations, Organization for Economic Cooperation and Development (OECD) Nuclear Energy Agency (NEA), February 1996

3.2.5-7 LA-UR-04-1227, “GSI-191: Experimental Studies of Loss-of-Coolant-Accident-Generated Debris Accumulation and Head Loss with Emphasis on the Effects of Calcium Silicate Insulation,” Los Alamos, April, 2004

Attachment A

WHITE PAPER
DEFINING THE ZONE OF INFLUENCE (ZOI) AND MINIMUM COATING DEBRIS SIZE FOR DBA-QUALIFIED AND ACCEPTABLE COATINGS IN PRESSURIZED WATER REACTOR (PWR) CONTAINMENTS

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APRIL 2, 2004

EXECUTIVE SUMMARY

This White Paper has been prepared to provide a conservative approach for determining the Zone of Influence (ZOI) and minimum coating debris size for DBA-qualified and Acceptable coatings in Pressurized Water Reactor (PWR) containments.

The criteria for DBA-qualification or designation as “Acceptable” of coatings applied to systems, structures and components in PWR containments do not provide data concerning coatings exposed to direct impingement of fluids. As such, the ZOI for DBA-qualified coatings or coatings determined to be “Acceptable,” applied to PWR containment surfaces, which results from fluid impingement from the break jet, has not been clearly defined.

An extensive body of data exists related to removal of industrial protective coatings by high-pressure and ultra-high-pressure waterjetting. Examination of this data and associated industry standards, compiled since the mid-1980’s, reveals that industrial protective coating systems, identical to the DBA-qualified and “Acceptable” coatings applied to systems, structures and components in Pressurized Water Reactor (PWR) containments, require a water jetting pressure of at least 7,000 psig to initiate destruction of sound coatings.

In the writer’s opinion, protective coating systems which have been successfully DBA-qualified will have a minimum waterjet destruction pressure of no lower than 7,000 psig. This 7,000 psig waterjet destruction pressure can be conservatively used to define a bounding “coating ZOI” for DBA-qualified coatings as 1,000 psig about the DBA pipe rupture.

All currently-available industrial high-pressure waterjetting equipment systems are equipped with 10 μm filtration to remove particles from discharge water to protect the environment. Based upon the acceptance of this lower-bound of filtration by environmental regulatory bodies throughout the United States, it can be conservatively assumed that debris generated from the destruction of industrial coatings identical to those coatings used in PWR containments to be no less than 10 μm in minor dimension.

DISCUSSION

The criteria for DBA-qualification of coating systems applied to systems, structures and components in PWR containments are contained in ANSI N101.2, "Protective Coatings (Paints) for Light Water Nuclear Reactor Containment Facilities (Reference A-1)," and its successor document, ASTM D 3911, "Standard Test Method for Evaluating Coatings Used in Light-Water Nuclear Power Plants at Simulated Design Basis Accident (DBA) Conditions (Reference A-2)." Both of these national standards are essentially identical to their requirements for DBA-qualification of coatings:

1. Fully-cured coated panels are placed in an autoclave chamber. Note that, by test method requirements, the panels are positioned such that they are not subject to direct steam impingement.

2. Using saturated steam, the autoclave pressure and temperature are adjusted to produce conditions approximating the DBA environment of a utility's containment structure.

3. After completion of the DBA cycle, each panel is examined. Any disbondment of the coating (including cracking, peeling, delamination and/or complete detachment) is rated unacceptable.

The only technical difference between ANSI N101.2 and ASTM D3911 is the acceptance criteria for intact blistering, which has no bearing on coating debris production.

The US Nuclear Regulatory Commission has reviewed ASTM D 3911 and found it "…acceptable to the NRC staff for the…qualification… of protective coatings applied in nuclear power plants," as stated in Regulatory Guide 1.54 Revision 1 (July 2000) (Reference A-3).

Nuclear plants licensed prior to the issuance of ANSI N101.2 selected and tested coating systems for use in containment by virtue of sound engineering practices. Containment coatings by this pre-ANSI N101.2 process are designated as “Acceptable” as defined in ASTM D5144-00 (Reference A-4):

> “*Acceptable Coating or Lining System* – A safety-related coating or lining system for which a suitability for application review which meets the plant licensing requirements has been completed and there is reasonable assurance that, when properly applied and maintained, the coating or lining will not detach under normal or accident conditions.”

In most cases, the coating products and systems applied to PWR containment structures, systems and components in pre-ANSI N101.2 plants are identical to those used in post-ANSI N101.2 plants. These coating materials were system combinations of inorganic zinc, epoxy and epoxy phenolic primers; and epoxy and epoxy phenolic topcoats supplied by Ameron, Carboline, and Keeler & Long. As such, the performance of “Acceptable” coating systems can be equated with the performance of “DBA-qualified” coating systems within the scope of this White Paper.

As part of the overall regulatory investigation of GSI-191, Savannah River Technology Center (SRTC) was engaged by the US Nuclear Regulatory Commission Division of Engineering Technology Office of Regulatory Research to “…investigate the potential for degradation and failure of such coating systems (safety-related coatings located inside containment, ed.) when subjected to DBA conditions, and to characterize failed coating debris…” (Reference A-5), and, “…investigate the performance and potential for debris formation of Service Level I (safety-related coatings located inside containment, ed.) used in nuclear power plant containment…” (Reference A-6). The two major findings concerning the performance of DBA-qualified coatings in PWR containment service which resulted from the SRTC research are presented in References A-4 and A-5 as follow:

> <u>Reference 5:</u>
>
> “Properly applied coatings that would contain only minor defects and that have not been subjected to irradiation of 10^9 rads, can be expected to remain fully adhered and intact on

> a **concrete substrate** (emphasis added, ed.), following exposure to simulated DBA-LOCA conditions."

> Reference 6:

> "Properly applied coatings that have not been subjected to irradiation of 10^9 rads, can be expected to remain fully adhered and intact on a **steel substrate** (emphasis added, ed.), following exposure to all simulated DBA-LOCA conditions."

Thus, the independent research by SRTC on behalf of the USNRC validates the DBA test methodology for containment coatings contained in ANSI N101.2 and ASTM D 3911.

The test method defined in ANSI N101.2 and ASTM D 3911 does not provide data concerning coatings exposed to direct impingement of fluids, however. As such, the ZOI for DBA-qualified coatings or coatings determined to be "Acceptable," applied to PWR containment surfaces, which results from fluid impingement from the break jet, was not clearly defined in the past. Understanding the performance of DBA-qualified protective coatings in fluid impingement conditions is necessary to quantify coating debris generation in DBA conditions and its contribution to the overall debris source term.

An extensive body of data and experience exists related to removal of industrial protective coatings by high-pressure and ultra-high-pressure waterjetting. National standards and related commentary related to coating removal by high-pressure waterjetting have been published under the auspices of SSPC: The Society for Protective Coatings and are contained in the following documents:

1. Good Painting Practice; SSPC Painting Manual Volume 1 (Reference A-7)

2. Systems and Specifications; SSPC Painting Manual Volume 2 (Reference A-8)

Reference A-7 contains an entire section on water-process paint and coating removal ("Chapter 2.7, Wet Abrasive Blast and Pressurized Water Cleaning (Waterjetting)"), which provides the following information concerning the effects of a high-pressure water jet on industrial coatings:

A. "At 10,000 psig, the velocity of the water is close to 1,100 ft. /sec., or a fluid jet. The velocity then starts to change the amount of cutting… from a hydraulic action to an erosion action." This permits correlation with the effects of a high-pressure single-phase water jet as used in industrial surface preparation with a two-phase steam-water jet which might be encountered in a DBA pipe break on industrial coatings.

B. "Typical cleaning applications for (sic) at various pressures include:

- **10,000-24,000 psig**: …most paints …" This sets the lower-bound damage pressure for sound industrial coatings, and similarly DBA-qualified PWR containment coatings, at 10,000 psig.

Reference A-8 contains the technical standards for high-pressure water blasting. The applicable standard, "Joint Surface Preparation Standard SSPC-SP 12/NACE No. 5, Surface Preparation and Cleaning of Steel and other Hard Materials by High- and Ultrahigh-Pressure Water Jetting Prior to Recoating (© 1995)," provides the following information applicable to determining the lower- bound damage pressure for sound industrial coatings, and similarly DBA-qualified PWR containment coatings:

A. "2.1.5 **High-Pressure Water Jetting (HP WJ)**:
HP WJ is cleaning performed at pressures from 70 to 170 MPa (10,000 to 25,000 psi)."

B. "D1.2 Typically, the water jet nozzle should be held 5 to 25 cm (2 to 10 in.) from the surface being cleaned…"

The industrial practice requirements related to high-pressure waterjetting at 10,000 psig to 25,000 psig fluid pressure for holding the waterjetting nozzle relatively close to the surface to be cleaned reflects industry experience of a relatively small pressure drop between the nozzle tip and the substrate, and provides additional correlation with an conservative lower-bound destruction pressure for industrial coatings of 10,000 psig.

Limited information is available concerning the use of high-pressure waterjetting for removal of PWR containment coatings. One utility has performed trials of high-pressure waterjetting for removal of standard PWR containment coating systems applied to concrete and steel substrates, and has determined a threshold waterjetting destruction pressure for coatings of 7,000 to 8,000 psi (Reference A-9). This information correlates well with the generally available industrial coating removal data.

Modern waterjetting nozzles are designed to produce turbulent, high energy water droplet flow, either by a single orifice with a diffusion pattern or a multiple orifice nozzle rotating up to 3,000 rpm (Reference A-7) to produce optimum coating destruction. As such, the effect of single-phase waterjetting on coatings can be conservatively equated to the effect of the two-phase impingement of fluid from a DBA pipe rupture in a PWR containment with regard to coating destruction.

In the writer's opinion, protective coating systems which have been successfully DBA-qualified using ANSI N101.2 or ASTM D3911 test methods, and "Acceptable" coating systems essentially identical to those later DBA-qualified, will have a minimum waterjet destruction pressure of no lower than 5,000 psig. This 5,000 psig waterjet destruction pressure can be conservatively used to define a "coating ZOI" for DBA-qualified coatings of 1,000 psig about the DBA pipe rupture.

All currently-available industrial high-pressure waterjetting equipment systems are equipped with 10 μm filtration to remove particles from both discharge water and thus to protect the environment (Reference A-10). Based upon the acceptance of this lower-bound of filtration by environmental regulatory bodies throughout the United States, it can be conservatively assumed that debris generated from the destruction of industrial coatings identical to those used in PWR containments to be no less than 10 μm in minor dimension. This 10 μm debris minimum dimension would apply to coatings within the 10,000 psig coating ZOI.

In the writer’s opinion, any coating debris produced within the coating ZOI by the destruction of DBA-qualified coatings can be conservatively assumed to be no less than 10 μm in minor dimension.

REFERENCES

A-1	ANSI N101.2-1972, “Protective Coatings (Paints) for Light Water Nuclear Reactor Containment Facilities” American National Standards Institute, Approved May 30, 1972
A-2	ASTM D 3911-95, “Standard Test Method for Evaluating Coatings Used in Light-Water Nuclear Power Plants at Simulated Design Basis Accident (DBA) Conditions” ASTM International, 1995
A-3	U.S. Nuclear Regulatory Commission Regulatory Guide 1.54, “Service Level I, II, and III Protective Coatings Applied to Nuclear Power Plants” Revision 1 (July 2000)
A-4	ASTM D 5144-00, “Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants” ASTM International, 2000
A-5	WSRC-TR-2000-00340, “Degradation and Failure Characteristics of NPP Containment Protective Coating Systems (U)” October 2000
A-6	WSRC-TR-2001-00067, “Degradation and Failure Characteristics of NPP Containment Protective Coating Systems (U) Interim Report No. 3” February 2001
A-7	SSPC Painting Manual Volume 1, Good Painting Practice, Fourth Edition, Copyright 2002 by SSPC: The Society for Protective Coatings
A-8	SSPC Painting Manual Volume 2, Systems and Specifications, Eighth Edition, Copyright 2000 by SSPC: The Society for Protective Coatings
A-9	Telephone correspondence between Jon R. Cavallo, PE, PCS (Corrosion Control Consultants and Labs, Inc.) and Garth Dolderer (Florida Power and Light) on March 31, 2004
A-10	“FLOW Waterjet is your competitive advantage for surface preparation” © 2000 Flow International Corporation FIC-B002 (11/00)