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Utility Resolution Guide for ECCS Suction Strainer Blockage

Volume 1

Prepared By
BWR Owners' Group

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Volume 1 of 4

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Utility Resolution Guidance

for

ECCS Suction Strainer Blockage

prepared by

Boiling Water Reactor Owners' Group

Volume 1

Recommendations for Use of NEDO-32686-A "Utility Resolution Guidance for ECCS Suction Strainer Blockage"

Overview

Background

To provide guidance to operators of BWRs for responding to NRC Bulletin 96-03, the BWR Owners' Group issued Licensing Topical Report NEDO-32686, Revision 0, "Utility Resolution Guidance for ECCS Suction Strainer Blockage" in November 1996. From November 1996 through August 1998 the BWR Owners' Group supported the NRC review of this document for which the NRC issued a Safety Evaluation Report on August 20, 1998.

The BWR Owners' Group elected not to rewrite NEDO-32686, Revision 0 to incorporate revisions required to assure that the guidance is consistent with the NRC Safety Evaluation. Instead, a "final" version of the document has been prepared which supplements the original utility guidance with the additional information provided during the NRC review and issuance of the Safety Evaluation Report.

NEDO-32686, Rev. 0 was originally comprised of an unnumbered overview document accompanied by three volumes of technical support documentation. This final version, NEDO-32686-A, is comprised of four volumes.

Volume One includes the original NEDO-32686, Rev. 0 as submitted along with the correspondence between the NRC staff and the BWR Owners' Group occurring during NRC review. The final Safety Evaluation Report from the staff is also included in Volume One (see Table of Contents for details). The user needs to be aware that in key areas there are differences between the approach recommended in the original submittal and those approved by the NRC in the Safety Evaluation. The relative importance of these differences to any individual utility will be affected by their plant specific design and debris loading assumptions. A table providing a summary of the major differences is provided herein (see Differences in Methodology). The NRC also compiled a summary of responses to BWROG comments on the draft Safety Evaluation (see Appendix L in Tab 1). This summary can be used to identify all of the areas in which the NRC did not fully accept the BWROG recommended guidance and should be reviewed in its entirety to avoid overlooking any plant specific problems.

Volumes Two, Three, and Four of this final report contain the Technical Support Documentation. These volumes were numbered One, Two and Three in the original NEDO-32686, Rev. 0 and are unchanged except for the Volume numbers. The documents contained in these supporting volumes provide the technical basis for the guidance provided in Volume 1 and are of integral importance.

Recommendations for Use of NEDO-32686-A "Utility Resolution Guidance for ECCS Suction Strainer Blockage"

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TAB NUMBER		
1.	Safety Evaluation for NEDO-32686, Rev. 0 "Utility Resolution Guidance Document for ECCS Suction Strainer Blockage" (including revised page B-5 transmitted to the BWR Owners' Group on October 13, 1998)	August 20, 1998
2.	Correction to Page B-5 of the Staff's Final Safety Evaluation on NEDO-32686, revision 0	October 13, 1998
3.	Initial Staff's Comments and Questions on URG	December 23, 1996
4.	BWR Owners' Group response to NRC comments and questions regarding NEDO-32686 Revision 0, "Utility Resolution Guidance for ECCS Suction Strainer Blockage"	January 30, 1997
5.	BWR Owners' Group Response to NRC Comments Regarding the Effect of RMI and Fiber Combination on Strainer Head Loss	September 19, 1997
6.	BWR Owners' Group Comments Regarding NRC Draft Safety Evaluation Report of the BWR Owners' Group Utility Resolution Guidance for ECCS Strainer Blockage (NEDO-32686) dated December 31, 1997	March 13, 1998
7.	NEDO-32686 "Utility Resolution Guidance for ECCS Strainer Blockage", Revision 0	November 20, 1996

Note that the Table of Contents for the Technical Support Documentation (Volumes 2, 3, and 4) is located immediately following the cover page in Volumes 2, 3, and 4.

Recommendations for Use of NEDO-32686-A "Utility Resolution Guidance for ECCS Suction Strainer Blockage"

Differences in Methodology Approved in Safety Evaluation Report Versus BWR Owners' Group Proposed Methodology Documented in NEDO-32686, Revision 0

Overall, the NRC has accepted most of the proposed BWR Owners' Group methodology documented in NEDO-32686, Revision 0. The Staff has agreed that there is sufficient overall conservatism in the URG methodologies to allow certain portions to be used even though the Staff may have specific technical concerns with respect to the conservatism of selected parameters. However, there are portions of the BWR Owners' Group guidance that the NRC staff has not accepted due to the need for further technical justification. In most cases, the BWROG chose not to pursue this type of additional work based on the recognition that it was not generic in nature; and would, therefore, not be an effective role for the BWROG. Licensees desiring to use portions of the URG which the Staff has not accepted will need to resolve the Staff's concerns on a plant specific basis.

Appendix L of the NRC's Safety Evaluation provides a summary of BWROG comments on the draft SER and the final proposed Staff resolution. This Appendix can be employed to readily identify methodologies and/or BWR Owners' Group positions which have not been approved for generic application. While the following table summarizes the major differences which could impact replacement ECCS strainer design requirements it is highly recommended that Appendix L be reviewed in its entirety to avoid overlooking any plant specific concerns:

Item	NRC App. L Comment No.	URG Section	Methodology/BWROG Position Not Approved
1	7, 9, 40	3.2.6	*Method for determining strainer head loss.* All US BWRs have employed vendor supplied head loss correlations instead of those documented in the URG. Therefore, this issue is not of particular significance except for the BWROG position on combined fiber/RMI debris beds where the recommendation is to use the higher of fiber plus miscellaneous debris (without RMI debris) or RMI debris only. The NRC is requiring licensees to assure that the strainer vendor reviews the plant specific debris combination and confirms that the head loss from fiber plus particulates plus RMI does not exceed that of fiber plus particulates. The NRC is specifically concerned about larger fiber loading in the presence of RMI debris.
2	10	3.1.3.4.3	*Use of banding and jacketing of insulation materials to reduce quantity of debris generated.* Sufficient guidance and test data has not been provided.
3	16	3.2.1.1	*Use of MEB 3-1 for selection of break locations to be evaluated.* The NRC requires evaluation of breaks that result in the maximum debris generation.

Recommendations for Use of NEDO-32686-A "Utility Resolution Guidance for ECCS Suction Strainer Blockage"

Item	NRC App. L Comment No.	URG Section	Methodology/BWROG Position Not Approved
4	23, 27	3.2.1.2	*Destruction pressure.* NRC has concluded that the jet-centerline pressure (JCP) approach would result in smaller than desired zone of influences (ZOI) for insulation with high destruction pressures. However, these materials with higher destruction pressure are RMI materials except for calcium silicate and Koolphen-K. For most applications, RMI debris is handled based on a strainer theoretical saturation thickness which is independent of the quantity of debris generated. Destruction of Koolphen-K and calcium silicate needs to be evaluated on a plant specific basis.
5	23, 27	3.2.1.2	*Erosion over time – Calcium Silicate.* Destruction of calcium silicate insulation needs to consider steam/water jet erosion over the time of initial vessel blowdown. This may require a plant specific evaluation to consider the differences in the plant specific application and the geometry tested by the BWR Owners' Group (see URG Volume 3, Tab 3).
6	24	3.2.1.2	*Single vs. double-ended flow from break.* If a single-ended flow is assumed from a steam line break, the effects of double-ended flow up to the time the MSIVs close should be considered.
7	26	3.2.1.2	*ZOI Method 4.* ZOI Method 4 which involves use of CFD has not been approved. No BWR plants elected to employ this methodology.
8	36	3.2.3	*Mark II transport factors.* Mark II containment transport factors not acceptable; use Mark I / Mark III values.

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

August 20, 1998

Mr. Rocky Sgarro
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SUBJECT: SAFETY EVALUATION FOR NEDO-326896, REV. 0, "UTILITY RESOLUTION GUIDANCE DOCUMENT FOR ECCS SUCTION STRAINER BLOCKAGE"

Dear Mr. Sgarro:

By letter dated November 20, 1996, the Boiling Water Reactor Owners group (BWROG) transmitted General Electric topical report NEDO-326896, Revision 0,"Utility Resolution Guidance for ECCS Suction Strainer Blockage," (URG) to the NRC staff for review. The staff completed its initial review and issued a draft safety evaluation report (SER) dated December 31, 1997. The draft SER identified several areas where the staff did not agree with URG conclusions. The staff requested that the BWROG review the draft SER and provide the staff with comments on these issues. By letter dated March 13, 1998 the BWROG provided the staff with comments on the staff's draft SER. The staff has evaluated the BWROG comments and has completed its review of the URG. The staff's final safety evaluation is enclosed.

Please contact Mr. Rob Elliott of the NRR staff at (301) 415-1397 if you have any questions about the staff's review.

Sincerely,

Thomas H. Essig, Acting Chief
Generic Issues and Environmental Projects Branch
Division of Reactor Program Management
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Enclosure: As stated

Project No. 691

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August 20, 1998

SAFETY EVALUATION BY

THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO NRC BULLETIN 96-03,

BOILING WATER REACTOR OWNERS GROUP

TOPICAL REPORT NEDO-32686,

"UTILITY RESOLUTION GUIDANCE FOR

ECCS SUCTION STRAINER BLOCKAGE"

(DOCKET NO. PROJ0691)

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Executive Summary

By letter dated November 20, 1996, the Boiling Water Reactor Owners Group (BWROG) submitted for review by the U.S. Nuclear Regulatory Commission (NRC) a document entitled "Utility Resolution Guidance for ECCS Suction Strainer Blockage," NEDO-32686 (also known as the URG). The guidance provided in the URG can be divided broadly into the following areas:

- selection of breaks for the analysis of strainer blockage
- generation of insulation debris by a postulated break
- drywell sources of debris other than insulation debris (e.g., concrete dust, paint chips etc.)
- transport of debris from the break location in the drywell to the suppression pool
- suppression pool debris (e.g., sludge and rust flakes)
- transport of debris in the suppression pool and its accumulation on the strainer
- head loss resulting from debris buildup for selected strainer geometries
- guidance for estimating the available net positive suction head (NPSH) margin
- other issues

The following sections briefly describe the guidance provided in each of these areas of the URG, along with the related findings from the staff's evaluation.

ES.1 Selection of Breaks for Analysis

The primary system piping in a boiling-water reactor (BWR) varies in diameter from 3.81 centimeters (cm) to 60.96 cm (1.5 inches (in.) to 24 in.) or greater. Therefore, postulated breaks in the main steamlines, recirculation lines or feed water lines can be small, medium or large. Because it is difficult to analyze each postulated break, a criterion is needed to select the bounding breaks that maximize head loss across the pump suction strainers of the emergency core cooling system (ECCS). To address this need, Regulatory Guide 1.82, Rev.2, (Reference 5) states that as a minimum, licensees should consider the following postulated break locations:

- breaks on the main steam, feedwater, and recirculation lines with the largest amount of potential debris within the expected zone of influence (ZOI)
- large breaks with two or more different types of debris within the expected ZOI
- breaks in areas with the most direct path between the drywell and wetwell
- large and medium breaks with the largest potential debris-to-insulation ratio by weight

The URG reiterates guidance from RG 1.82, Rev. 2 guidance; however, it also includes the following provisions:

- Plants licensed in accordance with the NRC's Standard Review Plan (SRP) and Branch Technical Position (BTP) MEB 3-1 need not analyze all of the identified break locations. Instead, such plants may evaluate only those breaks that are most likely to occur.
- Other plants may use the guidance from RG 1.82, or other guidance consistent with Title 10, Section 50.46, of the *Code of Federal Regulations* (10 CFR 50.46). However, licensees should exercise care to differentiate between pipe break locations used for ECCS evaluation and those that are in the plant's licensing bases.

- Plants employing alternate strainer designs (i.e., strainers with large surface areas and cavities to accommodate considerable quantities of debris without significant increase in head loss) need not analyze large and medium breaks with the largest potential debris-to-insulation ratio by weight.

After reviewing the URG, the staff reached the following conclusions:

- RG 1.82, Revision 2, provides the complete spectrum of breaks that should be analyzed to meet the intent of 10 CFR 50.46. The staff considers SRP Section 3.6.2 and BTP MEB 3-1 to be inappropriate for demonstrating compliance with 10 CFR 50.46.
- Licensees may screen out large breaks with the highest particulate-to-fiber debris ratio by weight and MLOCAs in performing their plant-specific analyses, if their resolution includes both of the following:

  1) Installation of a strainer similar to the stacked disk number 2, star strainer, or another geometrically similar strainer with deep crevices.
  2) The licensee has adequate assurance from the strainer vendor that the screened out breaks would not be more limiting in terms of head loss across the strainer. The vendor should have adequate test data to support screening of these breaks.

ES.2 Generation of Insulation Debris by a Postulated Break

Postulated breaks in the primary piping would destroy insulation located in the region closely surrounding the separated broken ends because of the combined effects of blast wave and jet impingement. This zone of influence (ZOI) over which the destruction occurs strongly depends on the type of insulation and mode of encapsulation. In addition, the ZOI depends on the type of break (i.e., main steamline break, recirculation line break or feedwater line break) as well as other considerations, such as the extent of axial and radial separation of the broken ends.

URG Section 3.2.1.2, "Zone of Influence" discusses the BWROG guidance related to mapping a ZOI around a postulated break location. The BWROG developed that guidance using experimental data obtained from air jet impact testing (AJIT) and the results of the associated computational fluid dynamics (CFD) modeling. Specifically, the URG identifies four options (or methods) for determining the ZOI over which insulation would be damaged, although not all of the damaged insulation is in a readily transportable form. These methods are as follows:

- Method 1 assumes that ZOI encompasses the entire drywell, and thus, all of the insulation contained in the drywell would be damaged by the postulated break.
- Method 2 defines the following procedure for determining the zone of influence:
  1) Assume that the break is a double-ended guillotine break (DEGB) with full separation resulting in continuous blowdown from both ends.
  2) Determine the lowest dynamic pressure at which destruction would begin to occur for each insulation material of interest. Estimate these destruction pressures after scaling the AJIT-measured values to the plant and taking into account that destruction pressure is inversely proportional to the target pipe diameter.
  3) For each insulation type, determine the ZOI by calculating the spatial volume enveloped by a specific damage pressure of interest for a jet expanding in free space, and mapping a

spherical zone of equal volume surrounding the break. The radius of the spherical zone is largest for the weakest insulation (i.e., lowest destruction pressure).

4) The ZOI for Method 2 is the largest volume sphere resulting from this analysis.
5) Determine the most limiting quantities of damaged debris by placing the ZOI at different locations in the drywell and estimating the volume of each type of insulation debris damaged by the jet.

- Method 3 is similar to Method 2, except for the following differences:
  1) Method 3 allows the licensee to take credit for break restraints and evaluate axial and radial offsets consistent with those restraints.
  2) Method 3 allows the licensee to take credit for single-ended blowdown (e.g., steamline break)
  3) Method 3 also allows the licensee to map different ZOIs for different insulation materials.
- Method 4 allows the user to directly employ the results of CFD analyses in conjunction with AJIT data to map the ZOI. However, the URG did not provide specific guidance regarding how to apply the CFD tools.

The staff has conducted several independent analyses to assess if the URG guidance is appropriate and bounding. On the basis of these analyses, the staff concludes that Method 1 is clearly a bounding and conservative method for evaluating the ZOI since it encompasses the entire drywell, and, therefore, bounds the amount of insulation debris that may be generated by the break. Method 2 uses the destruction pressure (P_{dest}), or the pressure at which destruction of insulation first occurs, to define a spherical ZOI around a given break. The staff believes that the spherical ZOIs developed using Method 2 would be sufficiently large to envelop the entire zone over which destruction would actually occur. This method is sufficiently conservative and, therefore, is considered acceptable for use on insulations with low P_{dest} values. However, for insulations with high P_{dest} values, the staff recommends that licensees develop the ZOI on the basis of the "target area averaged pressures" (TAAP) instead of jet-center-line pressures. In addition, the staff believes that the spherical ZOI developed using Method 3 is acceptable, with the same comments presented for Method 2. The staff has concluded that the BWROG's basis for using the jet centerline pressure as the insulation's characteristic damage pressure (i.e., P_{dest}) is inadequately supported by analysis or data. The staff's review of the data and independent CFD calculations lead to the conclusion that incipience of damage is more accurately characterized by TAAP or total jet impingement load rather than local maximum pressure. However, because of the limited number of insulations affected by this concern, the staff believes that this concern should be addressed on a plant-specific basis.

The staff notes that the URG does not provide guidance regarding the types of analyses that licensees must undertake to determine the extent of axial and radial separations of the broken ends. Licensees desiring to take credit for limited separation of the broken ends due to pipe restraints or single-ended blowdown should conduct supporting analyses. The staff expects that these supporting analyses will be retained for possible future inspection.

Section 3.2.1.2 of the URG does not provide detailed guidance regarding Method 4. Therefore, the staff cannot accept Method 4 at this time. Licensees intending to use Method 4 should address the staff's concerns including validatation of the selected CFD code.

ES.3 Other Sources of Drywell Debris

The URG provides guidance that individual utilities can use to identify other sources of debris in the drywell and to estimate the quantities of such debris that should be used in the ECCS strainer analysis. The URG also identifies the following other sources of debris:

- Dirt/Dust: The URG suggests that licensees assume 150 lbm of dust/dirt for estimating the strainer head loss. This estimate is based on engineering judgement.
- Other Transient Debris: The URG does not provide a specific value. Individual utilities should use their best judgement.
- Rust from Unpainted Steel Surfaces: The URG recommends a value of 50 lbm on the basis of engineering judgement.
- Particulate Debris: The URG does not provide a specific value. Individual utilities should use their best judgement.
- Paints/Coatings: The URG recommends values of 47 lbm for inorganic zinc coatings, 85 lbm for inorganic zinc top-coated with epoxy, and 71 lbm for 100% epoxy coating. These estimates are predicated on a study conducted by Bechtel Power Corporation.
- Concrete: The URG does not provide a specific value. Individual utilities should use their best judgement.
- Unqualified/Indeterminate Paint/Coatings: The URG does not provide a specific value. Individual utilities should use their best judgement. As an alternative, the URG notes that licensees may remove the unqualified or indeterminate coatings, or attempt to qualify them through *in situ* qualification. The URG does not provide guidance regarding how licensees should accomplish *in situ* qualification.

In addition, the URG cautions users that their foreign material exclusion (FME), housekeeping, and inspection programs must be adequate to ensure that the quantities of each of these types of debris will not exceed the quantities assumed in the evaluation of ECCS strainer loading.

The staff compared the URG recommended values with the estimates previously developed as part of the NRC sponsored study of a reference BWR 4 with a Mark I containment. The study was conducted by Science and Engineering Associates, Inc. and the results are provided in NUREG/CR-6224, "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris," dated October 1995 (Reference 31). On the basis of this comparison, the staff found that most of the values suggested in the URG are about the same or larger than the corresponding NUREG/CR-6224 values. As a result, the staff concludes that use of the URG values is acceptable; however, the staff notes that the NUREG/CR-6224 study was conducted on a reference Mark I containment. Because of the differences in plant design (e.g., size of containment, NPSH margin, and so forth), the staff believes that some individual licensees may wish to evaluate the applicability of the recommendations of this section for their specific plant. The staff provided some suggestions on estimating the sources of dirt, dust and rust in the containment, as well as paints/coatings for plants with unqualified or indeterminate coatings. These suggestions by the staff were provided for informational purposes and are not considered a requirement for use of the URG suggested values.

The staff notes that the sensitivity of the head loss calculations to these numbers may vary with the assumptions and the resolution option selected by each licensee. If the licensee is installing

a large passive strainer which is designed with very conservative assumptions relative to the quantities of fibrous debris and sludge assumed to reach the strainer surface, the licensee may be able to demonstrate (by sensitivity analysis) that variations in the quantities of dirt, dust, rust flakes, etc. may not significantly affect the overall head loss across the strainer. If, however, the licensee attempts to justify their current strainer or to use assumptions that are as "realistic" as possible, the significance of the values determined in accordance with Section 3.2.2 of the URG escalates significantly.

Consistent with the staff's guidance (discussed above), some licensees may also wish to evaluate the applicability of the conclusions of the Bechtel coatings report to their plant. Most importantly, the staff concludes that licensees should be cautioned to carefully evaluate the potential impact of unqualified and indeterminate coatings on ECCS suction strainer head loss. If available, licensees are encouraged to use test data to support their evaluation of coatings. It is the understanding of the staff that the BWROG is currently conducting a test program designed to evaluate the potential for coatings to become debris and transport to the suppression pool. However, if in doubt, assuming that these coatings reach the strainer surface would clearly be the conservative measure. This would reduce the licensees' risk relative to the coatings issue, and could lead to additional margin in the strainer design if URG statements minimizing the potential impact of unqualified or indeterminate protective coatings are supported by the results of the staff's coatings review.

ES.4 Transport of Drywell Debris to the Suppression Pool

Insulation debris is generated in the drywell and then transported to the suppression pool by the reactor vessel blowdown and the various mechanisms that can wash debris down to the suppression pool. The guidance provided in RG 1.82, Revision 2, requires licensees to assume that all debris would be transported to the suppression pool.

Section 3.2.3 of the URG, entitled, "Drywell Debris Transport," documents BWROG guidance regarding various options for estimating the fraction of the damaged insulation (generated in the drywell) that will be transported to the suppression pool as a result of these mechanisms. The basis for the URG guidance for fibrous insulation is the following research conducted by the BWROG:

- The damaged insulation was assumed to fall into three categories, including "fines", "large pieces," and "blankets." For each insulation, the BWROG used the AJIT data to derive the relative fractions of the insulation destroyed into each of these size categories (i.e., the size distribution factors). Specifically, the BWROG calculated these fractions as integral values averaged over the entire ZOI.
- The BWROG then estimated the fraction of the mass of "fines" that would be transported as a result of blowdown and washdown following a main steamline break or a recirculation line break. These estimates are predicated on the results of small-scale testing undertaken by the BWROG. As a result, the URG recommends values of 1.0 for Mark I and Mark III containments. For Mark II containments, however, this fraction is 0.5 for steamline breaks and 0.56 recirculation line breaks.
- The BWROG identified floor gratings as the major locations for capture of "large pieces" and "blankets." On the basis of engineering judgment, the URG concludes that 6.25% of the debris

generated above the lowest grating would be transported to the suppression pool. The URG also concludes that 78% of all debris generated below the lowest floor grating would be transported to the suppression pool.

The URG provides similar guidance related to the transport of debris from reflective metallic insulation (RMI). Specifically, the URG divides the RMI debris into "small pieces (<6.0 in^2) ", "large foils (>6.0 in^2)" and "intact assemblies." The BWROG again used AJIT data to derive the integrated size distribution fractions for the ZOI for each type of RMI. On the basis of small scale transport testing, the URG guides licensees to assume that all of the small pieces would be transported to the suppression pool in Mark I and III containments. For a Mark II containment, only 10% of the small pieces would be transported to the suppression pool in the event of a steamline break, while 5% would be transported in the event of a recirculation line break.

The staff has previously communicated several concerns related to scaling small-scale transport test data to BWR conditions. In addition, the staff conducted a series of experiments to verify the accuracy of guidance provided in the URG. The staff shared these results with the BWROG and individual utilities at appropriate forums. On the basis of these studies the staff reached the following conclusions:

- The URG guidance is non conservative for Mark II containments. The URG gives fractions for fine fibrous debris transport and RMI debris transport in Mark I and Mark III containments, assuming that 100% of the fine debris will transport to the suppression pool. The staff concludes that the same transport factors should be used for Mark II containments.
- For other containments, the URG guidance would yield conservative estimates for transport fractions.

ES.5 Suppression Pool Debris

The focus of Section 3.2.4 of the URG, entitled "Suppression Pool Debris," is on sources of debris which are present in the suppression pool before the occurrence of a LOCA. Both transient debris and sludge are potentially present in the suppression pool at any given time. This section of the URG also reviews the LOCA-generated debris and transient debris, both of which were discussed in earlier sections of the URG. The guidance was developed, in part, on the basis of an extensive BWROG survey of suppression pools of selected operating BWRs in the United States (Refs. 54 and 55).

The staff finds no deficiencies in the recommendations documented in the URG. The staff reiterates the importance of the FME program to minimize the quantity of other potential debris.

ES.6 Suppression Pool Transport

The staff has extensively considered the transport of debris within the suppression pool. As part of NUREG/CR-6224 study Alden Research Laboratory conducted NRC-sponsored experiments to explore the transport of fibrous and RMI debris when subjected to chugging and post-chugging periods following a LOCA. The BWROG primarily relied on these experiments to develop the guidance documented in Section 3.2.5 of the URG, entitled "Suppression Pool Transport."

The URG recommends that licensees not take credit for settling of debris in the pool during the high-energy phase of an accident during which the suppression pool undergoes thorough mixing. The URG also recommends that licensees assume that all suppression pool debris will be resuspended during this phase. Finally, the URG gives the individual licensees the option to assume that there will be no settling of debris in the pool even after the high-energy phase terminates and the pool returns to quiescent conditions, or to determine settling rates using the methods described in Appendix B to NUREG/CR-6224.

The staff finds no deficiencies in the recommendations documented in the URG. However, the staff notes that Appendix B to NUREG/CR-6224 provides the required data only for selected types of insulation and particulates. Licensees using the methods described in Appendix B to NUREG/CR-6224 for other types of insulation debris should be cautious about extrapolating the experimental data and models.

ES.7 Head Loss Across the Strainer

The BWROG devoted considerable resources to explore various generic designs for large passive strainers that can be used to replace the existing truncated cone strainers. The four designs included are the 20-point star strainer, small stacked disk strainer, 60-point star strainer, and large stacked disk strainer. For each design, the BWROG obtained head loss data for various combinations of fibrous insulation debris, sludge, recipe (paints + concrete chips), and RMI debris. The general characteristics (size, shape, etc.) of the debris used are consistent with those used in the NUREG/CR-6224 study. The reader should also note that the NUREG/CR-6224 study selected these characteristics to maximize the resulting head loss. On the basis of the test data, the BWROG developed two correlational methods that can be used to estimate head loss across the strainers.

The first method provides a non-dimensional head loss correlation that can be used to estimate head loss across an alternate strainer design. The URG specified that this correlation is valid for lower debris loadings. For higher debris loadings, the correlation is not applicable, and the URG recommends that licensees conduct strainer-specific testing.

The second method provides a six-step process for estimating the strainer's RMI capacity and head loss across RMI debris beds. This method recognizes that RMI beds on strainers reach a saturation thickness beyond which flow-induced drag forces are not large enough to retain the RMI pieces on the strainer surface. The URG specified this saturation thickness as a function of the type of RMI debris, and provided a correlation to estimate head loss across the RMI debris beds.

For mixed beds (i.e., RMI+fiber+particulate) the URG suggests that RMI does not contribute additional head loss in combination with other types of debris, and that it may actually reduce the head loss. On that basis, the URG states that head loss for mixed beds can be evaluated by ignoring RMI altogether and estimating the head loss resulting from other debris.

The staff conducted several confirmatory calculations to validate the calculational procedures provided in the URG and to examine the applicability of the calculational procedures to the actual plant conditions. The staff has since shared the results of these analyses with the BWROG. On the basis of these analyses, the staff finds that the head loss correlation in the URG is unreliable

and incomplete for plant analyses and, therefore, is unacceptable. The staff strongly recommends that utilities use vendor-provided data to qualify strainer designs, rather than relying on the correlations and calculational procedures specified in the URG. In addition, the staff recommends that licensees' designs should be able to accommodate experimental uncertainties associated with correlations and/or calculational methods developed by the vendors.

The staff concludes that the BWROG generalized statement regarding the head loss of a fiber plus corrosion product debris bed bounding the head loss of a fiber, corrosion product and RMI debris bed does not hold true in all situations. On the basis of the staff's analysis, the staff believes this issue should be resolved on a plant-specific basis. Licensees should ensure that their strainer vendor reviews the debris combinations of interest for their plant and ensures that the vendor data supports the head loss used in their plant-specific analysis.

ES.8 Estimation of Available NPSH for ECCS Pumps

Section 3.2.6 of the URG provides the BWROG guidance related to evaluating ECCS pump NPSH. The important points of this guidance are as follows:

- Licensees should not take credit for containment overpressure greater than atmospheric pressure in determining available NPSH, unless such credit is in conformance with the plant's existing licensing basis.
- When evaluating available NPSH, licensees should consider a range of expected fluid temperatures unless the plant's licensing basis specifies the maximum expected fluid temperature. If specified, this temperature should be used unless plant's licensing basis is changed. The fluid temperature could affect both the available NPSH margin and the head loss across the strainer.
- All strainers can be expected to be clean at the start of the postulated LOCA. It is not necessary to assume pre-existing blockage.
- If ECCS blockage analysis uses reduced ECCS flow through the strainers in order to meet NPSH requirements, licensees should exercise care to ensure that changes in ECCS flow rates are consistent with inputs and assumptions used in the evaluation model required by 10 CFR 50.46 to calculate ECCS cooling performance. Also, licensees should ensure that appropriate operating and emergency procedures are in place.
- Licensees should carefully evaluate the applicability of head loss correlations before applying such correlations to estimate head loss across the strainers.
- The ECCS strainer design should be consistent with the plant's limiting single-failure assumptions.

The staff finds no deficiencies in the recommendations presented in the URG. Licensees are strongly encouraged to design strainers with performance characteristics that increase the NPSH margin above the minimum required. Also, the reader should note that the staff is evaluating calculation of NPSH and plant licensing bases as part of its review of Generic Letter (GL) 97-04, "Assurance of Sufficient Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal Pumps."

ES.9 Other Issues

Section 3.1.3.4 of the URG discusses the nine "resolution options" available to licensees. However, the staff notes that many of the "resolution options" are partial solutions which would still likely require strainer replacement by the licensee. Specifically, Section 3.1.3.4 of the URG discusses the following resolution options:

- "Further Refinement of Fixed Debris Source Terms." This option is simply a more detailed analysis of the containment for calculating the amount of debris that could reach the strainers in order to reduce the debris source term for sizing of the strainers.
- "Replacement of Existing Strainers with Passive Strainers of Alternate Designs." This option would replace existing strainers with designs which have substantially lower head loss with high debris loadings. Examples include the stacked disk and star strainer designs.
- "Installation of Jacketing to Reduce the Insulation Debris Source Term." This option would seek to minimize the amount of debris generated during an accident by covering it with a protective jacketing and/or banding.
- "Reduction in Transient Debris Source Terms." This option would reduce debris source terms such as foreign material. To justify the reduction in transient debris, licensees may need to implement additional FME or housekeeping controls, or higher suppression pool cleaning frequency.
- "Change Existing Licensing Basis." Examples of potential licensing basis changes include the use of a more realistic decay heat curve in lieu of the conservative curve used in the original licensing basis (i.e., American Nuclear Society (ANS) 5.1 versus May-Witt) and credit for containment overpressure in calculating available NPSH. Use of realistic decay heat curves would increase NPSH margin by reducing the calculated suppression pool temperatures following a LOCA. The BWROG does not recommend taking credit for containment overpressure for the calculation of NPSH margin.
- "Reanalysis of ECCS Suction Line Penetration Loads." It is recommended that this be done without reopening the licensing basis for containment loads. This option seeks to maximize the size of the strainer that can be put in the suppression pool by minimizing the structural impact of that strainer on the piping penetration to which it is connected. The URG does not provide any guidance on how licensees can accomplish this option. Moreover, the BWROG does not recommend reopening the licensing basis for containment loads.
- "Partial Replacement of Fibrous Insulation with RMI." Since RMI debris is less detrimental to strainer head loss than fibrous debris, this option seeks to minimize the amount of fibrous debris that may be generated during an accident.
- "Use of a Strainer Backflush System." Should an ECCS suction strainer clog, this option would provide a method to clean the strainer by reversing water flow through the strainer.
- "Installation of Self-Cleaning Strainers." This option would eliminate the need for detailed plant analysis by installing a strainer which would continually clean itself, effectively preventing clogging and subsequent loss of NPSH.

The staff's has the following concerns with these resolution options:

- In discussing the resolution option on "Installation of Jacketing to Reduce the Insulation Debris Source Term" the URG states that, "Additional details on the use of jacketing is provided in Section 3.2.1." However, Section 3.2.1 does not provide guidance with regard to the types of

bands to be used, construction of the bands, or instructions for mounting. In addition, the characterization of the effectiveness of insulation jacketing in this section is inconsistent with the AJIT test report. That report states "In the case of fibrous insulation materials, the use of jacketing as a means of reducing debris generation does not appear to be effective without the use of an additional banding material which better secures the jacketing to the insulation assembly and the pipe." Without further detailed information on how to apply this option, the benefits achieved, and the technical basis supporting the use of this measure, the staff is unable to determine the acceptability of this option.

- In discussing the resolution option on "Reduction in Transient Debris Source Terms," the URG discusses the crediting FME and housekeeping programs as a justification for reducing the amounts of transient debris assumed in a plant analysis. The staff has two concerns related to incorporating this option into a licensee's final resolution. First, if a licensee selects too low an amount of transient debris in their analysis, the potential exists for operability concerns to be raised every time debris is found in the drywell, suppression pool, or wetwell. Second, if a licensee is considering increasing the amount of transient debris in sizing the new strainer, the staff believes that housekeeping or FME controls are not a substitute for periodic inspection and cleaning of the strainers or suppression pool. Given the numerous events reported over the last few years involving FME-related issues, the industry has not demonstrated that FME controls alone are effective in ensuring that materials are not left in the drywell, wetwell, or suppression pool. As such, the staff believes that licensees should conduct regular inspections of the suppression pool and ECCS suction strainers, and cleanings when necessary, during every refueling outage until licensees demonstrate over time the ability to control foreign materials. The staff believes it is more prudent to add margin when sizing strainers to account for the uncertainty in the effectiveness of housekeeping controls. This, in turn, will minimize the need for operability assessments when small amounts of foreign material are found in the containment or suppression pool.
- The URG notes that part of a licensee's resolution to the strainer clogging issue could include a licensing basis change. The URG cites an example in which a licensee may wish to use a more realistic decay heat curve to reduce the calculated post-LOCA suppression pool temperatures. Specifically, the URG states that use of credit for containment overpressure is not recommended. The staff concurs that additional containment overpressure (other than an amount already approved by the staff for the existing licensing basis) should not be used as part of the resolution of this issue.
- The URG also discusses the potential to reanalyze suction line penetration loads. Specifically, the URG states that it "may be possible to further increase the size of the alternate strainer design by reanalyzing ECCS suction penetration loads and suppression pool structural loads using more sophisticated techniques or by reducing conservatism in current design-basis calculations, but without reopening the licensing basis for containment loads." The staff has concerns regarding this statement. Specifically, the hydrodynamic load programs for the Mark I, Mark II, and Mark III programs were very specific in providing generic methodologies for calculating hydrodynamic loads. Each plant submitted a plant unique analysis report (PUAR) which provided the specific details of each plant's calculated hydrodynamic loads, including the methodology and coefficients used, etc. The approved methodologies had their basis in test data. The staff cautions licensees with regard to changing hydrodynamic load calculations without testing to demonstrate the validity of the revised calculations.
- The URG discusses the option of reducing the fibrous debris source term in the drywell by partially replacing fibrous insulation with RMI. The staff agrees that this is an appropriate option

for reducing the amount of fibrous debris which can be transported to the suppression pool; however, when using this option for a selected break, the licensee should reassess other breaks to ensure that the licensee has not changed which break is the most limiting in terms of NPSH margin. In addition, the licensee must now consider head loss in terms of combined fibrous/RMI debris beds.

Although NRC Bulletin 96-03 allows the use of self-cleaning strainer designs as a resolution option, the BWROG recommends that licensees use a self-cleaning strainer only if resolution with a passive strainer is not viable. The URG cites several concerns regarding the use of self-cleaning strainer designs. The staff finds that the URG provides comprehensive guidance on concerns to be addressed with an active strainer design. The staff notes no significant deficiencies in its review of this guidance. However, because of the concerns cited by the BWROG in the URG relative to the self-cleaning strainer, any licensee wishing to use an active strainer design as a resolution option should address the concerns stated in the URG.

Although NRC Bulletin 96-03 allows backflushing as a potential resolution option, the BWROG recommends against use of the strainer backflush systems as a primary means of resolving the ECCS suction strainer clogging issue. The basic concern expressed by the BWROG is that backflushing will be needed early and frequently during the first 30 to 60 minutes of an accident. The BWROG considers backflushing more viable as a defense-in-depth measure only. Because of the reliance on operator action and mechanical systems, the staff concurs with the BWROG that backflushing is more effective as a defense-in-depth measure only. Section 3.3 of the URG provides guidance on the types of considerations a utility should address if designing a backflush system either as a primary means of mitigating an accident or as defense-in-depth measure only. The staff did not note any significant deficiencies in its review of this section.

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO NRC BULLETIN 96-03,

BOILING WATER REACTOR OWNERS GROUP

TOPICAL REPORT NEDO-32686,

"UTILITY RESOLUTION GUIDANCE FOR ECCS SUCTION STRAINER BLOCKAGE"

(DOCKET NO. PROJ0691)

1.0 INTRODUCTION

By letter dated November 20, 1996, the Boiling Water Reactor Owners Group (BWROG) submitted for review by the U.S. Nuclear Regulatory Commission (NRC, the staff) a document entitled NEDO-32686, "Utility Resolution Guidance for ECCS Suction Strainer Blockage" (also known as the URG) (Ref 1) along with related technical support documentation (Ref 2). Then, on November 25, 1996, the BWROG submitted to the staff a facsimile containing additional information regarding the URG drywell transport methodology (Ref. 3). The purpose of the URG is to give boiling-water reactor (BWR) licensees guidance for complying with the requested actions of NRC Bulletin (NRCB) 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris" (Ref. 4). In particular, the URG focuses on providing detailed guidance for performing plant-specific analyses consistent with Regulatory Guide (RG) 1.82, Revision 2, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident" (Ref. 5). NRCB 96-03 and RG 1.82, Revision 2, were issued by the staff to resolve a safety issue regarding the potential for clogging of emergency core cooling system (ECCS) suction strainers by debris during a loss-of-coolant accident (LOCA).

Prior to its submittal of November 20, 1996, the BWROG had submitted eight draft sections of the URG in order to facilitate the staff's review of the final document. Specifically, the BWROG submitted four sections on March 31, 1996 (Ref. 6), and four more on May 28, 1996 (Ref. 7). By letters dated July 25, 1996 (Ref. 8), and August 20, 1996 (Ref. 9), the staff transmitted comments regarding the draft URG sections to the BWROG. The staff also discussed those comments with the BWROG in a meeting on August 19, 1996. The results of the meeting are described in a meeting summary dated September 4, 1996 (Ref. 10). In addition, by facsimile dated December 23, 1996, the staff transmitted a request for additional information (RAI) on the final URG to the BWROG (Ref. 11). On January 13, 1997, the BWROG provided the staff with survey results showing how many utilities intended to use the various options provided in the URG (Ref. 12). The BWROG then provided their response to the staff's RAI on January 30, 1997 (Ref. 13). Additional supporting documentation was provided to the staff by the BWROG in a letter September 19, 1997 (Ref. 62).

Before reviewing the URG, the staff closely followed the generic effort conducted by the BWROG to resolve the issue regarding strainer clogging in the ECCS of BWRs. Throughout that monitoring, the staff continuously provided the BWROG with feedback. Then, in a letter dated June 13, 1994 (Ref. 14), the staff identified its initial concerns about the resolution being developed by the

BWROG. The BWROG then began conducting testing to support their generic effort, and on August 9, 1994, the BWROG forwarded to the staff a facsimile presenting a draft plan for testing the performance of alternate strainer designs (Ref. 15). The staff responded with a letter dated September 12, 1994, (Ref. 16) containing comments on the proposed test program. By letter dated March 15, 1995 (Ref. 17), the BWROG submitted their final test plan to the staff. In RAI letters dated June 22, 1995 (Ref. 18), August 21, 1995 (Ref. 19) and April 22, 1996 (Ref. 20), the staff identified its concerns regarding the test program and the application of the test results. The staff transmitted additional concerns to the BWROG via facsimile dated August 14, 1995 (Ref. 21). The BWROG provided a written response to the RAI dated June 22, 1995 by letter dated July 17, 1995 (Ref. 22), and to the RAI from April 22, 1996 by letter dated July 9, 1996 (Ref. 23). The BWROG did not formally respond to the staff concerns from the RAI dated August 21, 1995, although the staff concerns were discussed in meetings on May 31, 1995; September 28-29, 1995; April 4, 1996; July 9-11, 1996; and August 19, 1996 (see meeting summaries and trip reports dated June 13, 1995 (Ref. 24); October 6, 1995 (Ref. 25); April 16, 1996 (Ref. 26); July 25, 1996 (Ref. 27); and September 4, 1996 (Ref. 10)). The BWROG also provided copies of their proposed test matrices in facsimiles dated June 23, 1995 (Ref. 28), and June 30, 1995 (Ref. 29).

In a letter dated December 31, 1997, the staff issued a draft safety evaluation report (SER) on the URG to the BWROG (Ref. 63). The draft SER identified several areas where the staff did not agree with the conclusions stated in the URG (referred to as open issues in the staff's letter). It was requested that the BWROG review the draft SER and provide the staff with its response to any open issues identified in the draft SER. By letter dated March 13, 1998, the BWROG provided its response to the draft SER (Ref. 64). Appendix L to this SER provides the BWROG's comments and the staff's resolution of those comments.

The staff has since completed its review of the URG, the supporting documentation, the BWROG's comments and all relevant documents, and its conclusions are documented in this SER. In general, the staff found that portions of the URG are acceptable for use in conducting plant-specific analyses to estimate combined debris loadings for sizing of ECCS suction strainers. However, the staff found that several portions of the URG are not acceptable because the methods lack sufficient guidance, supporting data, or analysis to justify their technical basis. This SER discusses each section of the URG, along with the basis for the staff's conclusions. Licensees desiring to use the portions of the URG not accepted by the staff should address the staff's concerns cited herein. In addition, the staff believes that several portions of the URG need additional clarification to minimize the potential for misinterpretation of the information provided. The staff has stated its position regarding these portions of the URG in the associated section of this SER.

The staff closely reviewed the materials contained in the references cited above, as well as other pertinent references. In addition, the staff conducted independent confirmatory analyses to identify inadequacies in the generic guidance provided in the URG, as well as inaccurate or unsubstantiated assumptions used to develop the stated guidance.

This SER is intended to address each part of a plant-specific analysis. For this reason, the SER includes sections on each of the following topics:

- resolution options (Section 3.1)
- pipe break locations (Section 3.2.1.1)

- debris generation/ZOI (Section 3.2.1.2)
- other drywell debris sources (Section 3.2.2)
- drywell debris transport (Section 3.2.3)
- suppression pool debris (Section 3.2.4)
- suppression pool transport and settling (Section 3.2.5)
- net positive suction head (NPSH) including strainer head loss (Section 3.2.6)
- backflush (Section 3.3)
- self-cleaning strainers (Section 3.4)
- conservatism (Section 5.0)
- general/overall URG comments

These sections are also consistent with the sections of the URG on the same topics. In addition, Appendices A through K to this SER summarize the results of the confirmatory analyses performed by the staff.

1.1 BACKGROUND

On July 28, 1992, an event occurred at Barsebäck Unit 2, a Swedish BWR, which involved the plugging of two containment vessel spray system (CVSS) suction strainers. The strainers were plugged by mineral wool insulation that had been dislodged by steam from a pilot-operated relief valve that spuriously opened while the reactor was at 3100 kPa [435 psig]. Two of the three strainers on the suction side of the CVSS pumps that were in service became partially plugged with mineral wool. Following an indication of high differential pressure across both suction strainers 70 minutes into the event, the operators shut down the CVSS pumps and backflushed the strainers. The Barsebäck event demonstrated that the potential exists for a pipe break to generate insulation debris and transport a sufficient amount of the debris to the suppression pool to clog the ECCS strainers.

Similarly, on January 16 and April 14, 1993, two events involving the clogging of ECCS strainers occurred at the Perry Nuclear Power Plant, a domestic BWR. In the first Perry event, the suction strainers for the residual heat removal (RHR) pumps became clogged by debris in the suppression pool. The second Perry event involved the deposition of filter fibers on these strainers. The debris consisted of glass fibers from temporary drywell cooling unit filters that had been inadvertently dropped into the suppression pool, and corrosion products that had been filtered from the pool by the glass fibers which accumulated on the surfaces of the strainers. The Perry events demonstrated the deleterious effects on strainer pressure drop caused by the filtering of suppression pool particulates (corrosion products or "sludge") by fibrous materials adhering to the ECCS strainer surfaces. This sludge is typically present in varying quantities in domestic BWRs, since it is generated during normal operation. The amount of sludge present in the pool depends on the frequency of pool cleaning/desludging conducted by the licensee. As a result, the BWROG and the NRC have conducted separate test programs to quantify the sludge-related filtering effect.

On the basis of these events, the NRC issued NRCB 93-02, "Debris Plugging of Emergency Core Cooling Suction Strainers" (NRCB 93-02), on May 11, 1993 (Ref. 30). That bulletin requested licensees to remove from the containment fibrous air filters and other temporary sources of fibrous material, which were not designed to withstand a LOCA. In addition, NRCB 93-02 requested that

licensees take any immediate compensatory measures necessary to ensure the functional capability of the ECCS.

Following these events, the staff performed calculations to assess the vulnerability of each domestic BWR. The results of these calculations showed that the potential existed for the ECCS pumps to lose NPSH margin as a result of clogging of the suction strainers by debris generated during a postulated LOCA. The staff then conducted a detailed study of a Reference BWR 4 plant with a Mark I containment. That study's results confirmed the results of the earlier staff calculations, and were published in NUREG/CR-6224, "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris," in October 1995 (Ref. 31).

On January 26 and 27, 1994, members of the NRC staff also attended a workshop in Stockholm, Sweden, which was sponsored by the Organisation for Economic Co-operation and Development/Nuclear Energy Agency (OECD/NEA), to discuss the Barsebäck event. At this workshop, representatives from other countries discussed actions taken or planned to prevent or mitigate the consequences of BWR strainer blockage. On the basis of the preliminary results of the staff's study, as reinforced by information learned at the OECD/NEA workshop, the staff issued NRCB 93-02, Supplement 1, "Debris Plugging of Emergency Core Cooling Suction Strainers," on February 18, 1994 (Ref. 39). The purpose of this supplement was to request that BWR licensees take appropriate interim actions to ensure the reliable operation of the ECCS following a LOCA so that the staff and industry would have sufficient time to develop a permanent resolution. In addition, the bulletin supplement apprised licensees of pressurized-waterreactors (PWRs) and BWRs of the latest information on the vulnerability of ECCS suction strainers in BWRs and containment sumps in PWRs to clogging during the recirculation phase of a LOCA.

On September 11, 1995, Limerick Unit 1 was being operated at 100-percent power when control room personnel observed alarms and other indications that one safety relief valve (SRV) was open. The licensee implemented emergency procedures. Attempts by the reactor operators to close the valve were unsuccessful, and a manual reactor scram was initiated. Prior to the opening of the SRV, the licensee had been running the "A" loop of suppression pool cooling to remove heat being released into the pool by leaking SRVs. Shortly after the manual scram, and with the SRV still open, the "B" loop of suppression pool cooling was started. The reactor operators continued their attempts to close the SRV and reduce the cooldown rate of the reactor vessel. Approximately 30 minutes later, operators observed fluctuating motor current and flow on the "A" loop of suppression pool cooling. Cavitation was believed to be the cause, and the loop was secured. After it was checked, the "A" pump was successfully restarted and no further problems were observed. After the cooldown following the blowdown event, the licensee sent a diver into the Unit 1 suppression pool to inspect the condition of the strainers and the general cleanliness of the pool. The diver found that both suction strainers in the "A" loop of suppression pool cooling were found to be almost entirely covered with a thin "mat" of material, consisting mostly of fibers and sludge. The "B" loop suction strainers had a similar covering, but less of it. Analysis showed that the sludge primarily consisted of iron oxides and the fibers were polymeric in nature. The source of the fibers was not positively identified, but the licensee has determined that the fibers did not originate within the suppression pool, and contained no trace of either fiberglass or asbestos.

The Limerick event demonstrated the need to ensure adequate suppression pool cleanliness. In addition, it re-emphasized that materials other than fibrous insulation could also clog strainers. The staff notes that Perry's strainers were clogged by fibrous filter media.

In response to this event, the staff issued NRCB 95-02, "Unexpected Clogging of Residual Heat Removal (RHR) Pump Strainer While Operating in Suppression Pool Cooling Mode," on October 17, 1995 (Ref. 40). The bulletin requested that licensees (1) assess the operability of their ECCS on the basis of the cleanliness of their suppression pool and ECCS strainers, (2) verify the operability of the ECCS through an appropriate pump test and strainer inspection within 120 days from the date of the bulletin, (3) establish a pool cleaning program, (4) review their foreign material exclusion (FME) practices and correct any identified weaknesses, and (5) implement any additional appropriate measures for ensuring the availability of the ECCS.

Licensee responses to NRCB 93-02 and its supplement demonstrated that licensees had implemented appropriate interim measures to ensure adequate protection of public health and safety, and to allow continued operation until a final resolution to the strainer clogging issue could be achieved. NRCB 96-03 requested that licensees implement the final resolution to this issue. In responding to NRCB 93-02 and its supplement, licensees ensured that alternative water sources (both safety and nonsafety-related) to mitigate a strainer clogging event were available, emergency operating procedures (EOPs) provided adequate guidance for mitigating such an event, operators were adequately trained to recognize and mitigate a strainer clogging event, and loose and temporary fibrous materials stored in containment were removed. Similarly, licensee responses to NRCB 95-02 showed that most licensees had recently cleaned their suppression pools, and that those who had not were scheduled to do so during the upcoming refueling outage. Moreover, a generic safety assessment conducted by the BWROG concluded that operators would have adequate time to use alternative water sources (25~35 minutes) after initial reflood of the reactor vessel. The staff also notes that the probability of the initiating event is low. For these reasons, the staff allowed BWR licensees to continue operation until they were able to fully implement their resolution to NRCB 96-03. Satisfactory resolution of NRCB 96-03 will ensure that the ECCS can perform its safety function and minimize the need for operator action to mitigate a LOCA.

The results of the staff study, documented in NUREG/CR-6224, demonstrate that for the reference plant, there is a high probability that the available NPSH margin for the ECCS pumps will be inadequate after a LOCA dislodges insulation and other debris which are then transported to the suction strainers. In addition, the study calculated that the loss of NPSH could occur less than 10 minutes into the event. The study also demonstrated that the adequacy of NPSH margin for an ECCS system is highly plant-specific because of the large variations in such plant characteristics as containment type, ECCS flow rates, insulation types, plant layout, plant cleanliness, and available NPSH.

In addition, the Barsebäck event demonstrated that a pipe break can generate and transport sufficient quantities of insulation and other debris to the suppression pool/ECCS strainers where they can potentially cause the ECCS to lose NPSH. The Perry events further demonstrated that fibrous debris combined with corrosion products present in the suppression pool (sludge) can exacerbate the problem. This phenomenon was confirmed in the staff's study (described above). Alden Research Laboratory (ARL) in Holden, Massachusetts, further confirmed that the pressure drop across the strainer was greatly increased by the effect of fibrous debris on the strainer surface

filtering sludge from the suppression pool water. The results of these tests are discussed in NUREG/CR-6367, "Experimental Study of Head Loss and Filtration for LOCA Debris," dated December 1995 (Ref. 41). Additional NRC-sponsored testing conducted by ARL demonstrated that the energy conveyed to the suppression pool during the high-energy phase of a LOCA is sufficient to ensure that the fibrous debris and sludge are well mixed and evenly distributed in the suppression pool, and can remain suspended for a sufficiently long period to allow large quantities to be deposited onto the strainer surfaces. As a result, the staff has concluded that this problem is applicable to all domestic BWRs with pressure suppression types of containments. The basis for the staff's conclusion is as follows. There do not appear to be any features specific to a particular plant, class of plants, or containment type that would mitigate or prevent the generation, transport to the suppression pool, or deposition on the ECCS strainers of sufficient material to clog the strainers. Parametric analyses performed in support of the NUREG/CR-6224 study, using parameter ranges which bound most domestic BWRs, failed to identify parameter ranges that would prevent BWRs with other containment types from being susceptible to this problem. Notably, the staff's study was conducted on a Mark I containment; Barsebäck, which is similar in design to a Mark II containment, experienced a strainer clogging event; and Perry, a Mark III containment, also experienced a strainer clogging event.

Title 10, Section 50.46 of the *Code of Federal Regulations* (10 CFR 50.46)(Ref. 42) requires that licensees design their ECCS systems to meet five criteria, one of which is to provide long-term cooling capability following a successful system initiation for a sufficient duration so that the core temperature is maintained at an acceptably low value and decay heat is removed for the extended period of time required by the long-lived radioactivity remaining in the core. The ECCS is designed to meet this criterion, assuming the worst single failure. However, experience gained from operating events and detailed analyses, as previously discussed, has demonstrated that excessive buildup of debris from thermal insulation, corrosion products, and other particulates on ECCS pump strainers is highly likely to occur. This creates the potential for a common-cause failure of the ECCS, which could prevent the ECCS from providing long-term cooling following a LOCA. The staff has concluded, therefore, that licensees must resolve this issue in order to ensure compliance with the regulations. RG 1.82, Revision 2, provides an acceptable method for ensuring compliance with 10 CFR 50.46. Thus, the BWROG wrote the URG to give licensees guidance for complying with 10 CFR 50.46 in a manner consistent with the RG 1.82, Revision 2.

Nonetheless, the staff recognizes that it is difficult to perform plant-specific analyses to resolve this issue because a substantial number of uncertainties are involved. Examples of these uncertainties include the amount of debris generated by a pipe break for various types of insulation; the amount of debris transported to the suppression pool; the characteristics (e.g., size and shape) of debris reaching the suppression pool; and head-loss correlations for various types of insulation combined with suppression pool corrosion products, paint chips, dirt, and other particulates. Many of these uncertainties are plant-specific because of the differences in plant characteristics such as layout, insulation types, ECCS flow rates, containment types, cleanliness, and NPSH margin. Consequently, testing and analyses were conducted by both the BWROG and the NRC to quantify many of these uncertainties.

The staff closely followed the work of the BWROG to resolve this issue. The BWROG evaluated several potential solutions, and completed testing on three new strainer designs, including two passive strainer designs and one self-cleaning design. The BWROG effort was consistent with the

options proposed in NRCB 96-03 for resolution of the potential ECCS strainer clogging issue. The BWROG then developed the URG to provide utilities with (1) guidance, including a calculational methodology, for plant-specific evaluation of the potential ECCS strainer clogging issue, (2) a standard, technically sound, industry approach for resolution of the issue, and (3) guidance that is consistent with the actions requested in NRCB 96-03 for demonstrating compliance with 10 CFR 50.46.

Also, in NRCB 96-03, the staff noted that much of the effort and discussion on this issue has focused on the threat caused by fibrous insulation. While the staff recognized that fibrous insulation represents the largest source of fibrous material in the containment, NRCB 96-03 reminded licensees that the events at both Perry and Limerick involved other sources of fibrous debris. Thus, NRCB 96-03 cautioned licensees to focus their resolution for this issue on protecting the functional capability of the ECCS from all potential strainer clogging mechanisms.

2.0 DISCUSSION

The issue of potential strainer blockage is complex. Head loss across the suction strainers is a function not only of the amount of debris, but also of the types (e.g., fibrous insulation, paint, reflective metallic insulation, dirt, corrosion products, etc.) and characteristics (size, shape, etc.) of the debris. This creates a challenge for the analyst to evaluate the worst case for potential strainer debris loadings. The analyst must also consider the potential for foreign material to be introduced during normal plant evolutions such as refueling and maintenance outages. In addition, the analyst must evaluate plant maintenance practices, including the maintenance of qualified coatings in the drywell and wetwell.

To simplify this process, RG 1.82, Revision 2, provided non-prescriptive guidance for performing a plant-specific analysis (e.g., what should be considered, but not how to perform the calculations). To augment that guidance the BWROG developed the URG in order to give the individual licensees additional details on how to conduct the plant-specific analysis and provide a consistent response by the industry to NRCB 96-03.

The URG is a comprehensive, but complex, document providing both general guidance concerning the various options available to resolve the issue, as well as detailed guidance for performing plant-specific analyses to estimate potential worst-case debris loadings on ECCS suction strainers during a LOCA. The document consists of one volume providing the analysis guidance (Ref. 1) and three volumes of technical support documentation (Ref. 2). The technical support volumes include test reports and analyses that form the basis for the methodologies used to calculate strainer debris loadings and ECCS pump NPSH. Specifically, the URG provides methodologies for the following aspects of a plant-specific analysis:

- estimating the amounts and types of debris that could be generated by a LOCA
- estimating the amount of the debris that could be transported to the suppression pool
- estimating the amount of debris that could accumulate on the ECCS suction strainer surfaces
- determining the head loss caused by the estimated debris accumulation
- calculating the NPSH margin.

Various plant-specific factors may affect the level of engineering effort and resources a given licensee may wish to devote to performing the analyses to ensure adequate sizing of its ECCS suction strainers. Flexibility in the generic guidance for performing these analyses is, therefore, desirable for licensees to accommodate the plant-specific design details affecting the necessary level of detail. For instance, some plants have more margin than others in the structural design for the ECCS suppression pool penetrations. When evaluating the loads (e.g., standard and acceleration drag forces) that would be caused by bulk fluid motion across the strainer and its associated suction piping during a postulated transient or accident (i.e., hydrodynamic loads), a plant with more structural margin may be able to accommodate larger suction strainers without the significant structural modifications that a plant with a lesser margin might require. Therefore, the plant with more margin may opt to conduct a bounding analysis rather than expending engineering resources in an unnecessarily detailed plant analysis.

In order to give utilities this flexibility, the URG provides multiple methods for performing each part of the plant-specific analyses. This allows plants with more hydrodynamic load margin or more

space for larger strainers in their suppression pool to use more conservative, or bounding, approaches which are less detailed and require less licensee resources to perform. Plants with less margin or less space in the pool could opt for methodologies which result in lower calculated debris loadings, but require a higher level of licensee engineering effort.

In providing flexibility, the BWROG opted not to link methodologies for calculating each part of a plant-specific analysis (e.g., a licensee may use Method 1 for estimating the amount of debris generated, but then use Method 3 for estimating the amount of debris transported from the drywell to the wetwell, etc.). Therefore, individual utilities have the flexibility to choose the methods they will use for each part of the analysis. This flexibility complicated the staff's review because it created 38 different ways a licensee could apply the URG guidance. Because of incomplete guidance and inadequate supporting documentation or analysis in several areas, the staff was unable to determine if all of the methodologies, or combinations of methodologies, were acceptable. To maximize efficiency of the review effort, the staff primarily focused on the guidance (or methods) that are reasonably well supported by data or analyses. Other methods, that lacked sufficient detail or technical justification to permit staff review, were rejected. If individual licensees desire to use any portions of the URG (analytical or resolution options) that are rejected by the staff, they should resolve the staff's concerns cited herein.

3.0 URG GUIDANCE FOR DEMONSTRATING COMPLIANCE WITH 10 CFR 50.46

In Sections 3.1 through 3.4 of the URG, the BWROG provides general guidance on plant "resolution options" and detailed guidance on plant-specific analysis methodologies. Section 3.1 provides an overview of the various resolution options available to licensees. Section 3.2 provides the detailed guidance on performing plant-specific analyses for sizing of passive ECCS suction strainers. Sections 3.3 and 3.4 provide additional detailed guidance on the two active resolution options which are specifically cited in NRCB 96-03 as potential ways to resolve the strainer clogging issue.

3.1 EVALUATION OF RESOLUTION OPTIONS

This section of the URG gives utilities guidance for determining the level of detail they should use to analyze their plant and implement their resolution in response to NRCB 96-03. In this section, the BWROG also identifies key factors affecting the complexity and cost of evaluating strainer performance and implementing potential resolutions. This section also includes four flow diagrams (Figures 1 through 4), which display the process recommended by the BWROG for sizing ECCS suction strainers.

Figure 1 provides an overview of the plant analysis process. For plants that have more than a minimal amount of fibrous insulation, the URG recommends that licensees size their strainers as large as possible without violating their penetration hydrodynamic load limits. Licensees should then evaluate the strainer performance with the calculated debris loading to ensure that it provides adequate performance for maintaining the ECCS pump NPSH margin. For plants with almost all reflective metallic insulation (RMI), Figure 1 provides two suggested methodologies:

1) Size the strainers on the basis of the head loss when the strainer is loaded at the saturation level with RMI.
2) Size the strainer on the basis of a calculated expected debris loading.

For mostly RMI plants, Figure 1 does not recommend one sizing methodology over the other.

Figure 2 provides a flow diagram showing two methods for performing a plant evaluation to determine the amount of debris generated and transported to the suppression pool. (The diagram also references the sections of the URG and RG 1.82, Revision 2, which relate to each step in the analysis). According to Figure 2, licensees would use the first method to specifically perform a detailed analysis of the zone of influence (ZOI) for a pipe break and to calculate the amount of insulation debris generated as a result. In parallel with this ZOI calculation, the analyst would evaluate non-insulation debris such as dirt, dust, rust, coatings, and so forth. These two calculations would then be input into the next part of the analysis shown in Figure 3. As an alternative to the detailed analysis, on Figure 2 shows a second method in which licensees would perform a simple bounding calculation assuming that all of the materials of interest are generated as debris and transported to the suppression pool. As with the first method shown in Figure 2, this method would provide the input into the next part of the analysis shown in Figure 3.

Figure 3 provides the flow diagram for evaluating the amount of debris present in the suppression pool and calculating the total debris loading on the strainer, including the debris from the drywell.

The total debris loading on the strainer then serves as one input to Figure 4, which illustrates the process for calculating the ECCS pump NPSH.

Section 3.1 of the URG also gives additional guidance for estimating debris sources, establishing the current licensing basis, and evaluating resolution options. The URG categorizes debris sources as either fixed or transient. Specifically, fixed debris sources are those which must be impacted by the LOCA break jet or blowdown forces to form debris that is transportable to the ECCS suction strainers. Examples of fixed debris sources include piping insulation and coatings. Transient debris sources are those which generally result from normal plant operations, and would be present in a transportable form prior to the postulated LOCA. Examples of transient debris sources include dirt, dust and any other loose materials present in the drywell or suppression chamber. Section 3.1 also points to some of the important licensing-basis assumptions that each utility must identify. These considerations include containment overpressure and suppression pool temperatures assumed in the NPSH calculations, as well as pipe break locations. In addition, Section 3.1 includes an important recommendation, which is that licensees "should consider, if practicable, use of a strainer that results in acceptable ECCS pump NPSH without reliance on containment pressure." The staff notes that this statement is consistent with the recommendations of RG 1.1, "Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal System Pumps" (Ref. 57).

In Section 3.1.2, the URG provides general guidance for plants with reflective metallic insulation (RMI). The BWROG notes that even plants with mostly RMI will have to demonstrate the adequacy of their strainers or implement an appropriate resolution. This statement reflects the results of testing which demonstrates that only a small amount of fiber combined with corrosion products can result in unacceptable head losses. The staff notes that the Perry and Limerick events also demonstrated this same conclusion.

In Section 3.1.3, the URG provides guidance for plants with significant amounts of fibrous insulation in their containments. Specifically, the URG indicates that small amounts of fiber can lead to unacceptable head losses on ECCS systems employing the conical or cylindrical perforated plate strainers typically used by many BWRs prior to the issuance of NRCB 96-03. The BWROG recommends replacing existing strainers with one of the alternate designs that have demonstrated better performance characteristics. The BWROG also recommends the use of the largest possible strainer, provided that the change would not alter the licensing basis for hydrodynamic loads. (The BWROG believes that staff review of new hydrodynamic load methodologies could delay final resolution of this issue.) The rest of Section 3.1.3 discusses various considerations that utilities should keep in mind when considering their final resolution of this issue. These considerations include evaluating containment penetration load margins, plant physical constraints, and suction strainer type and size. Section 3.1.3.4 discusses the nine resolution options available to licensees. however, the staff notes that many of these options are only partial solutions and would still likely require strainer replacement by the licensee. The following discussion provides a brief overview of the resolution options discussed in URG section 3.1.3.4:

- The first option (Section 3.1.3.4.1) involves "further refinement of fixed debris source terms." This option is simply a more detailed containment analysis intended to reduce the debris source term for sizing the strainers by calculating the amount of debris that could reach the strainers. A simplified calculation with bounding assumptions would more quickly provide an answer requiring the least amount of engineering effort, but would tend to be very conservative. By

contrast, the more refined analysis discussed in Section 3.1.3.4.1 would likely yield a lower debris source term, but would cost the licensee more in engineering time and effort.

- The second option (Section 3.1.3.4.2) involves replacing the existing strainers with alternate passive designs such as the stacked disk or star strainer designs. The underlying rationale is to install a strainer that has a higher capacity for debris capture. Specifically, the strainer would have a lower head loss when compared against the existing strainer for the same debris loading. This option is the same as resolution option 1 of NRCB 96-03 (Ref. 4).

- The third option (Section 3.1.3.4.3) is to install jacketing to reduce the insulation debris source term, along with an appropriate attachment mechanism to hold the jacketing in place. The URG states that BWROG test data have shown that metal-jacketed insulation generates less debris than its unjacketed counterpart when exposed to a high pressure jet. The URG also states that use of the jacketing and attachment mechanism "will significantly reduce the amount of fibrous debris which can be transported to the suppression pool and contribute to strainer blockage." In addition, the URG notes that the manner in which the jacketing is attached is critical to its effectiveness.

- The fourth option (Section 3.1.3.4.4) involves "reduction in transient debris source terms." The BWROG recommends this option if a licensee needs a small reduction in head loss to demonstrate an acceptable NPSH margin. To justify the reduction in transient debris, licensees may need to implement additional foreign material exclusion (FME) or housekeeping controls, or more frequent suppression pool cleaning.

- The fifth option (Section 3.1.3.4.5) is to pursue a licensing basis change with the NRC. One example cited as a potential licensing basis change is the use of a more realistic decay heat curve in lieu of the conservative curve used in the original licensing basis (i.e., American Nuclear Society 5.1 versus May-Witt). This, in turn, would improve the calculated NPSH margin by reducing the calculated suppression pool temperatures following a LOCA. The BWROG does not recommend crediting containment overpressure in calculating NPSH margins.

- The sixth option (Section 3.1.3.4.6) is to reevaluate ECCS suction line penetration loads without reopening the licensing basis for containment loads. The BWROG does not provide any guidance for how licensees can accomplish this option. Moreover, the BWROG does not recommend reopening the licensing basis for containment loads.

- The seventh option (Section 3.1.3.4.7) is to partially replace fibrous insulation with RMI. For this option licensees would selectively replace fibrous insulation in the containment to reduce the amount of fibrous material that ultimately could be deposited on the ECCS suction strainers. The URG did not provide any further guidance for how licensees could implement this option.

- The eighth option (Sections 3.1.3.4.8 and 3.3) is to install a backflush system. The BWROG does not recommend this option as a primary mitigating strategy because it would likely increase operator burden by requiring operator action early in the accident, and it would likely require repeated use within 30~60 minutes following the accident. Instead, the BWROG recommends this option as a defense-in-depth measure only.

- The ninth option (Sections 3.1.3.4.9 and 3.4) is to install self-cleaning strainers. The BWROG notes, however, that licensees would need to resolve significant design, qualification, and surveillance issues before implementing this option. URG Section 3.4 provides further guidance on this option.

Section 3.1.4 of the URG discusses other potential solutions that the BWROG has not yet fully evaluated. Consequently, licensees desiring to use these solutions would first be required to perform additional evaluation and testing. All of these potential solutions are alternate strainer designs which are either large-capacity passive strainers or strainers with a self-cleaning capability.

Staff Evaluation for Section 3.1: Figure 1 of the URG provides guidance for plants with a "minimal" amount of fibrous insulation, but does not define what constitutes a minimal amount. In its response (Ref. 64) to the draft SER on the URG (Ref. 63), the BWROG clarified this point. It stated that less than a 0.32 cm (1/8 inch) coverage of the strainer surface by fibrous material is considered minimal. While the staff considers the definition provided by the BWROG to be acceptable, the staff notes that a licensee reviewing Figure 1 is likely in the process of defining the resolution path it intends to follow, and therefore, is unlikely to have performed sufficient analysis to determine if it could potentially entrain "minimal" amounts of fibrous material on its strainer surface during an accident.

Figure 2 of the URG presents a discrepancy between Section 3.2.1.2.3.1 and the associated step in the flow diagram. The text in the diagram indicates that all of the material of interest in performing a bounding analysis is assumed to be debris which is transported to the suppression pool. This clearly would be the most conservative method for calculating the amount of debris that could be transported to the suppression pool, and would eliminate the need for a detailed analysis. However, the staff notes that the flow diagram for this method cites Section 3.2.1.2.3.1 of the URG, which provides detailed guidance regarding Method 1 for calculating debris generation. The text of this section (page 37 of the URG) indicates that licensees may apply transport factors to the total amount of debris assumed in the drywell. It is not clear which is the intended URG recommendation for Method 1. It appears, however, that two methods are being combined into one. It would be clearer if they were separated. The bounding case would be to assume that all potential debris material in the containment is dislodged and transported to the suppression pool during a LOCA. A second method would be to assume that all of the material is generated as debris, but only a fraction of the total (predicted with the use of a transport factor) reaches the suppression pool. The staff's draft SER on the URG (Ref. 63) indicated that the BWROG should clarify the intent of the URG guidance. In its response (Ref. 64) to the draft SER, the BWROG clarified its intent for Method 1 in Figure 2 stating, "There are really two methods intended, either of which is acceptable. One method is to use a zone of influence that encompasses 100% of the material of interest in the drywell and 100% transport to the suppression pool. The second method is to take 100% of the material of interest in the drywell and then use the transport factors provided in the URG to determine the amount of insulation that reaches the suppression pool." The staff concurs with the BWROG that both of these methods are acceptable.

In Section 3.1.2 (page 14 of the URG), the BWROG states, "The head losses which resulted from the tests with combined RMI, fiber, and particulate debris were bounded by those seen in similar tests for the equivalent loading of fiber and particulate without RMI debris." This statement is not entirely correct. The staff evaluated the test data contained in Volume I of the URG Technical

Support Documentation (Ref. 2) and concluded that the data do not support this conclusion under all cases. For example, test run number 15 was conducted with a 20-point star strainer at 9462 liters per minute (l/m) (2500 gallons per minute (GPM)) with 1.36 kilograms (kg) (3 pounds (lbs)) of NUKON® insulation and 108.9 kg (240 lbs) of corrosion products. The resultant head loss across the strainer was 127 centimeters (cm) (50 inches (in.)) of water (H_2O). Test run number 33 was conducted with the same strainer at similar conditions and debris loadings except for the addition of 8.2 square meters (m^2)(88 square feet (ft^2)) of RMI debris. Test run number 33 resulted in a head loss across the strainer of 292 cm of H_2O (115 in. H_2O). The results of test run numbers J6 and J7 (with pump 2 mixing the tank for test run J7) present another example involving a truncated cone strainer at 18,924 l/m (5000 GPM), while test runs J23 and J24 present a similar example involving a 60-point star strainer.

The NRC sponsored independent confirmatory testing, conducted by ARL, with fiberglass insulation, corrosion products, and RMI. The results of these tests are documented in the ARL test report, entitled "Head Loss of Reflective Metallic Insulation Debris With and Without Fibrous Insulation Debris and Sludge for BWR Suction Strainers," dated May 1996 (Ref. 43). After analyzing the results of these ARL tests, the URG and its supporting technical documentation (Refs. 1 and 2), the BWROG response (Ref. 64) to the draft SER on the URG (Ref. 63), the staff concludes that the BWROG generalized statement regarding the head loss of a fiber plus corrosion products debris bed bounding the head loss of a fiber, corrosion product and RMI debris bed does not hold true in all situations, but can be generalized into three categories. First, in plants with minimal amounts of fibrous debris, the head loss of the RMI will tend to dominate. Second, in plants with more than minimal amounts of fibrous debris, but where RMI is the still the dominant debris source, the BWROG statement that the head loss of the combined debris bed would be bounded by the head loss of just the fibrous debris and sludge tends to hold true. However, in the third case, if a licensee has large quantities of both fibrous debris and RMI which may reach the strainer surface during an accident, the staff believes that the head loss would be additive. In other words, in this scenario, the head loss would be bounded by summing the numerical values of the head loss across the strainer with a fibrous debris/corrosion product debris bed only, and the head loss across the strainer for an RMI debris bed only (see Appendix K). However, further staff review of the URG led the staff to conclude that "the URG head loss correlation is unreliable and the guidance is inadequate to prevent inconsistent application of the correlation. On that basis that the staff recommends that licensees employ vendor test data to demonstrate the head loss used to calculate the NPSH margin" (see section 3.2.6 of this SER). Because of the staff's conclusion on the URG head loss correlation, the staff believes this issue (head loss from combined fiber/RMI debris beds) should be resolved on a plant-specific basis. Licensees should ensure that their strainer vendor reviews the debris combinations of interest for their plant and ensures that the vendor's test data supports the head loss used in the licensee's plant-specific analysis.

In the last paragraph on page 16 of the URG, the BWROG implies that utilities should take no action until the NRC completes its review of the URG. Although any change to that discussion would be made moot with the issuance of this SER, the staff emphasizes that licensees should take whatever action they can to resolve this issue as soon as possible. The staff encourages interim actions which help to ensure the licensees' ability to mitigate a LOCA or a strainer clogging event until such time as the licensees are able to fully implement their final resolution for this issue.

Section 3.1.3.1 of the URG discusses the evaluation of containment load penetration margins. The URG states that a licensee's evaluation of containment penetration load margin should "also identify any excess conservatism used in the existing structural analysis which could be reduced through the use of alternate analysis methods." The staff has concerns regarding this statement. Specifically, the hydrodynamic load programs for the Mark I, Mark II, and Mark III programs were very specific in providing generic methodologies for calculating hydrodynamic loads. Each plant submitted a plant unique analysis report (PUAR) for staff review and approval. These PUARs provided the specific details of each plant's calculated hydrodynamic loads, including the methodology used and coefficients used, and so forth. The staff notes that part of the basis for acceptance of these methodologies included supporting test data and conservative assumptions. One main assumption was that the strainers were treated as solid cylinders since testing had not been performed to determine the drag coefficients for the perforated strainers. In essence, since the strainers are perforated, the drag on a solid cylinder would bound the actual drag on the perforated strainer. However, the staff's review of licensee responses to NRCB 96-03 has shown that many licensees are changing the coefficients used for calculating the standard and acceleration drag coefficients used in determining the hydrodynamic loads to take credit for the fact that their new strainers are not solid cylinders. While the staff intuitively agrees that the perforated strainers have lower drag coefficients than similarly sized solid cylinders, the licensees have not demonstrated that the standard and acceleration drag coefficients of a perforated strainer can be accurately determined by analysis alone. The staff cautions that licensees making changes to hydrodynamic load calculation coefficients and/or methodologies should not do so without testing to demonstrate the validity of the revised calculations.

In Section 3.1.3.4 and its subsections, the URG discusses nine "resolution options." Three of these options are consistent with the resolution options proposed in NRCB 96-03 (installation of alternate passive design strainers, self-cleaning strainers, or backflush); However, in the opinion of the staff, the remainder are not "resolution options." That is, none of the other six options are sufficient to resolve this issue for any plant. On the basis of its current knowledge of existing plant strainer designs and the deleterious phenomena that can affect head loss across the strainer and NPSH margin, the staff does not believe that any BWR licensee can justify maintaining their existing strainer design for resolution of the strainer clogging issue. Rather, the other six "resolution options" discussed are better characterized as potential licensee actions, which could help licensees reduce the size of the strainer needed to resolve the issue. However, the resolution options lack substantial detail regarding the technical basis for these options and the specific details concerning how to apply each option. For this reason, a licensee should resolve the staff's concerns regarding a given option before using the option as a part of their resolution for the strainer clogging issue. The staff's specific concerns related to the "resolution options" discussed in Section 3.1.3.4 are as follows:

- In Section 3.1.3.4.2 (page 20), the URG states that, "When properly applied, the results of the extensive testing conducted by the BWROG may be applied to strainers other than those tested by the BWROG." The staff finds that there is insufficient information regarding how to apply the BWROG test results to other strainers. In addition, the URG does not discuss the basis for this statement. Without further guidance and justification, the staff cannot consider this statement acceptable. For this reason, the staff recommends that licensees use vendor-specific data based on the plant-specific analyzed conditions as the basis for determining head loss across the strainer.

- In Section 3.1.3.4.3 (page 20), the URG states that, "Additional details on the use of jacketing is provided in Section 3.2.1." However, Section 3.2.1 does not provide any further guidance other than information regarding debris generation. Section 3.2.1 also indicates the importance of banding to obtaining the desired effect of reducing debris generation; however, guidance regarding the types of bands to be used, construction of the bands (e.g., details as to size, thickness, material, weld versus riveted construction, etc.), and mounting instructions is not provided. Because of the lack of information as to how a plant is to apply this option, the staff is unable to reach any conclusion regarding the acceptability of this option. In addition, the characterization of the effectiveness of insulation jacketing on this page is inconsistent with the test report from the BWROG air jet impact testing (AJIT) conducted at the Colorado Engineering Experimental Station, Inc. (CEESI). (The AJIT test report is included in Tab 3 of Volume II of the URG technical support documentation.)

- In Section 5.1, "General Test Conclusions" (page 181), the AJIT report states, "In the case of fibrous insulation materials, the use of jacketing as a means of reducing debris generation does not appear to be effective without the use of an additional banding material which better secures the jacketing to the insulation assembly and the pipe." However, the wording in Section 3.1.3.4.3 (page 20) of the URG contradicts the test conclusion by stating that "Testing performed by the BWROG (Reference 6) confirms that the fibrous insulation which is protected with metal jacketing is able to survive without producing debris at distances much closer to a pipe break than the same fibrous insulation without jacketing." This statement is contrary to the test report conclusions in that it implies that jacketing by itself provides an improvement. The title of the section, "Installation of Jacketing to Reduce the Insulation Debris Source Term," also implies that jacketing by itself provides an additional degree of reduction in debris generation. Without further detailed information on how to apply this option, the associated benefits to be achieved, and the technical basis supporting the use of this measure, the staff is unable to render a determination as to the acceptability of this option.

- In Section 3.1.3.4.4 (pages 20 and 21), the URG discusses the option of taking credit for FME and housekeeping programs as a justification for crediting lower amounts of transient debris in a plant analysis. The staff has two concerns related to incorporating this option into a licensee's final resolution. First, if a licensee selects too low an amount of transient debris for its analysis, the potential exists for operability concerns to surface anytime debris is found in the drywell, suppression pool, or wetwell. Second, if a licensee is considering an increase in transient debris in order to reduce the need for inspections, the staff believes that housekeeping or FME controls are not a substitute for periodic inspections of the drywell, strainers or suppression pool. Given the numerous events reported over the last few years involving FME-related issues, the industry has not demonstrated that FME controls alone are effective in ensuring that materials are not left in the drywell, wetwell, or suppression pool. Consequently, the staff believes that licensees should conduct regular inspections of the drywell, suppression pool and ECCS suction strainers, and perform cleaning when necessary, during every refueling outage until the industry demonstrates over time the ability to control foreign materials. The staff believes adding margin when sizing strainers to account for the uncertainty in the effectiveness of housekeeping controls is a prudent measure. This, in turn, will minimize the need for detailed operability assessments when small amounts of foreign materials are found in the containment or suppression pool.

- In Section 3.1.3.4.5 (page 21), the URG notes that a part of a licensee's resolution to the strainer clogging issue could include a licensing basis change. The URG cites an example in which a licensee may wish to use a more realistic decay heat curve to reduce the calculated post-LOCA suppression pool temperatures. Specifically, the URG states that the BWROG does not recommend that licensees take credit for containment pressure greater than atmospheric pressure. When discussing the resolution of NPSH-related issues in a letter to the NRC's Executive Director for Operations (EDO) dated June 17, 1997 (Ref. 44), the Advisory Committee on Reactor Safeguards (ACRS) explicitly stated, "We believe that allowing some level of containment overpressure is not an acceptable corrective action because adequate overpressure may not be present when needed." The staff concurs that additional containment overpressure (other than an amount already approved by the staff for the existing licensing basis) should not be used as part of the resolution of this issue. Moreover, the staff is evaluating its position regarding the use of containment overpressure in calculating NPSH margin as part of its review of Generic Letter (GL) 97-04, "Assurance of Sufficient Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal Pumps," dated October 7, 1997 (Ref. 45).

- In Section 3.1.3.4.6 (page 21), the URG discusses the potential to reanalyze suction line penetration loads. Specifically, the URG states that it "may be possible to further increase the size of the alternate strainer by reanalyzing ECCS suction penetration loads and suppression pool structural loads using more sophisticated techniques or through reduction of conservatism in current design basis calculations, but without reopening the licensing basis for containment loads." The staff's concerns regarding Section 3.1.3.1, stated above, also apply to this section of the URG.

- Section 3.1.3.4.7 of the URG indicates that an option for reducing the fibrous debris source term in the drywell is to partially replace fibrous insulation with RMI. The staff agrees that this is an appropriate option for reducing the amount of fibrous debris that can be transported to the suppression pool; however, when using this option for a selected break, licensees should reassess other breaks to ensure that the changes does not affect which break is the most limiting in terms of NPSH margin. In addition, licensees must consider head loss in terms of combined fibrous/RMI debris beds. (See the staff evaluation of Section 3.1.2 above.)
  In Section 3.1.3.4.8 (page 22), the URG states that the BWROG does not recommend backflush as a primary means of ensuring ECCS flow to the core. The basis for the BWROG's recommendation is that backflushing would place an unnecessary burden on operators early in an accident and would likely require repeated initiations during the accident. The staff concurs with the BWROG that backflush is a more viable option as a defense-in-depth measure. The staff also believes that, if used as a primary means of ensuring adequate ECCS flow, backflushing should be combined with the installation of a large-capacity passive strainer to maximize the amount of time before backflush initiation would be required.

- In Section 3.1.3.4.9 of the URG, the BWROG discusses the use of self-cleaning strainers as a resolution option. See the staff evaluation of Section 3.4 of the URG for a discussion regarding the use of self-cleaning strainers as a resolution option.

The staff also notes that a good practice would be to maintain defense-in-depth because of the uncertainties associated with any resolution to this issue. The staff strongly encourages the

enhancement of alternate water sources (including maintenance of crossover valves which connect the ECCS to alternate water sources), operator training, and EOPs to ensure that operators can mitigate any situation involving loss of ECCS flow resulting from strainer clogging. In its letter to the EDO dated February 26, 1996 (Ref. 46), the ACRS stated that a diverse means of providing emergency core cooling is desirable because of the difficulty in predicting with confidence the amount of debris that would challenge the ECCS strainers. In its response to the ACRS dated March 22, 1996 (Ref. 47), the staff concurred with the ACRS comment and agreed to "place more emphasis on the need to improve, where appropriate, the procedures to better address core cooling from alternative sources of water."

3.2 METHODOLOGY FOR SIZING PASSIVE ECCS SUCTION STRAINERS

In Section 3.2 of the URG, the BWROG presents their analysis methods for performing a plant-specific evaluation to size ECCS suction strainers. Each subsection presents a different part of the analysis including calculation of drywell debris sources, other sources of drywell debris, transport of drywell debris to the suppression pool, transport of debris within the suppression pool, head loss, and NPSH.

3.2.1 Sources of Drywell Insulation Debris

This section of the URG discusses the methodologies that the BWROG recommends for calculating the amount of LOCA-generated debris from piping insulation. The guidance provided includes determining the break locations to be analyzed, the ZOI for the break jet, and the destruction factors for piping insulations typically used in domestic BWRs. Section 3.2.2 discusses other potential sources LOCA-generated debris.

3.2.1.1 Pipe Break Locations

Section 3.2.1.1 of the URG discusses the BWROG guidance related to selecting pipe break locations. The introduction to Section 3.2.1.1 discusses general considerations for the selection and summarizes important guidance provided in 10 CFR 50.46 (Ref. 42) and RG 1.82 (Ref. 5). In addition, this section includes guidance from Section 3.6.2 and Branch Technical Position (BTP) MEB 3-1 of NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," which is also known as the SRP (Ref. 48).

The URG correctly states that 10 CFR 50.46 explicitly requires that "ECCS cooling performance must be calculated in accordance with an acceptable evaluation model and must be calculated for a number of postulated loss-of-coolant accidents of different sizes, locations, and other properties sufficient to provide assurance that the most severe postulated loss-of-coolant accidents are calculated." The staff believes a licensee evaluating its compliance with 10 CFR 50.46 should look to this statement for the criteria to be met when choosing the number and locations of the breaks to be analyzed.

The URG then provides a discourse concerning SRP Section 3.6.2 and BTP MEB 3-1. On page 26, the URG quotes SRP Section 3.6.2 as stating, "Acceptable criteria to define postulated pipe rupture locations and configurations inside containment are specified in Branch Technical Position

(BTP) MEB 3-1." The staff notes that this statement is taken completely out of context and, as such, does not accurately convey the position stated in the SRP Section 3.6.2, which is preceded in the SRP by the statement that "Specific criteria necessary to meet the relevant requirements of GDC 4 are as follows:"

The URG then notes that NUREG-0897, Revision 1, "Containment Emergency Sump Performance" (Ref. 58), states that "SRP Section 3.6.2, 'Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping,' should be used to identify potential break locations." The URG then quotes BTP MEB 3-1, stating that "...The rules of this position are intended to utilize the available piping design information by postulating pipe ruptures at locations having relatively higher potential for failure, such that an adequate and practical level of protection may be achieved." The BWROG includes these quotations in the URG to establish a basis for using SRP Section 3.6.2 to define the pipe break locations that should be evaluated in order to demonstrate compliance with 10 CFR 50.46. In addition, Section 3.2.1.1.1 of the URG cites RG 1.82, Revision 2, as a source of guidance for pipe break locations to be analyzed. Specifically, the URG quotes the following guidance from Section 2.3.1.5 of RG 1.82, Revision 2:

"As a minimum, the following postulated break locations should be considered.

- Breaks on the main steam, feedwater, and recirculation lines with the largest amount of potential debris within the expected ZOI,
- Large breaks with two or more different types of debris within the expected ZOI,
- Breaks in areas with the most direct path between the drywell and wetwell, and
- Medium and large breaks with the largest potential particulate debris to insulation ratio by weight."

The BWROG does not consider the fourth criterion dealing with the largest particulate-to-insulation ratio to be applicable for licensees using an alternate strainer design. Section 3.2.6.2.3 of the URG discusses the basis for this omission.

After providing the above information as background, Section 3.2.1.1.2 of the URG presents the BWROG guidance for determining pipe break locations. Specifically, Items 1, 2, and 3 of this section present alternative approaches for the selection of pipe break locations. (Item 1 gives pipe break selection criteria for three different licensing-basis situations. Item 1.a provides pipe break location selection criteria for plants that were licensed with an MEB 3-1 analysis. Item 1.b provides pipe break location selection criteria for licensees who have not performed a stress analysis consistent with MEB 3-1, but may desire to perform such an analysis. Item 1.c discusses the pipe break location selection criteria for licensees who have not identified pipe break locations using an approved stress analysis technique.) Item 4 cautions licensees about differentiating between pipe break locations used for ECCS evaluations and those which are in the plant licensing basis. Item 5 gives guidance regarding the treatment of pipe breaks inside the bio-shield walls.

Staff Evaluation for Section 3.2.1.1: In its evaluation, the staff compared the guidance provided in this section of the URG to the corresponding guidance provided in RG 1.82, applicable sections of the SRP, and with 10 CFR 50.46.

In this section of the URG, the BWROG focuses on the postulated pipe break locations that the licensee analyzes to demonstrate compliance General Design Criterion (GDC) 4, as presented in Appendix A to 10 CFR Part 50 (Ref. 42). GDC 4 requires that licensees must protect structures, systems and components (SSCs) important to safety from the dynamic effects (e.g., pipe whip, direct steam jet impingement, etc.) and environmental effects (e.g., temperature, pressure, radiological effects) of postulated pipe ruptures. Consequently, GDC 4 imposes a requirement that licensees must provide physical means (e.g., pipe restraints, physical barriers (walls), or physical separation) to protect equipment important to safety from the effects of postulated pipe breaks and to ensure that those components are capable of performing their safety function(s) in a post-LOCA environment. Because it is not practical to physically protect equipment in the containment from every postulated LOCA, the staff concluded in SRP Section 3.6.2 that licensees could provide an adequate and practical level of protection for compliance with GDC 4 by physically protecting equipment important to safety from the postulated pipe breaks that have a relatively higher potential for failure (e.g., postulated failures at high-stress and fatigue locations). As a result, when demonstrating compliance with GDC 4, licensees may analyze pipe breaks through the use of pipe stress analysis methodologies similar to that provided in BTP MEB 3-1 of SRP Section 3.6.2. The staff, therefore, evaluates licensee's safety analysis reports against the requirements of SRP Section 3.6.2 to "confirm that requirements for the protection of structures, systems, and components relied upon for safe reactor shutdown or to mitigate the consequences of a postulated pipe rupture are met." Notably, the only acceptance criterion specified in SRP Section 3.6.2 is compliance with GDC 4. GDC 4, SRP Section 3.6.2, and BTP MEB 3-1 are not to be used for ECCS functional design or compliance with 10 CFR 50.46. The staff considers SRP Section 3.6.2 and BTP MEB 3-1 to be inappropriate for demonstrating compliance with 10 CFR 50.46.

The primary concern in the ECCS strainer clogging issue is the adequacy of ECCS strainer design relative to ensuring that the ECCS can meet the cooling performance requirements of 10 CFR 50.46. The staff notes that no concerns have been identified during the resolution of this issue relative to physically protecting the ECCS from the dynamic or environmental effects of a LOCA. In order to ensure adequate ECCS cooling capability, 10 CFR 50.46 requires that ECCS cooling performance "must be calculated for a number of postulated loss-of-coolant accidents of different sizes, locations, and other properties sufficient to provide assurance that the most severe postulated loss-of-coolant accidents are calculated." The staff notes that the worst breaks from the standpoint of peak clad temperature may not be the worst from the standpoint of NPSH margin. As a result, additional breaks may have to be evaluated. When evaluating ECCS performance for compliance with 10 CFR 50.46, SRP Sections 6.3 and 15.6.5 are the appropriate sections of the SRP to consider. For instance, the review procedures of Section 15.6.5 specifically require reviewers to ensure that "a variety of break locations and the complete spectrum of break sizes were analyzed." This is consistent with 10 CFR 50.46.

RG 1.82 provides the staff's position on what constitutes an appropriate spectrum of breaks to be considered when evaluating the potential for strainer clogging. Specifically, Regulatory Position 2.3.1.5 of RG 1.82 states, "As a minimum, the following postulated break locations should be considered: (a) Breaks on the main steam, feedwater, and recirculation lines with the largest amount of potential debris within the expected zone of influence, (b) Large breaks with two or more different types of debris within the expected zone of influence, (c) Breaks in areas with the most direct path between the drywell and wetwell, and (d) Medium and large breaks with the largest

potential particulate debris to insulation ratio by weight." The staff believes that the RG provides the complete scope of breaks needed to meet the intent of 10 CFR 50.46.

Criterion 4 of Regulatory Position 2.3.1.5 of RG 1.82 states that one group of break locations a licensee should identify as a minimum are "Medium and Large Breaks with largest potential particulate debris to insulation ratio by weight." The reason these breaks should be considered is the "thin-bed effect," which has been observed by the BWROG and the staff in cylindrical and truncated cone strainer tests. Specifically, testing has shown that high head losses can occur on cylindrical or conical strainers with thin fiber beds and high concentrations of sludge. The reason for this observation is that thinner fibrous debris beds compress more tightly to the strainer surface. When this occurs, the filtration efficiency (entrapment of particulates by the strainer and fibrous debris bed) increases resulting in a significantly higher head loss than in debris beds containing significantly higher quantities of fibrous debris.

In URG Sections 3.2.1.1.1 and 3.2.6.2.3, the BWROG states that they did not observe a thin-bed effect for alternate strainers; therefore, licensees who propose to use alternate strainers need not analyze medium or large breaks with the largest potential particulate-to-insulation debris ratio by weight. The URG does not provide sufficient data to support this conclusion. There are three reasons for this. First, the data provided only apply to two specific types of alternate strainers (star and stacked-disk), and it is evident that not all licensees will limit their plants to using only these two alternate strainer designs. Second, other "alternate" strainer designs may not have the critical features that eliminate the "thin-bed effect." Third, even for the two types of alternate strainer designs that were tested, the data set is too limited to support such a broad conclusion.

Because of these concerns, a confirmatory analysis was performed in support of this review. The staff's confirmatory analysis is documented in Appendix E. The staff's analysis does suggest that licensees may screen out medium LOCAs (MLOCAs) if they use the stacked disc strainer number 2, the star strainer, or another geometrically similar alternate strainer design that has deep cavities sufficient to hold debris loadings consistent with a MLOCA for their plant. The basis for the staff's conclusion is that the test data provided in the URG do demonstrate that with fiber loadings up to the equivalent amount to fill the crevices in the stacked disk strainer number 2, high head losses were not experienced even with high sludge-to-fiber mass ratios. The amounts of debris that would be required to completely fill the cavities between the disks in the stacked disk number 2 strainer would be approximately 0.28 cubic meters (m^3) (10 cubic feet (ft^3)). This amount of fibrous debris is similar to the amount estimated for a MLOCA for the reference plant in NUREG/CR-6224 (Ref. 31). For these types of strainer designs, the MLOCA does not appear to be the bounding break. However, the staff notes that its conclusion is founded on limited amounts of test data, estimates of debris loadings for the reference plant MLOCA only, and evaluation of two strainer designs only. Consequently, the staff believes that licensees considering a resolution option using an alternate strainer design may screen out MLOCAs from their plant-specific analysis if they ensure that the vendor confirms that the thin-bed effect is not a problem for their plant-specific strainer application (i.e., the strainer design is such that lesser debris loadings could not result in higher head losses than those calculated for large break LOCAs). This can be done by evaluating the effect of varying debris loads through parametric analyses. Where possible, the staff believes that these analyses should be validated through comparison with applicable vendor test data. A second option would be to experimentally verify that the thin-bed effect is not an issue for the strainer design being considered using debris quantities which approximate those for a MLOCA for a given plant.

Likewise, on the basis of the staff's review of several plant-specific submittals detailing licensees' design bases for estimating maximum debris loadings on their new strainer design (see Refs. 32 through 38), it appears unlikely in most cases that large LOCAs with the highest particulate to fiber ratios by weight will be the limiting break in terms of creating the worst-case head loss across the strainers. Review of licensee submittals has shown that when using Method 1 or 2 for calculating the pipe break ZOI, the calculated amount of fibrous debris is sufficiently conservative to bound the head losses in breaks with the highest ratio of particulates to fibrous debris by weight. However, the staff believes that in certain plant configurations, the potential exists for debris beds with higher particulate-to-fiberratios to have the bounding head losses. One such case may be in plants with large quantities of both calcium silicate and fibrous insulation materials. The difference between the breaks with the largest amounts of fibrous debris and the breaks with the highest particulate to fibrous debris ratios may not be significant enough for the former to bound the latter. Consequently, as in the case with MLOCAs above, the staff believes that licensees considering a resolution option using an alternate strainer design may screen out large break LOCAs with the highest particulate-to-fiber debris ratio if they ensure that the vendor confirms that smaller breaks with higher particulate-to-fiber debris ratios do not result in higher head losses for their plant-specific strainer application. This can be done by evaluating the effect of varying debris loads through parametric analyses. However, the staff believes that vendors should have sufficient test data to support these analyses. A second option would be to experimentally verify that large breaks with the highest particulate-to-fibrous debris ratio are bounded by large breaks which generate higher fibrous debris loadings, but lower particulate-to-fibrous debris ratios.

The staff notes that if the BWROG intends to include generic statements regarding all alternate strainer designs, it should support the guidance with additional data in one of two ways. First, the URG might cover a wider range of experimental parameters (e.g., fiber volume, sludge to fiber ratios, different strainer geometries, etc.) for all alternate designs that are actively considered by various individual licensees. Alternatively, the URG might demonstrate which parameters are key in strainer design to ensure that breaks with high particulate-to-fibrous debris ratios are not the bounding breaks for the strainer design under consideration.

Conclusions Regarding Section 3.2.1.1: In summary, the staff reached the following conclusions:

- To be consistent with NRC requirements, the URG should give clear guidance that helps licensees select break sizes and locations that reasonably ensure acceptable ECCS performance under the most severe conditions. URG Section 3.2.1.1 largely, but not entirely, succeeds in meeting this objective. The staff's concern deals with the clarity of the guidance and the unnecessary focus on SRP Section 3.6.2. The staff concludes that it is inappropriate for the URG to cite SRP Section 3.6.2 as a basis for determining pipe break locations to demonstrate compliance with 10 CFR 50.46. There are two reasons for the staff's conclusion. First, SRP Section 3.6.2 does not provide guidance or acceptance criteria for demonstrating compliance with 10 CFR 50.46. Second, the BWROG has not demonstrated that break locations selected consistent with SRP Section 3.6.2 would bound the worst-case debris generation scenarios and, therefore, meet the intent of 10 CFR 50.46.

- 10 CFR 50.46 and RG 1.82, Regulatory Position 2.3.1.5, give licensees adequate guidance regarding selection of pipe break locations for performing a plant-specific analysis relative to

debris generation. This guidance concisely indicates where a licensee should focus its analytical efforts.

- Licensees may screen out large breaks with the highest particulate-to-fiberdebris ratio by weight and MLOCAs in performing their plant-specific analyses, if their resolution includes both of the following:

  1) Installation of a strainer similar to the stacked disk number 2, star strainer, or another geometrically similar strainer with deep crevices.
  2) The licensee has adequate assurance from the strainer vendor that the screened out breaks would not be more limiting in terms of head loss across the strainer. The vendor should have adequate test data to support screening of these breaks.

In addition, the staff notes the following observations and guidelines:

- Each alternative evaluation method presented must reasonably ensure that licensees will suitably evaluate the most severe ECCS suction strainer debris loadings (from drywell insulation sources).

- Bounding analyses, if used by licensees in lieu of specific pipe break location analyses, must address all debris species (from insulation sources) that would have been addressed by the specific pipe break location evaluations.

- The URG provides incomplete guidance regarding pipe breaks located inside the bio-shield wall. The staff forwarded this position to the BWROG in Ref. 11. The related BWROG response is documented in Ref. 13. Citing utility responses documented in Ref. 12, the BWROG argued in Ref. 13 that breaks inside the bio-shield wall are not major contributors of debris. As a result, the BWROG does not believe that generic guidance is needed on this issue. However, the staff contended in its draft SER on the URG (Ref. 63) that additional guidance on the analytical considerations to be evaluated by licensees would be beneficial and consistent with the BWROG's stated goal of providing a consistent industry response to NRCB 96-03. In its response to the draft SER (Ref. 64), the BWROG stated, "The BWROG believes that the plant unique aspects of the amount and type of insulation inside the bio-shield will govern the most appropriate means of addressing this debris source. For many plants the amount of debris available inside the bio-shield is negligible relative to other debris sources and can be discounted. The BWROG recommends that this issue is best addressed on a plant-specific basis." On the basis of the staff's review of Ref. 64, the staff concludes that this issue should be addressed on a plant-specific basis.

3.2.1.2 Zone of Influence

URG Section 3.2.1.2, entitled "Zone of Influence," documents the BWROG's guidance regarding various options for selecting a ZOI model that individual utilities can use to estimate the volume of debris generated by a postulated pipe break. The URG guidance provided in this section is predicated on the following supporting analyses which are included in the URG Technical Support Documentation (Ref. 2):

(1) "ZOI as Defined by Computational Fluid Dynamics," Revision 3, URG Technical Support Documentation, Vol. II, Tab No. 1, Continuum Dynamics Inc., Princeton, NJ.
(2) "Air Jet Impact Testing (AJIT) of Fibrous and Reflective Metal Insulation," Revision A, URG Technical Support Documentation, Vol. II, Tab No. 3, Continuum Dynamics Inc., Princeton, NJ.
(3) "Evaluation for Existence of Blast Waves Following Licensing Basis Double-Ended Guillotine Breaks," URG Technical Support Documentation, Vol. III, Tab No. 13, General Electric Nuclear Energy, San Jose, CA.
(4) "Total Pressure Topography and Zone of Destruction for Steam and Mixture Discharge from Ruptured Pipes," URG Technical Support Documentation, Vol. III, Tab No. 14, General Electric Nuclear Energy, San Jose, CA.

The staff reviewed URG section 3.2.1.2, along with the supporting analyses listed above, to assess the completeness and accuracy of the guidance provided. In addition, the staff compared the guidance provided in the URG to that provided in RG 1.82, Revision 2.

Section 3.2.1.2 of the URG provides four options (or methods) for selecting the ZOI over which LOCA jets would damage the insulation. Each method reduces the amount of conservatism relative to the previous method, but requires more rigorous analysis by the licensee. The method is selected on the basis of licensee resources and the amount of conservatism the licensee desires to build into its strainer design. Method 1, the most conservative, bounds the ZOI by assuming that it encompasses the entire drywell. Methods 2 and 3 define a ZOI by determining the spatial volume enveloped by a specific damage pressure of interest for a jet expanding in free space and mapping a spherical ZOI of equal volume surrounding the break. All of the insulation contained within that spherical volume is then assumed to be damaged[1]. Methods 2 and 3 have several important differences, but they are essentially refinements that reduce the amount of conservatism introduced by assumptions associated with Method 2. For example, Method 2 defines the ZOI by assuming full separation of both ends of a double-ended guillotine break (DEGB). In contrast, Method 3 allows the licensee to take credit for pipe restraints and to evaluate axial and radial offsets consistent with those restraints. Finally, Method 4 allows the user to define the ZOI by directly employing the results of computational fluid dynamics (CFD) modeling.

The BWROG guidance allows flexibility for licensees to select a ZOI modeling option that best suits their solution, and use it to construct the ZOI surrounding each break location selected for analysis. All of the insulation contained in that ZOI is assumed to be "damaged." Licensees who do not wish to take credit for debris retention in the drywell can put all the "damaged" insulation into a single category and track it as it is transported to the ECCS strainer via the suppression pool model of interest. On the other hand, licensees wishing to take credit for debris retention in the drywell divide the total "damaged" insulation into two bins, 1) debris generated above the lowest elevation grating, and 2) debris generated below the lowest elevation grating. Such a division is required to facilitate application of drywell transport factors that are dependent on the location of insulation with respect to the lowest grating. However, URG Section 3.2.1.2 does not address the size distribution of the "damaged" debris. (Such information is provided in Section 3.2.3, "Drywell Debris Transport.")

[1] It is important to note that not all of the damaged insulation is assumed to be transportable.

Staff Evaluation of Section 3.2.1.2: The staff's confirmatory analyses performed in support of its review of this section are documented in appendices A, B, C, D, and F to this report. The staff's key conclusions from these confirmatory analyses are summarized as follows:

- The BWROG calculations in the URG underestimate the bulk dynamic pressures in Mark I containments by a factor of 10 at some locations. However, the staff's conclusion is that the bulk dynamic pressures would likely be insufficient to damage insulation materials such as those presently used in operational BWRs, provided that the insulations are properly installed and well-maintained. The tables in the URG for debris generation and transport assume that insulation is correctly installed and well-maintained. Licensees should ensure that the analysis reflects the actual plant conditions. In addition, the staff notes that in the BWROG's response to staff RAIs (Ref. 13) showed that the bulk dynamic pressures in Mark I and Mark III containments could be 5-10 times higher than that calculated for a Mark II containment because of smaller containment cross-sections. While this issue was resolved in Ref. 13, the staff notes that the URG will not be updated again. Therefore, the staff wishes to note that this technical error still remains in the URG.

- The BWROG's basis for using the jet center line (JCL) pressure at the distance from the jet nozzle (L/D) at which incipience of insulation damage was first observed in the AJITs as the insulation's characteristic damage pressure is inadequately supported by either analysis or experimental data. In the staff's opinion, the experimental evidence from the AJIT seems to contradict the JCL concept. Rather, the staff's review of the data leads to the conclusion that the incipience of damage is related to the total jet impingement load rather than the local maximum. This intuitively makes more sense. In the staff's opinion, it does not seem logical that a peak pressure at one point on the insulation blanket would be responsible for destruction over the entire blanket where other portions are clearly exposed to lower pressures.

  The staff also notes two additional concerns related to use of the JCL. First, the choice of the JCL to characterize damage raises questions related to scaling BWROG AJIT results to BWR drywells. Second, interpreting JCLs as the damage pressures, and subsequently using them in enveloping the volume over which debris damage occurs, may make the volume estimates for ZOI non-conservative. For all of the reasons discussed above, the staff conducted a confirmatory analysis (see Appendix B to this SER). On the basis of the staff's analysis, the staff believes that a target area averaged pressure (TAAP) or total jet impingement load are more technically correct bases for assessing potential damage.

  The staff's concerns over the use of JCL pressure can be characterized in the following way. The BWROG's logic of assuming that damage relates only to JCL pressure would lead to the conclusion that an insulation blanket that survived at 10 L/D in the AJITs would also survive at 10 L/D if the 7.6-cm (3-inch) nozzle is replaced by 30.5-cm (12-inch) nozzle. However, no basis exists for this conclusion. Similarly, there would be no need for the suggested correction formula ($P^{D}_{dest} = P^{12}_{dest} * (12"+2t)/(D+2t)$) if damage relates only to the JCL (or alternately to the maximum pressure an insulation blanket is subjected to). The BWROG's rationale is unclear for extrapolating AJIT experimental results to pipes of different diameters.

  The staff notes that this concern is only significant for insulations with high P_{dest} values. The further the jet impact is from the nozzle, the more closely JCL approaches TAAP and the choice

between the two metrics becomes inconsequential. As a result, there are only five types of insulation which are affected by this comment. The first two affected insulations are Darchem and Transco RMIs. The staff notes, however, that the URG contains very conservative destruction and transport fractions for RMI debris (see Section 3.2.3 of this SER). These factors are used to calculate the amount of insulation in the ZOI that will be destroyed into a fine debris and transported to the suppression pool. For RMI debris, the factor used for debris generation exceeded the maximum amount of debris observed during the AJIT by 500%. The staff believes that the conservative debris generation/transport assumptions of that part of the analysis outweigh the staff's JCL concern cited herein; therefore, this comment is not considered to be significant for RMI insulations. The second two affected insulations are fibrous insulation that are banded to reduce debris generation. Since banding has not been accepted as a resolution option, the staff recommends that debris generation concerns related to banded insulation be resolved on a plant-specific basis. The fifth affected insulation is calcium silicate (Cal-Sil) which the staff notes should be treated as being eroded over time by the break jet. Use of the JCL to calculate the ZOI, in this case, is not applicable. The BWROG debris generation tests were of insufficient duration to show how Cal-Sil debris generation changes with time; however, Swedish testing (Ref. 67) has demonstrated that Cal-Sil and similar insulations erode over time. Because of the limited number of insulations affected by this staff concern, the staff believes that its concerns regarding the use of JCL versus TAAP for ZOI calculations should be addressed on a plant-specific basis.

- The BWROG's suggested correction formula is reasonable for scaling damage pressures measured in the AJIT facility for insulation blankets installed on 30.5-cm (12-in.) pipe to pipes of different diameters. The staff notes that this formula also supports a choice of a target area averaged pressure in place of the JCL suggested by the BWROG.

- The BWROG's estimates of volume of a freely expanding steam jet that is bounded by a pressure isobar of interest are conservative and well supported. Typically, the BWROG estimates of jet volumes are higher than or equal to ANSI/ANS 58.2 model estimates for both extremes (DEGB with full and limited separation). Therefore, the staff believes that the jet volumes listed in Table 1 of the URG are reasonable.

- The BWROG's suggested correction factors appear reasonable for scaling the jet volumes computed for steam breaks to recirculation breaks. Therefore, the staff believes that it is acceptable to use these correction factors to compute the jet volume bounded by a pressure isobar of interest following a recirculation line break.

- The BWROG choice of mapping a spherical ZOI with a volume equal to the volume of the double-ended conical ZOI for a freely expanding jet is unsupported either by analytical modeling or experimental evidence. The BWROG's rationale, however, appears logical (although qualitative). As a result, the staff conducted a confirmatory analysis using a limited CFD model to demonstrate the effect of the jet interaction with structures and piping in the drywell. This analysis demonstrated the diffusion of the break jet as it interacts with structure and piping. On the basis of this analysis, the staff concludes that the spherical ZOIs developed using Methods 2 or 3 in Section 3.2.1.2 of the URG are conservative and acceptable. The basis for the staff's conclusion is that the jet emanating from a broken pipe will lose energy and diffuse with distance and its interaction with surrounding pipes and structures, and the URG methodology does not

account for this piping/structural interaction which conservatively increases the calculated size of the ZOI. (It will likely diffuse into a high-velocity flow within 5 -10 L/D from the nozzle as it interacts with various structures.) The staff also notes that if the jet were not interacting with the surrounding structures (i.e., it was on a path that allowed free expansion), debris would not likely be generated. The staff concurs with the URG's recommended use of a spherical model as the best means to account for the impact of drywell congestion, drywell structural interactions, and the dynamic effects of pipe separation.

- The ZOIs developed using Methods 1, 2, and 3, and subsequently the volume of insulation assumed to be damaged and available for drywell transport, are very large. For some insulations, the ZOI enveloped between a fourth to a third of the drywell. As an example, the ZOI computed for steel jacketed NUKON® using Method 2 is a spherical region approximately 11 break diameters (D) in radius, which is much larger than the volume of the ZOI calculated using CFD codes by the staff and the 7D sphere used in the NUREG/CR-6224 study, as well as the NUREG-0897 guidance. The smallest ZOI is greater than 10D in radius.

- The staff identified a concern related to the use of Method 3, which allows the licensee to "determine whether the break results in a single jet (such as a steamline break) or double jet (such as for a recirculation line break)." The staff points out that until the main steam isolation valves (MSIVs) close (about 0.3 - 0.5 s), fluid is expelled from both sides, although the jet may not be as energetic because of the effect of the flow restrainer (i.e., choking occurs in the restrainer). Licensees should pay close attention to account for these phenomena if they wish to take credit for a single jet following a main steamline break (MSLB). The staff recommends that utilities not take credit for a single jet in the case of a MSLB inside the containment. Since this is a design-basis accident (DBA), licensees' assumptions should be consistent with past design-basis scenarios in their Updated Final Safety Analysis Report (UFSAR).

- The staff notes that the experimental data for certain insulations is not very comprehensive, since testing was conducted for only a limited number of L/D values. Specifically, the staff notes that in the AJIT, the BWROG did not adequately explore the exact location at which damage first occurs for certain types of insulation. For example, in the case of stainless steel jacketed NUKON®, the AJIT test report documented damage at 50 L/D with 12% of insulation destroyed into fines and 29% into larger pieces. But the BWROG has not explored damage beyond 50 L/D. Similarly, in the case of unjacketed NUKON® significant damage occurred at 60 L/D and no damage at 119 L/D, but the BWROG did not report any data points in between. In view of this lack of data, some of the conclusions stated in URG become questionable, especially considering that the BWROG subsequently uses this damage-related information to estimate the fraction of fines generated. Another AJIT testing deficiency is that, for selected insulation blankets, the URG may overestimate the JCL pressures at which damage was first noted, and this would lead to non-conservative ZOIs. For example, in the case of Diamond Power (DPSC) Mirror Insulation with "Sure-Hold" bands, the URG reported a damage pressure of 190 psid. However, using the same experimental data and same NPARC computer code results (see URG Technical Support Documentation, Tab 1, page 18, Figure 9), the staff's confirmatory analysis estimated the value to be 150 psid. The staff found several such discrepancies, as annotated in Table 1 of Appendix B to this report by an "*". In all cases, the estimated damage pressures are lower than the URG values. The staff recommends the use of the values in Table 1 of Appendix B to this report for insulations annotated by an "*", since these values are taken

directly from the BWROG's data. The data provided in the URG on page 46, Table 2 appears to be inaccurate and non-conservative. With regard to the number of data points taken in the AJITs, the staff recognizes that the BWROG's choice of limiting the number of air jet tests was resource related. However, on the basis of the conservative methods developed by the BWROG for calculating the ZOI, the staff believes that the calculated ZOI will adequately bound any uncertainties related to minimal P_{dest} data for certain insulations, and as a result, the staff concludes that use of the P_{dest} values provided by the BWROG, as modified by Table 1 in Appendix B to this report is acceptable.

The strengths of URG Section 3.2.1.2 and the associated technical support documentation are as follows:

- The method used to develop the ZOI models is, for the most part, logical and supported by a large number of analytical and experimental studies.

- The AJIT results provide valuable experimental data related to the destructive nature of expanding high-pressure jets. Such data were previously unavailable in the public domain, which limited the previous understanding of insulation destruction by high energy jets.

- The URG reviews important considerations of which licensees should be aware of in selecting a ZOI model and in tracking the damaged insulation.

- The method for developing the size of the ZOI is conservative. The size and shape of the ZOI neglect the effects of the break jet interaction with piping and structures. Piping and structures would tend to deflect the jet in different directions. For this reason, the shape of the ZOI would be more spherical in shape than conical. As a result, the BWROG's choice of a spherical model for the ZOI appears logical. However, the interactions with piping and structures would cause the jet to lose energy and also shadow other targets from the jet. The URG methodologies for determining the ZOI do not take credit for these conservative elements.

The staff identified the following weakness in the technical support documentation for the URG:

- The supporting documentation does not provide a scaling analysis justifying how the experimental damage generated by jets originating from a 7.6-cm (3-in.) diameter nozzle can be scaled up to BWR drywells where the jet stagnation diameter is as large as 24 inches.

Conclusions Regarding Section 3.2.1.2: Overall, the staff concludes that Method 1 is clearly a bounding and conservative method for evaluating the ZOI, since it encompasses the entire drywell, and therefore, bounds the amount of insulation debris that may be generated by the break. The staff also believes that the spherical ZOIs developed by using Methods 2 and 3 would be sufficiently large to envelop the entire zone over which destruction would actually occur. These two methods are thus sufficiently conservative to compensate for the weaknesses noted above and, therefore, are considered acceptable for use on insulations with low P_{dest} values. However, for the insulations noted above with high P_{dest} values, the staff recommends that licensees address the staff's concerns relative to calculation of the ZOI based on JCL on a plant-specific basis.

Section 3.2.1.2 of the URG does not provide detailed guidance regarding Method 4, which would use an unnamed CFD code to determine the ZOI. Consequently, the staff cannot accept Method 4. Any licensee desiring to use Method 4 should address the staff's concerns relative to the details of the analysis and how the code will be benchmarked. The staff believes that CFD codes are useful in obtaining insights, such as in the staff's evaluation of the interaction of a break jet with surrounding piping and structures. The BWROG has not yet demonstrated, however, that a CFD code can accurately predict the specific ZOI for a pipe break or the amount of debris transport to the suppression pool. The purpose of Method 4 is to reduce the conservatism in the calculation of a ZOI. Because of the uncertainties involved in a LOCA and the plant-specific nature of debris generation and transport in a LOCA, the staff would require a much higher level of review in order to accept Method 4. However, the BWROG has not yet provided sufficient detail for the staff to reach any specific conclusions relative to the adequacy of using a CFD model for the purpose of determining the ZOI for a pipe break. As a result, the staff does not consider Method 4 acceptable without further detailed justification on a either a generic or plant-specific basis.

3.2.2 **Sources of Other Drywell Debris**

Section 3.2.2 of the URG focuses on quantifying the sources of debris in the drywell other than pipe insulation. The introduction to this section reviews the relevant guidance provided in RG 1.82, Revision 2, and categorizes the other sources of drywell debris as transient, fixed, or latent debris. Specifically, the URG defines transient debris as non-permanent plant material brought into the drywell, typically during an outage. Examples of transient debris include tools, rags, and temporary filters. Fixed debris is part of the plant, and only becomes debris during a LOCA. Paints and coatings which are delaminated from the coated surface by direct steam impingement from a pipe break is an example of fixed debris. Latent debris appears after prolonged exposure to a LOCA environment, such as an unqualified coating which is not directly impinged upon by the LOCA break jet, but which subsequently fails as a result of prolonged exposure to the temperature, pressure, and radiation of the post-LOCA environment.

The URG also cautions users that their FME, housekeeping, and inspection programs must be adequate to ensure that the quantities of each of these types of materials do not exceed the quantities assumed in the plant's evaluation of ECCS strainer loading. In developing the guidance for this section, the URG used the following supporting analyses from the Technical Support Documentation (Ref. 2):

(1) "Performance of Containment Coatings During a Loss of Coolant Accident," Bechtel Power Corporation, Vol. III, Tab 12, of the URG Technical Support Documentation (Ref. 51).
(2) "BWR Owners' Group Suppression Pool Sludge Generation Rate Data," BWROG, Vol. III, Tab 4, of the URG Technical Support Documentation.

The URG provides the following recommendations for "other drywell debris sources" when performing a plant-specific analysis for sizing the strainer:

- Dirt/Dust: The URG suggests that licensees assume a value of 150 lbm in the strainer head loss correlation. This value is founded on engineering judgement. The URG states that this value is believed to be conservative and considers concrete dust generated by break jet impingement on the containment boundaries. In addition, the URG states that, if licensees use a lower value,

they should document the basis for that value, including any programmatic controls that would help to maintain the value within limits.

- Other Transient Debris: The URG does not provide any specific values for other transient debris. This judgment is left to the individual licensees, and should reflect their own baseline assumptions. The URG states that the inspection frequency should be consistent with the amount of NPSH margin, with smaller NPSH margins requiring (in the BWROG's opinion) greater inspection frequency.

- Rust from Unpainted Steel Surfaces: The URG recommends a value of 50 lbm, on the basis of engineering judgment. Again, the URG states that this value is believed to be conservative and considers "unpainted steel surfaces in the drywell, the main vents/downcomers, and those in the suppression chamber above the pool level which may be swept as a result of LOCA-induced swell." In addition, the URG states that, if licensees use a lower value, they should document the basis for that value, including any programmatic controls that would help to maintain the value within limits.

- Particulate Debris Sources: The URG does not provide any specific guidance for particulate debris sources, beyond cautioning licensees that other sources of fixed particulate debris may be present in the drywell on a plant-specific basis.

- Paints/Coatings: On the basis of the Bechtel report cited above (Ref. 51), the URG recommends that licensees assume specific "bounding" values for coatings as available for transport to the suppression pool. The recommended values are 47 lbm for inorganic zinc coatings, 85 lbm for inorganic zinc topcoated with epoxy, and 71 lbm for 100% epoxy coating. These coatings are assumed to be in the ZOI of the steam jet from the break.

- Concrete: The URG does not provide any specific recommendations other than a licensee should evaluate the potential for concrete debris if the licensee is not using the value for dirt/dust noted above.

- Unqualified/Indeterminate Paint/Coatings: The URG does not provide any specific guidance other than a licensee should determine the quantity of such debris that can be available to transport to the suppression pool. As an alternative, the URG notes that licensees may remove the unqualified or indeterminate coatings, or attempt to qualify them through *in situ* qualification. However, the URG does not provide any guidance regarding how licensees can accomplish this *in situ* qualification.

- Other Latent Material: The URG cautions licensees to consider the possibility that other latent materials might become debris as a result of exposure to the LOCA environment. The kinds of materials that might be of concern in this category include adhesive tags backed with an unqualified adhesive.

Staff Evaluation of Section 3.2.2: Although much of the guidance in this section is general, the guidance appears adequate to caution licensees about considerations needed for an adequate ECCS analysis. However, the staff believes that licensees should exercise caution in using the guidance in this section, especially when considering plant operation relative to strainer design. For

example, the URG states (on page 50) that "Licensees should recognize that the rigor of FME programs should be adequate to ensure that the transient debris source term used as a design input value in the strainer sizing calculations is not exceeded. Consequently, licensees should consider the trade-off between operational flexibility and strainer size when establishing the values of drywell debris considered to be available for transport to the suppression pool." While this statement is accurate as far as the ECCS suction is concerned, it lays open a potentially larger problem with FME. ***FME is not solely an ECCS suction strainer issue.*** The FME problem also deals with materials left in piping systems and system components such as valves (See Refs. 49, 50, 59, 60 and 61). Licensees should also consider other potential problems caused by poor or inadequate FME programs, not just the potential impact on suction strainers. The staff believes that FME should always be maintained at the highest possible level when the potential exists to impact a safety system.

Providing margin in strainer size to allow for breakdowns in FME controls is prudent to avoid operability concerns; however, it in no way relieves the licensee of the responsibilities regarding foreign material control. As a result, the staff concludes that page 51 of the URG presents an unacceptable assertion in stating, "Note that where use of an adequately conservative value is assumed for a particular debris species (e.g., dirt/dust), periodic inspection are not necessary." In its response (Ref. 64) to the draft SER (Ref. 63) on the URG, the BWROG attempted to clarify this assertion by stating, "The BWROG notes that the intent of this URG statement is that inspections to quantify the amount of dirt/dust are not required. It was not intended to imply that general cleanliness inspections were not appropriate." The staff agrees with the BWROG's clarification. It is the staff's opinion that periodic cleanliness inspections are ***always*** necessary, regardless of any baseline assumptions used in the ECCS analysis. The interval between such inspections should only be adjusted on the basis of actual licensee performance, opportunity for introduction of additional debris, and the amount of conservatism in the base assumption. Similarly, the staff notes the same problem with the assertion on Page 56 of the URG that "A larger NPSH margin should require less frequent inspection/audit than a smaller margin." NPSH margin is not the only characteristic of significance when evaluating inspection and maintenance intervals. If licensee performance does not demonstrate effective FME controls, inspection frequency must be increased. In addition, the potential for introduction of debris since the last inspection should also be a consideration in determining inspection scope and interval.

The principal strength of Section 3.2.2 is that it reviews important considerations of which licensees should be aware in assessing debris sources other than pipe insulation. It also provides some quantitative suggestions for the amounts of debris that may exist in drywells and suppression chambers. The discussions emphasize that FME, housekeeping, and inspection programs must be capable of keeping debris quantities within the limits assumed in the evaluation of the ECCS strainer loading from such debris.

However, the staff believes that Section 3.2.2 has some technical shortcomings. First, some of the guidance is too vague to be used in a consistent generic manner. Second, important assumptions regarding debris quantities are not supported by technical analysis or plant observation. While the staff does not believe these judgments are inappropriate, there is still concern regarding the lack of adequate justification for the recommended assumptions. On that basis, the staff offers the following specific comments:

- Dirt/dust: The discussion in Section 3.2.2.1 states that only a small fraction of dirt/dust not directly exposed to the LOCA jet or impacted by break leakage flow would be expected to be transported by the break flow or because of sprays if containment sprays are used. The statement that only a small fraction might be transported to the suppression pool is not supported by test data or actual observation. Licensees should also consider the fact that steam/air velocities may be high throughout the drywell following a large-break LOCA. Also, steam condensation and run-off on structures could contribute to entraining dirt/dust in the runoff. Once reaching the floor of the drywell, the turbulence in the water pool on the floor may be sufficient for the dirt to remain suspended and be transported to the suppression pool. (This is especially likely in the case of a recirculation line break where water flowing out the break can provide a substantial amount of turbulence in the water pool on the drywell floor.) The staff believes that conditions in the post-LOCA environment would be conducive to transport dirt/dust to the suppression pool.

  The URG suggests a value of 150 lbm of dirt/dust as the value licensees could use to "conservatively" address this type debris originating in both the drywell and suppression chamber areas above the suppression pool where dirt and dust could be entrained by pool swell. The URG also states that this quantity includes concrete that would be eroded by the LOCA jet. This quantity of 150 lbm is termed a judgment and is not supported by any analysis or investigations. While the staff does not believe that use of the 150-lbm assumption is inappropriate, the staff does believe that some licensees may wish to conduct a more thorough evaluation for applicability to their plant. The staff believes this could be done very easily through sampling. It would be relatively straightforward for an individual licensee to take samples of dirt and dust from drywell and suppression pool areas, determine the typical weight-per-unit-area on collecting surfaces, and estimate a bounding value for all applicable surfaces. An allowance would then have to be added for concrete dust generated by LOCA forces. The current approach is simply a judgement, and as a result, some licensees may wish to ensure that it is conservative. In addition, licensees may wish to consider the potential impacts on the baseline assumption of containment size and the accumulation of additional dirt/dust over the operating life of the plant. This method could also be used to estimate the amount of conservatism in the 150-lbm assumption for a given plant. ***The staff is not requiring that this type of assessment be performed by licensees.*** Rather, the staff is only noting that some licensees may wish to perform this type of evaluation for their plant. For example, a licensee with a small NPSH margin may wish to determine the amount of conservatism in their baseline assumptions for other drywell debris sources.

- Rust Flake: The URG states that 50 lbm of rust flakes in the strainer head loss evaluation "conservatively" addresses the amount of rust that may be removed from unpainted steel surfaces and transported to the suppression pool. This URG-recommended assumption includes surfaces in the drywell, the vents/downcomers, and the suppression chamber above the suppression pool. However, the URG does not document the basis for the 50-lbm recommendation (other than engineering judgment). Again, as with the dirt/dust assumption discussed above, the staff does not believe that using the 50-lbm assumption is inappropriate. However, the staff believes that an individual utility may wish to evaluate the applicability of this value to their plant as was discussed above for the URG's recommended assumption for dirt/dust. The staff believes that a licensee could develop a sound technical basis for the rust flake assumption by sampling applicable drywell and suppression chamber areas and

conducting walkdowns to establish typical quantities of rust per unit area. (This information could be obtained and used to develop total plant estimates.) The URG also states that the BWROG expects that only a small fraction of the rust would become detached from steel surfaces during a LOCA event. However, the staff points out that this statement is unsupported by data or technical evaluations. As a result, the staff believes that some licensees may wish to more thoroughly evaluate applicability of this assumption to their plants.

- Coatings: The URG provides estimates of the quantities of three types of qualified paints and coating materials that may become debris as a result of LOCA jet impingement forces. The values presented in Table 3 (on page 58 of the URG) are predicated on a study performed by Bechtel for the BWROG (Ref. 51) and apply to qualified coatings delaminated by direct jet impingement from a pipe break. The staff has not identified any concerns relative to the conclusions presented in Ref. 51. However, the staff notes that the issue of coatings and their potential impact on the ECCS is an issue currently under staff review, and is the subject of GL 98-04, "Potential for Degradation of the Emergency Core Cooling System and the Containment Spray System After a Loss-of-Coolant Accident Because of Construction and Protective Coating Deficiencies and Foreign Material in Containment," dated July 14, 1998 (Ref. 68). As a result, the conclusions presented in Ref. 51 are still under staff review.

  By contrast, the guidance for unqualified coatings is incomplete and unsupported. For example, on page 61, the URG states, "After exposure to the LOCA environment, but only after containment pressure is reduced, there is a possibility that indeterminate/unqualified coatings may detach from the surface to which they were applied and become a debris source." The staff is particularly concerned because there is no basis for this statement and, in the staff's opinion, it is entirely inaccurate. In fact, there is no evidence that indeterminate or unqualified coatings would be latent debris at all. For instance, if the coatings have lost adhesion over time because of improper application or lack of qualification for the environment, there is no reason to assume that the turbulent environment of the reactor vessel blowdown could not cause the coating to detach and transport to the suppression pool. On page 62, the URG continues, "Dependent on several plant-specific factors, it may be possible to show that the failure of indeterminate/unqualified coatings would not occur until late enough in the LOCA progression that there is no transport mechanism available to transport the failed coating from the drywell to the wetwell." However, the URG does not identify the "plant-specific factors" or discuss the basis for the statement. The staff is very concerned that this part of the URG greatly downplays the potential significance of unqualified/indeterminate coatings.

  While not providing explicit guidance, the URG as currently written tends to lead licensees away from accounting for this potential debris source by merely discussing why these coatings might not have an impact on the ECCS. In actuality, the potential significance of these coatings depends on the amount of such coatings in the containment, the licensee's NPSH margin, how well these coatings were applied, and the coating performance characteristics in both normal operation and LOCA environments. In light of recent events involving qualified coatings, as discussed in GL 98-04 (Ref. 68), and the lack of substantive technical basis for the BWROG guidance regarding unqualified and indeterminate coatings, the staff does not have enough information to evaluate the adequacy of the BWROG guidance. However, the staff considers it prudent to address unqualified/indeterminate coatings in the sizing of the new strainers installed in response to NRCB 96-03. This would help to avoid potential operability concerns

and hardware modifications (e.g., resizing of the suction strainers) in the future if clogging concerns are raised as part of the staff's review of coatings-related issues. For the same reason, licensees should consider the potential impact of "qualified" coatings that are improperly applied or maintained.

Conclusions Regarding Section 3.2.2: The NRC devoted considerable effort to developing the NUREG/CR-6224 study (Ref. 31) and to conservatively estimate dirt/dust and rust debris. Where provided, the values suggested in the URG are about the same or larger than NUREG/CR-6224 values. As a result, the staff concludes that use of these values is acceptable; however, the staff notes that the NUREG/CR-6224 study was conducted on a Reference Mark I containment. For this reason and the additional reasons cited above, the staff believes that some licensees may wish to evaluate the recommendations of this section for applicability to their plant. ***This is a staff recommendation only, and is not considered a requirement for acceptance of the URG by the staff.*** This concern is especially true for Mark III containments because they have larger concrete areas. In addition, the potential for dirt/dust accumulation may be greater in the larger containments if they have significantly larger areas of horizontal surfaces. The sensitivity of the head loss calculations to these numbers may vary with the assumptions and the resolution option selected by the licensee. If a given licensee is installing a large passive strainer which reflects very conservative assumptions relative to the quantities of fibrous debris and sludge assumed to reach the strainer surface, then that licensee may be able to demonstrate by sensitivity analysis that variations in the quantities of dirt, dust, rust flakes, and so forth may not significantly affect the overall head loss across the strainer. If, however, a licensee attempts to justify their current strainer, reduce the amount of conservatism in the baseline URG methodologies, or use assumptions that are as "realistic" as possible, then the significance of the values determined in accordance with Section 3.2.2 of the URG may escalate significantly.

Consistent with the staff's guidance (discussed above), some licensees may wish to evaluate the applicability of the conclusions of the Bechtel coatings report to their plant. Most importantly, as noted above, the staff concludes that licensees should be cautioned to carefully evaluate the potential impact of unqualified and indeterminate coatings on ECCS suction strainer head loss. If available, licensees are encouraged to use test data to support their evaluation of coatings. It is the understanding of the staff that the BWROG is currently conducting a test program designed to evaluate the potential for coatings to become debris and transport to the suppression pool. However, if in doubt, assuming that the coatings reach the strainer surface would clearly be the conservative measure. This would reduce the licensees' risk relative to the coatings issue, and could lead to additional margin in the strainer design if URG statements minimizing the potential impact of unqualified protective coatings are supported by the results of the staff's coatings review.

3.2.3 Drywell Debris Transport

Section 3.2.3 of the URG, entitled "Drywell Debris Transport," documents the BWROG's guidance regarding various options for estimating the fraction of the damaged insulation (generated in the drywell) that will be transported to the suppression pool as a result of the reactor vessel blowdown and various mechanisms that can wash debris down to the suppression pool. The guidance provided in this section is based on the following supporting analyses found in the URG Technical Support Documentation (Ref. 2):

(1) "Testing of Debris Transport Through Downcomers/Vents into the Wetwell," Revision 1, URG Technical Support Documentation, Vol. II, Tab 2, Continuum Dynamics, Inc., Princeton, NJ.
(2) "BWR Drywell Floor Flow Modeling Following Pipe Break Loss-of-Coolant Accident," URG Technical Support Documentation, Vol. III, Tab 1, General Electric Nuclear Energy, San Jose, CA.
(3) "Summary of Debris Washdown Experience," URG Technical Support Documentation, Vol. III, Tab 17, BWROG.

The staff reviewed the completeness and accuracy of the guidance in URG Section 3.2.3, as well as the associated supporting analyses. In addition, the staff evaluated this guidance against the guidance provided in RG 1.82, Revision 2 (i.e., transport fraction = 1), the results of the BWROG-sponsored research, and the results from the NRC-sponsored research conducted by Science and Engineering Associates, Inc. (SEA).

This review revealed that the BWROG developed the following methodology to determine the amount of debris transported from the drywell to the wetwell:

For each insulation type tested at the AJIT facility:

- The BWROG estimated the fractions of insulation contained in the ZOI that would be destroyed (destruction factor). The debris was then divided into three distinct size categories on the basis of the test data ("fines," "large pieces," and "blankets"). These fractions were calculated as integral values applied over the entire ZOI volume for several insulation types making use of experimental data obtained from the AJIT. In addition, the URG estimates assume that, for NUKON, all insulation contained within 3 L/D of the break is destroyed into fines. In its response (Ref. 64) to the drat SER (Ref. 63) on the URG, the BWROG provided further clarification on their methodology by stating that "100% destruction within 3 L/D was assumed for all debris types."

For "fines":

- The BWROG estimated the fraction of the mass of "fines" that would be transported as a result of blowdown following a steamline break and a recirculation (water) line break. Different estimates were developed for Mark I, II, and III containments, on the basis of small-scale tests of downcomer geometries which were sponsored by BWROG and conducted by Continuum Dynamics, Incorporated (CDI).

- The BWROG estimated the fraction of the mass of fines that would be transported as a result of washdown following a blowdown. For the recirculation line break, the ECCS runout flow was used as the basis, while spray flow was used as the basis for the steamline break. These estimates were founded on 1) small-scale experimental data from BWROG tests, 2) washdown test data obtained from previous sources, and 3) one-dimensional (1-D) and three-dimensional (3-D) modeling of water flow on the drywell floors. Different estimates were developed for Mark I, II, and III containments.

- The sum of these fractions (transport factor) provides the total fraction of fines transported to the suppression pool. Multiplication of this transport factor by the estimated fraction of fines in

the damaged insulation provides a total mass of fines from the damaged insulation that would be transported to the suppression pool by blowdown and washdown.

For large pieces:

- No direct transport was assumed for the pieces located above the lowest grating. The URG considers that they can only be transported after erosion.

- The BWROG estimated a fraction for "large pieces" located below the lowest grating that would be transported during blowdown, and for the amount that would be eroded and transported during the washdown phase that follows the reactor vessel blowdown.

For blankets:

- According to the BWROG, no transport is possible.

The individual destruction and transport fractions were used to develop combined destruction/transport factors for each insulation type as a function of the containment type and location of the debris. Tables 5 and 6 (on pages 83 and 84 of the URG), list these fractions for several insulations.

To estimate the fraction of insulation debris (contained in the ZOI) reaching the suppression pool, individual licensees may choose to use a drywell transport factor of 1.0, the value listed in the Regulatory Guide 1.82, Revision 2 (Ref. 5), or the values listed in Tables 5 and 6 of the URG. For other drywell debris, the URG recommends a drywell transport factor of 1.0. The URG states that use of other transport values by licensees should be supported by an evaluation justifying their bases.

Staff Evaluation of Section 3.2.3: In evaluating this section, the staff conducted a confirmatory analysis (see Appendix H to this report), which yielded the following results:

Drywell To Suppression Pool Transport Factors:

- The experimental data for drywell transport is dependent on the results of small-scale tests which have not been properly scaled. The staff forwarded its scaling concerns about the BWROG testing at the time of their inception by letter (Ref.. 20). None of the staff's comments appear to have been resolved to date. In addition, the staff's analysis (See Appendix H to this report) suggests that the flow rates and duration simulated in BWROG testing are not prototypical of conditions that exist in BWR drywells following a LOCA. For example, the flow velocities simulated in these tests are about 50% of the flow velocities expected following a postulated 61-cm (24-inch) diameter steamline break. As a result, these tests may provide erroneous estimates of drywell transport. It was not clear to the staff in evaluating the BWROG test program whether the test results would be reasonable, conservative, or non-conservative if scaled to a full-size plant. There is inadequate substantiation for the BWROG's claims that use of these test results would conservatively bound the drywell transport fraction.

- From the staff's research, the two primary keys to debris transport are debris size distribution and location. Testing conducted by the NRC in support of its confirmatory research in the area of debris transport has shown that floor gratings typically used in BWR plants are very effective at limiting transport of larger debris sizes. However, these gratings are not very effective at limiting transport of fine debris. The results of the staff's study and testing will be documented in NUREG/CR-6369, "Drywell Debris Transport Study," which is scheduled to be published in September 1998. The study's findings lead to the conclusion that calculation of fine debris is critical in evaluating the amount of debris that could ultimately transport to the suppression pool during a LOCA. In addition, it is also critical to calculate the amount of debris generated below the lowest continuous grating in the drywell.

- Another significant finding is that the staff-sponsored tests of Mark II downcomer geometry did not identify any basis to conclude that the transport fraction for a Mark II containment would be different from that of a Mark I or Mark III containment. Therefore, the staff finds that the transport fractions for Mark II containments listed on pages 75 and 80 of the URG are unacceptable. The URG also gives fractions (on the same pages) for fine fibrous debris transport and RMI debris transport in Mark I and Mark III containments assuming that 100% of the fine debris will transport to the suppression pool. These fractions are consistent with the staff's transport study and RG 1.82, Revision 2 (Ref. 5), and, therefore, are considered acceptable. Moreover, the staff believes that these same fractions should also be used for Mark II containments.

- Page 76 of the URG provides guidance regarding the transport fractions to be used for large fibrous debris (not whole or partial blankets which are considered unlikely to transport) generated below the lowest grating. Specifically, the values given are 70% for Mark I and Mark III containments and 30% for Mark II containments. As noted above, the staff's confirmatory testing in support of its drywell transport study did not identify any basis for different transport fractions for Mark II containments. Given the results of the drywell transport study, the staff concludes that the transport fractions used should be the same for all three containment types. Similarly, pages 83 and 84 of the URG provide combined debris generation and transport factors for various insulation type. Each factor is further divided into containment type and location of the debris source (above and below the lowest grating in the drywell). On the basis of the staff-sponsored drywell debris transport study, the staff concludes that (1) the factors for Mark II containments are unacceptable, (2) the factors Mark I and Mark III containments are acceptable, and (3) the Mark I and Mark III factors should also be applied to Mark II containments.

- In the draft SER (Ref. 63) on the URG, the staff evaluation of the BWROG's guidance for assuming erosion of large fibrous debris concludes that the URG guidance is adequate given that the unthrottled ECCS flow does not continue for more than 3 hours. However, the staff stated that if the flow does continue for more than three hours, licensees should determine an appropriate fraction to assume. NRC-sponsored tests demonstrated that erosion of NUKON® is linear, which would facilitate ease in scaling of NUKON erosion. The staff also noted that similar testing could be conducted for other insulation types, if necessary, to determine an appropriate fraction to assume for erosion. In its response (Ref. 64) to the draft SER, the BWROG responded to this issue by stating "The staff concern discusses the erosion rate but does not consider the conservative position taken in the URG on the amount of insulation material that would be exposed to erosion.....the URG assumes that 25% of fibrous "large

debris" (i.e., not fines) is exposed to the eroding effects of the spill from the break. The BWROG believes that any concerns regarding the effect of erosion over periods greater than 3 hours are more than offset by the conservative assumption on the amount of insulation and that adopting the staff position could result in additional operator burdens and would require a change to emergency operating procedures which would be inconsistent with their symptom-based design." On the basis of the BWROG's comments and further review of the level of conservatism in the URG analysis methodologies (see Section 5.0 of this SER), the staff concludes that the URG guidance on erosion of large fibrous debris from break flow is acceptable.

Destruction Factors:

- The BWROG calculated the destruction factors provided in the URG from the AJIT results. The test results and associated data analysis are documented in Reference 52. The destruction factors are derived on the basis of the calculation of η_B, which is defined as the fraction of debris generated in a form that would have a low transport efficiency (e.g., large pieces or blankets). The BWROG conducted tests at several different distances from the jet nozzle (x/D) to determine the pressure at which debris would be generated, the amount of debris generated, and the rough size distribution of the debris. The BWROG then calculated η_B for each x/D test result and integrated the values to give an average η_B ($\eta_{B(average)}$)over the entire ZOI where damage would be expected to occur. For each insulation type and mode of encapsulation, the URG thus provided a set of destruction factors in the URG that can be used to estimate the fraction of the insulation contained in the ZOI that would be destroyed into "fines." In principle, these values were derived on the basis of the following methodology:

  (1) Full-scale insulation blankets were mounted on a target pipe located normal to the JCL. In almost all cases, the blankets were mounted such that the latches on the steel jacketing (if jacketing was used) were arranged to face the nozzle, while the seams in the blanket were arranged to face away from the nozzle. This resulted in a conservative situation because the protective steel jacket was quickly blown off, exposing the canvas-covered blanket to the jet. Meanwhile, because the blanket seam faced away from the nozzle, the blanket was maintained in position for a longer duration.

  (2) After exposure to approximately 5 seconds of blowdown (although the valve was closed at the 5 second mark, the blowdown continued for at least 3-4 more seconds), the amount of debris generated and the rough estimate of the debris size distribution was measured.

  (3) The size and amount measurements were carried out for different L/D values. The fraction of debris not destroyed into fines (η_B) was then plotted as a function of L/D and integrated over the entire ZOI to estimate the $\eta_{B(average)}$ for that insulation and mode of encapsulation.

  (4) To account for unforeseen phenomena, the η_B numbers were further reduced by assuming that all of the insulation contained in a spherical region within a radius of 3 pipe diameters from the break would be destroyed into fines.

- The staff reviewed this derivation process and its overall results. In addition, the staff conducted both experimental and analytical studies. On the basis of these studies, the staff concludes that

  — The blanket arrangement used in the BWROG testing is highly conservative. In the NRC-sponsored testing, the amount of debris generated was substantially less when the latches were arranged to face away from the nozzle or when the blanket seams were located facing the nozzle. In the former case, the steel jacket remained for longer duration and protected the blanket. In the latter case, the blanket was stripped off the target in such a short time that very little damage was observed.

  — The targets and structures located in the jet pathway would provide considerable protection to the blankets. In the NRC-sponsored experiments, artificial means (high-strength steel bands) had to be used to hold the blankets in place to maximize debris generation. Otherwise, no more than 25-30% of the insulation blankets were destroyed by the jets.

- The BWROG approach has the following conservatisms:

  — Not all the targets in a BWR drywell are normal to the JCL. In fact, the staff's survey suggests that a majority of the piping (>65%) would be located parallel to the jet flow. In such a case, only a small portion of the blanket would be subjected to high dynamic pressures (unlike the BWROG experiments where most of the blanket was subjected to jet flow).

  — Not all of the targets have steel jacket latches facing toward the nozzle and blanket seams facing away from the nozzle. The vendor survey indicates that no order is followed for installing the steel jackets or insulation blankets (although accessibility considerations often play a role).

  — The blowdown does not continue at high pressures as tested in the BWROG studies.

  — Finally, the structures offer considerable protection. The staff performed a CFD calculation to quantify the impact of structural impediments. This calculation used more realistic structural elements to demonstrate how the jets are diffused by structures.

- On that basis, the staff concludes that the approach followed by the BWROG would yield conservative estimates for most insulations. This can be demonstrated by an analysis of steel-jacketed NUKON insulation, for which Method 2 yields a spherical ZOI approximately 11 pipe diameters in radius. In the NUREG/CR-6224 reference plant, such a ZOI would include approximately 25.5 m^3 (900 ft^3) of insulation. Using an η_B value of 0.78, this translates into fines of approximately 5.7 m^3 (200 ft^3). This value is slightly lower than the total volume of NUKON® insulation contained in a spherical ZOI with a radius of 7D in the reference plant used in the staff study (NUREG/CR-6224). The CFD calculations conducted by the staff clearly demonstrate that, given the structural congestion, high-velocity flows (sonic flows) do not continue beyond a spherical region with a radius of 5D. Thus, the staff concludes that BWROG's suggested numbers are probably conservative. However, the staff identified a weakness in the URG data because the BWROG obtained η_B values for several insulations on the basis of a very limited set of experimental data. (Examples are Temp-Mat, K-wool and some of the RMI.) In these

cases, the BWROG used less than 5 data points to derive the η_B values. The staff believes that the URG methods for determining ZOI (see Section 3.2.1.2 of this SER) and debris generation (noted above) are sufficiently conservative to outweigh the weakness identified regarding limited data points for certain insulation types. Section 5.0 of this SER provides a more detailed discussion on the amount of conservatism in the URG analysis methodologies.

The staff's review identified the following strengths of this URG section:

- The URG follows a logical path for conservatively estimating the amount of insulation debris and the associated drywell transport factor. This path is somewhat similar to the one used in NUREG/CR-6224 (Ref. 31) and in the staff's Drywell Debris Transport Study.

- This section reviews important considerations of which licensees should be aware in estimating the drywell transport factor.

- The transport fractions for fibrous debris above the lowest grating (provided on pages 75 and 80 of the URG) for Mark I and Mark III containments are considered to be conservative and appropriate for use.

The major weakness of this URG section is that the test data from the BWROG-sponsored drywell transport tests were not obtained over the range of experimental variables that would support scaling the data for full-size drywells. Similarly, the chosen experimental set-up does not scale appropriately to the BWR drywells.

Conclusions Regarding Section 3.2.3: In summary, the staff draws the following conclusions regarding URG Section 3.2.3:

- The staff finds that the transport fractions for Mark II containments (listed on pages 75 and 80 of the URG) are unacceptable. The URG also gives fractions (on the same pages) for fine fibrous debris transport and RMI debris transport in Mark I and Mark III containments, assuming that 100% of the fine debris will transport to the suppression pool. The staff concludes that these values are acceptable and should also be used for Mark II containments. Similarly, for the combined debris generation and transport factors for various insulation types(pages 83 and 84 of the URG), the staff concludes that (1) the factors for Mark II containments are unacceptable, (2) the factors for Mark I and Mark III containments are acceptable, and (3) the Mark I and Mark III factors should also be applied to Mark II containments.

- Page 76 of the URG presents guidance regarding transport fractions to be used for large fibrous debris (not whole or partial blankets) generated below the lowest grating. Specifically, the values given are 70% for Mark I and Mark III containments, and 30% for Mark II containments. The staff concludes that (1) Mark II containments should use the same transport fraction as Mark I and Mark III containments, (2) the BWROG provided insufficient technical justification for assuming a transport fraction less than 100% for large debris generated below the lowest drywell grating. However, the staff notes that the combined debris generation/transport factors (pages 83 and 84 of the URG) conservatively bound these transport fractions. In its response (Ref. 64) to the draft SER (Ref. 63) on the URG, the BWROG noted "the BWROG approach is to calculate a transport factor as a percentage of the <u>total</u> debris while the staff approach is to

use a transport factor for transportable debris. The BWROG notes that in the NRC Drywell Debris Transport Study, the NRC interpretation of the AJIT test report is that 40% of the NUKON® insulation within the ZOI is in the form of "canvassed debris" which is not transportable. Hence, the NRC position is that the maximum amount of debris which can be transported to the suppression pool from the lower portion of the drywell is 60% of the initial insulation within the ZOI, a lower number than the corresponding 78%" that would be predicted using the URG combined debris generation/transport factors. The staff concurs with the BWROG comment.

- The staff believes that the URG provides adequate guidance for assuming erosion of large fibrous debris.

- The approach followed by the BWROG for determining destruction factors would yield conservative estimates for the insulations included in the URG and is, therefore, acceptable. The staff notes, however, that banding of insulation to reduce debris generation has not been accepted by the staff as a resolution option.

3.2.4 **Suppression Pool Debris**

The focus of Section 3.2.4 of the URG, entitled "Suppression Pool Debris," is on sources of debris which are present in the suppression pool before the occurrence of a LOCA. Both transient debris and sludge are potentially present in the suppression pool at any given time. This section of the URG also reviews the LOCA-generated debris and transient debris, both of which were discussed in earlier sections of the URG. The guidance was developed, in part, on the basis of an extensive BWROG survey of suppression pools of selected operating BWRs in the United States (Refs. 54 and 55).

The BWROG survey showed that suppression pools can contain various types of debris unrelated to a LOCA. This debris would be transported to the ECCS suction strainers and could contribute to head loss across the strainer. Section 3.2.4 provides guidance related to identifying various sources of debris and important considerations that should be used to estimate the quantities of such debris.

The URG identified the following sources of suppression pool debris:

- fibrous debris entrained in the pool volume prior to a LOCA.
- non-fibrous debris entrained in the pool volume prior to a LOCA.
- the dirt/dust above the pool area which may be washed down during pool swell.
- other potential debris, such as operational debris and unqualified/indeterminate coatings.

During its evaluation of the strainer clogging issue, the BWROG conducted a survey to estimate the quantities of sludge entrained in the suppression pools. On the basis of this survey, the BWROG recommended a sludge generation rate of 150 lbm per year. This sludge generation rate can be coupled with frequency of pool cleaning to estimate the total quantity of sludge for use in the analysis of ECCS strainer blockage.

The URG does not specify generic estimates for any other types of debris. However, the URG does list the considerations that licensees should address while estimating the quantities of other debris to be used in the analysis of ECCS strainer blockage. The URG cautions licensees to recognize that the operability of the ECCS system may be challenged if the licensee cannot demonstrate that suppression pool debris source terms will be controlled at values less than assumed in the strainer sizing calculations.

Staff Evaluation of Section 3.2.4: A single analysis was performed in support of this review. Its objective was to evaluate the adequacy of the BWROG recommended sludge volumes and their tractability. This analysis is documented in Appendix J. On the basis of that analysis, the staff concludes that the BWROG interpretation of survey information is acceptable and the URG guidance in this section is acceptable.

3.2.5 Suppression Pool Transport and Settling

The BWROG recommended that licensees should not take credit for settling of debris in the pool during the high-energy phase where the pool undergoes chugging and/or condensation oscillations. The BWROG also recommended that all suppression pool debris should be assumed to be resuspended during this phase. Finally, the URG gives individual licensees an option to select no settling in the pool, even during later low-energy phase, or to estimate fraction settling making use of data and results from Appendix B to NUREG/CR-6224.

Staff Evaluation of Section 3.2.5: The principal strength of URG Section 3.2.5 is that it reviews important considerations of which licensees should be aware in estimating the quantity of debris settling in the pool. The staff did not identify any concerns related to this section, and therefore, it is acceptable. However, the staff notes that Appendix B to NUREG/CR-6224 provides the required data only for selected insulation and particulate types. Licensees using methods from Appendix B to NUREG/CR-6224 for other types of insulation debris should exercise caution in extrapolating the experimental data and models.

3.2.6 Verification of Adequate ECCS Pump NPSH

Section 3.2.6 presents the BWROG's guidance related to calculating strainer head losses and pump NPSH. This guidance is developed on the basis of the following report presented in the URG Technical Support Documentation (Ref. 2):

- CDI Report CDI-95-09, Revision 4, "Testing of Alternate Strainers with Insulation Fiber and Other Debris," Continuum Dynamics, Inc. (CDI), URG Technical Support Documentation, Volume I, Tab 2.

This guidance specifically refers to Appendices A and B of that document for methodology and calculational procedures. (Appendix A applies to passive strainer head loss predictions with fibrous debris, while Appendix B applies to RMI debris.) The staff used the calculational procedures described in Appendices A and B to assess the ability to predict the head losses associated with a number of the tests used to develop the procedures. The following discussion summarizes the staff's findings.

URG Section 3.2.6.2.3 summarizes important guidance for applying Appendices A and B to CDI Report CDI-95-09. That technical support document describes the strainer head loss tests performed in developing the calculational procedures presented in Appendices A and B, including the test facility, testing procedures, data reduction, and test results. The procedures in Appendices A and B are recommended for use by individual utilities to estimate head loss across the strainer as a function of the flow velocity and the quantity and type of debris reaching the strainer. A dimension less head loss equation was provided for this estimate.

Staff Evaluation of Section 3.2.6: The strainer head loss was predicted for a number of tests using the procedures outlined in Appendices A and B and compared with the corresponding experimental head losses. The staff notes that the test results presented in CDI Report CDI-95-09 are the only data provided by the BWROG, and are for the stacked disk and star strainer types.

The staff had two objectives in conducting its analysis. First, the staff sought to validate the calculational procedures by determining their ability to predict the test results from which the procedures were developed. Second, the staff sought to evaluate the applicability of the procedures to actual plant situations. This analysis is documented in Appendices I (fibrous debris) and K (for RMI debris) to this safety evaluation. In general, the results of the staff's analysis led to the conclusion that the approach outlined in Appendices A and B to CDI Report CDI-95-09 was unreliable and incomplete.

The URG contains valuable and useful data for predicting strainer head losses. However, the staff's review revealed several concerns regarding the quality and applicability of these data.

- The BWROG developed the URG model from test data where a true steady-state condition was not generally achieved. This implies that the debris loadings used in developing the model were somewhat different than the actual loadings on the strainers.

- The BWROG developed the URG model for limited ranges of data (i.e., fiber, RMI and particulate debris loadings, velocities, and strainer design), and using the model beyond these limitations is especially risky because the models are non-mechanistic in nature, as illustrated by the following examples:

  — The BWROG developed the model for lower debris loadings where the amount of fibrous debris was only large enough to fill the troughs in the strainer. Extending the correlation to higher loadings is inappropriate without additional substantive experimental or analytical work.

  — The BWROG primarily developed the model on the basis of NUKON® data. Its extension to other fibers is inappropriate without additional substantive experimental or analytical work.

  — The BWROG primarily developed its RMI saturation thickness guidance using star strainer data, and an assumption that the debris bed would resemble a sphere. The URG does not provide a basis for extension of this relationship to other strainer geometries.

  — The BWROG RMI head loss correlations for the star and stacked disk strainers are based on data obtained for low debris loadings (insufficient volume of debris to fill the strainer

troughs). The URG does not provide a basis for extrapolating the correlations to higher debris loadings. The staff believes that such an extrapolation will lead to non conservative head loss estimates.

— The gravity head loss data for RMI was obtained for a chosen RMI debris size distribution. Each utility must determine the applicability of the size distribution to their plant. For example, it is not likely that a plant having aluminum RMI would have the same RMI debris size distribution as a plant with stainless steel RMI.

- The staff has shown that, in many cases, the URG model under predicts the experimental data used to develop the model; therefore, a licensee would need to review each head loss prediction in detail relative to the applicable data, to ensure a valid prediction. In addition, in many situations, such as the 60-point star strainer, a licensee would need to employ a significant safety factor in the prediction.

- The BWROG used limited data (gravity head loss tests) to develop the "bump-up" factors used to account for miscellaneous debris. In many situations, the bump-up factors have been shown to severely over predict the head loss. While this over prediction is conservative, it can lead to severe design impacts.

- Some of the head loss test runs (e.g., test run number J6) were conducted with thin fiber beds and large amounts of particulate debris. In these tests, the BWROG assumed that all particulate debris was captured by the debris bed, but this assumption is incorrect. The amount of particulate debris captured in the debris bed is unknown (i.e., underestimated). As a result, the use of these data to develop a correlation may under predict the impact of particulate debris and lead to erroneous head loss predictions.

- Two types of RMI debris were used in the URG strainer debris bed head loss tests (i.e., two different size distributions of the 2.5 mil stainless steel foils), and each size distribution was used over a different period of time. Thus, the tests for a specific strainer design are generally valid only for one type and size distribution of RMI debris. For example, the stacked disk tests (stacked-disk section of the self-cleaning strainer) only used the RMI debris obtained from Diamond Power. Therefore, the URG model only applies to the stacked-disk strainer for this one type and size distribution of RMI debris.

- The URG did not specify model validation, parameter sensitivity, or uncertainty analysis. This omission leaves open the question of whether a particular combination of input parameters could cause the URG model to severely under predict head loss.

On the Basis of this analysis, the staff has the following specific comments regarding this section of the URG:

- The staff is concerned that applying the URG strainer head loss model by blindly plugging numbers into a cookbook step-by-step procedure as outlined in the report may lead to erroneous head loss predictions. Rather, each prediction must be carefully anchored into head loss data to ensure that it is both reasonable and conservative. The staff communicated this concern to the BWROG in Ref. 11. However, the BWROG's response (Ref. 13) did not address the overall

head loss prediction, instead relying on the accuracy of the bump-up factors. The staff, therefore, does not believe that the BWROG has resolved this concern. Moreover, the staff believes that resolution of this issue is vital to judging whether the BWROG correlation (if used by any licensee) is conservative, best-estimate, or under predicts. Resolution of this concern will also need to address the confidence level of the data (i.e., repeatability and uncertainties).

- The head loss predictions should use the same NUKON® debris properties that were employed in developing the URG model (i.e., densities and diameters) because the models are not sufficiently mechanistic to account for the effects of varying these properties. Also, the URG study used the fiber density of 38.4 kilograms per cubic meter (kg/m^3) (2.4 pounds per cubic foot (lbm/ft^3)) which is the density generally assumed for the intact fiber insulation (sometimes referred to as the as-fabricated density). However, there are data showing that the density of actual debris is considerably reduced by the destruction process. For example, fibrous debris used in tests conducted by Pennsylvania Power & Light Company (PP&L) at ARL had an actual density of 20.8 kg/m^3 (1.3 lbm/ft^3). By using this density rather than the as-fabricated density, the user would obtain a different fiber spacing distance, which would result in a different head loss than if the user actually employed the as-fabricated density that is inherent in the non-mechanistic URG model. Since the basis for the URG correlation is not mechanistic and the procedure does not use more empirical parameters (rather, licensees are required to estimate more complex parameters), it is likely that use of the correlation by licensees will be inconsistent

- The staff is concerned that applying the URG head loss prediction models to plant conditions that differ markedly from those conditions tested could lead to erroneous head loss predictions. Use of selected dimension less numbers creates the impression that the equation can be generalized. However, the BWROG has not presented any analytical evidence to that effect. As a result, licensees should carefully evaluate any extrapolations from the conditions tested. At the inception of the alternate strainer test program, the staff cautioned the BWROG that its approach for developing of a head loss correlation did not have a sound basis for extrapolating the correlation beyond the conditions for which it was developed. The BWROG responded that its testing was designed to be "functional" rather than a means for developing a correlation. However, the URG attempts to use the data compiled and correlation developed in a more generalized form. For example, the data were obtained for conditions that simulate lower fiber loading on the strainers. The correlation should then be applicable, at best, to those conditions. However, the URG and its appendices do not state any such limitations. The staff therefore concludes that generalized use of the correlation beyond the original range of testing is unacceptable.

- The experimental data, as well as the correlation presented for fibrous beds, were obtained for low-debris loading on the strainer surface. The staff has been unable to identify any rationale supporting use of the URG correlation for thick combination fibrous/particulate debris beds, and it is the staff's opinion that the equation and procedures are not applicable for such beds. As a result, the staff recommends that licensees use vendor-specific test data demonstrating the strainer head loss for various debris loadings up to and including the licensee's limiting debris load.

- The experimental data are neither complete nor supported by sufficient quantitative analytical reasoning to substantiate the URG statement that the thin-bed effect is not a concern for

alternative strainers. The staff's analysis of the BWROG's data suggests that for the alternate strainer designs tested, small fiber loads coupled with large quantities of sludge will not result in very high pressure losses. In that context, it is reasonable to state that medium breaks will not result in large head losses that are not bounded by large breaks, but a statement that no 'thin-bed effect' was observed is incorrect.

- In calculating NPSH, licensees should ensure that their calculations are consistent with their licensing bases. For instance, no operator action is typically credited for the first 10 minutes during a postulated LOCA. Therefore, NPSH should be evaluated at runout flow until the plant's licensing basis allows otherwise.

- Reference 31 in the URG is considered an unacceptable methodology for determining the minimum NPSH for RMI debris beds. The staff finds that this methodology incorrectly assumes that head loss across the strainer will be governed by laminar flow. While laminar flow is expected to be the case for fibrous debris beds, it would not be the case for RMI, where head loss will be dominated by turbulent flow. In the latter case, temperature correction is not necessary and, where used, will lead to non-conservative head loss estimates.

Conclusions Regarding Section 3.2.6: The staff concludes that the URG head loss correlation is unreliable and the guidance is inadequate to prevent inconsistent application of the correlation. On that basis that the staff recommends that licensees employ vendor test data to demonstrate the head loss used to calculate the NPSH margin. The test data should include debris combinations up to and including the worst-case debris loadings calculated for the plant. If a scaled strainer model is used for conducting the head loss tests, the licensee should ensure that they have an adequate technical basis for applying the vendor data to the full-size strainer.

3.3 BACKFLUSH

Section 3.3 of the URG provides the BWROG's guidance regarding backflushing of strainers. In general, the URG guidance can be summarized as follows:

- The BWROG recommends against use of strainer backflush systems as a primary means of resolving the ECCS strainer clogging issue, for the following reasons:

  — The time frame during which backflushing would be required is significantly less than 30 minutes. This places a hardship on the operators and raises human factors concerns.

  — For many plants, the BWROG anticipates that backflushing would need to be repeated within 30 to 60 minutes. This may not be feasible, depending on the type of design used for the backflush.

- The BWROG also notes that the staff believes that backflushing, by itself, would probably not be sufficient to resolve the issue. This is because the staff concurs with the issues cited by the BWROG above.

- The BWROG believes that backflushing may be a viable defense-in-depth measure for plants with the necessary capability.

Section 3.3 of the URG also gives a detailed list of design considerations for any licensee desiring to implement a backflush system.

Staff Evaluation of Section 3.3: The staff reviewed the guidance provided in URG Section 3.3 and concludes that it completely discusses the types of considerations a licensee must address in implementing a backflush system. In addition, the staff agrees with the BWROG that backflushing is better used as a defense-in-depth measure (rather than the primary means of mitigating a LOCA). Therefore, the staff finds that the guidance presented in this section is acceptable.

3.4 SELF-CLEANING STRAINERS

This section of the URG describes the design considerations that licensees must address in implementing a self-cleaning strainer design to resolve the strainer issue. In that context, this section correctly identifies some of the technical difficulties associated with developing an adequate self-cleaning strainer design to resolve the strainer issue:

- optimizing the clean head loss and torque
- startup of the plow which sweeps the strainer surface after debris has accumulated on the strainer surface during low-flow conditions
- the effect of debris which gets chopped up by the plow on downstream ECCS components
- surveillance/maintenance requirements

Because of these issues, the BWROG recommends the use of this resolution option only if a passive strainer solution is not viable.

Staff Evaluation of Section 3.4: The staff did not identify any deficiencies in this section. Because a self-cleaning strainer design relies on mechanical moving parts, the staff agrees with the BWROG that such a design is less desirable than a passive strainer for resolving the ECCS suction strainer issue.

4.0 ADDITIONAL FEATURES THAT PROVIDE DEFENSE-IN-DEPTH

This section of the URG discusses the other plant features and operator training used to provide defense-in-depth. A key statement in this section relative to availability of alternative water sources reads as follows:

> "System alignment to make use of alternate water sources may require manipulation of valves or other equipment that is infrequently operated. The valves and other equipment used to provide alternate water sources for injection in support of the EOPs should be considered for inclusion in the scope of the Maintenance Rule. It is expected that most if not all of the valves and other equipment will already be encompassed by the plant maintenance program. However, licensees should review the alternate water sources available as described in the plant EOPs and ensure that all valves and other infrequently operated equipment necessary to accomplish injection from these alternate water sources are appropriately addressed by the plant maintenance program."

Staff Evaluation of Section 4.0: The staff did not identify any deficiencies in this section. The staff concurs with the statement cited above relative to including alternate water source components in the scope of the maintenance program, and strongly encourages licensees to do so. This is an excellent way to ensure defense-in-depth by ensuring that alternative water sources are likely to be available should they be called upon during an accident.

5.0 CONSERVATISM

This section of the URG presents the BWROG's position on the degree of conservatism in the analytical methods described in Section 3.0. The staff has reviewed the BWROG's viewpoints on the conservatism contained in the URG methodologies and has reached the general conclusion that there are two types of conservatisms in the URG: voluntary and built-in. The first type is strictly voluntary on the part of the licensee. For example, a licensee may choose to not credit settling of debris in the suppression pool. This clearly would be the conservative approach to addressing settling. However, the licensee may also choose to allow credit for settling in its analysis. Credit for settling is not in itself "non-conservative;" however, such credit eliminates any conservatism added in using the "no credit for settling" option, and would be better characterized as a realistic or "best estimate" calculation. The staff believes that voluntary conservatism is a good practice and provides additional margin; however, voluntary conservatism is difficult to quantify since each licensee may do something different. For the purposes of discussing the amount of conservatism in the URG methodologies, the staff has focused its evaluation in this section on the built-in conservatism that any licensee conforming with the URG will have automatically included in its analysis as a matter of following the minimum required URG guidelines.

Throughout the staff's evaluation of the URG, several areas have been identified in which the staff believes that there is uncertainty as to whether a certain portion of the methodology is conservative. Examples of this are use of JCL to define P_{dest} for each insulation type; assumptions used for dirt/dust, rust, and coating debris; and erosion of fibrous debris by break-water flow. The staff believes that the built-in conservatism of the URG is adequate to overcome the uncertainties in these areas and gain a conservative result; however, if a licensee attempts to further reduce the conservatism in the analysis by using analytical methods not approved herein (e.g., use of a CFD code to determine the size and shape of the ZOI), the staff believes that the licensee should also address the uncertainties cited in this SER and demonstrate that the analysis retains sufficient conservatism to ensure that the results bound the worst-case scenario for debris blockage of the ECCS suction strainers.

5.1 Selection of Break Locations

In Section 3.2.1.1 of this SER, the staff concluded that use of SRP Section 3.6.2 and BTP MEB 3-1 was unacceptable for demonstrating compliance with 10 CFR 50.46. In addition, the staff stated that the guidance of RG 1.82 and 10 CFR 50.46 are adequate for determining pipe break locations to be analyzed. The guidance of the regulatory guide and the rule lead the analyst to evaluate the bounding break with respect to debris generation and transport to the ECCS suction strainers. Although this guidance does not in itself produce "conservatism" or "margin," selection of the bounding break for sizing of the strainers does enhance safety since a great majority of the breaks in a plant would result in the generation of significantly less debris and/or a lower head loss across the strainer than the bounding break.

5.2 Size of the ZOI

The majority of the built-in conservatism in the BWROG's analytical methodologies lies in this part of the analysis. In Section 3.2.1.2, the staff rejected the use of Method 4, which uses a CFD code

to define the ZOI, because the URG provided insufficient guidance on which codes to use, benchmarking the code, and so forth.

Of the remaining methods, Method 3 has the least built-in conservatism of the three methods approved for calculating ZOIs. The staff considers Method 3 to be conservative for two reasons. The primary reason is because the method does not account for the interaction of the break jet with surrounding pipes and structures (see the staff's analysis in Appendix F). This interaction would likely cause the jet to lose energy and, therefore, the actual ZOI during a LOCA would probably be smaller than the calculated. Second, although the use of a spherical ZOI appears to be a reasonable approximation of a ZOI in a congested portion of the containment because of the jet interaction with structures and piping, it appears to be a somewhat conservative assumption. The analysis method in the URG (i.e., Methods 2 and 3) assumes that debris is generated equally throughout the ZOI. No credit is taken for shadowing of debris sources by piping and structures. As a result, the assumption of a spherical ZOI in itself appears to add some conservatism to the analysis. Methods 1 and 2 represent additional levels of voluntary conservatism.

5.3 Debris Generation

This part of the analysis adds more conservatism in two ways. First, the debris generation tests were conducted in a manner to maximize the amount of debris generated — in particular, the amount of fine or transportable debris generated (see Section 5.4 on drywell debris transport to the suppression pool). This was done by orienting the air jet at a 90° angle to the target pipe and by orienting the seam in the insulation away from the jet to maximize exposure to the jet (i.e., residence time for the blanket in the jet flow), and hence, debris generation. Testing by both the BWROG and the NRC demonstrated that this configuration maximized the amount of debris generated. In actual plants, insulation seams are randomly oriented, so it is highly unlikely that any one break would impact all targets so as to maximize the amount of fine debris generated. In addition, the URG debris generation factors conservatively assume that all fibrous insulation within 3 L/D of the break is generated as fine debris.

5.4 Drywell Debris Transport

In Section 3.2.3, the staff concluded that the transport fraction for fibrous debris in a Mark II containment is unacceptable, and that Mark II containments should use the same transport fractions as Mark I and III containments. This means that all three containment types would assume 100% transport of fine fibrous debris from the drywell to the suppression pool. The staff considers this number a bounding number that does not necessarily add more conservatism to the analysis. The NRC-sponsored study on drywell debris transport (see NUREG/CR-6369) demonstrated that a very high percentage of fine debris will transport to the suppression pool. The study also showed that transport of debris is both plant-specific and break-specific. Because a high percentage of fines will transport to the suppression pool and because of the uncertainty associated with trying to pick maximum transport fraction, the staff believes that a 100% transport fraction is within the uncertainty of the calculation and, in itself, does not add significant conservatism. The staff does believe, however, that the number is bounding.

5.5 Suppression Pool Transport

The URG allows for settling of debris in the suppression pool after the high-energy phase of the accident. In the staff's opinion, assuming settling of debris in the suppression pool is a realistic calculation, and does not add conservatism to the overall analysis. No settling should be assumed during the high-energy phases of the accident (i.e., blowdown, chugging, and condensation oscillations) because NRC-sponsored testing conducted at ARL has demonstrated that the suppression pool would be sufficiently turbulent during these phases of the accident to keep this debris suspended in the pool.

5.6 Head Loss and NPSH Margin

The staff rejected the URG head loss correlation developed by the BWROG. It is recommended that vendor data be used to conservatively bound the head loss across the strainers. The staff notes that certain licensing-basis assumptions can increase the conservative margin of the analysis. For instance, any containment pressure present during an accident over and above that which a licensee has credited in its licensing-basis represents additional conservative margin. Similarly, use of conservative decay heat curves that would maximize suppression pool temperature in performing an NPSH analysis would add margin, as these curves would over-predict the amount of decay heat added to the containment/suppression pool during an accident. Single failure criteria will also add conservative margin. Licensees with individual strainers on each pump suction would typically assume a loss of one ECCS train, maximizing the debris loading on the strainers for the other train and maximizing the head loss across the strainers. Similarly, a plant with a ring head suction (all pumps taking suction off the same strainers) would assume that all pumps are operating. This would maximize flow through the strainers and, as a result, the head loss across the strainers.

6.0 MISCELLANEOUS REVIEW COMMENTS ON BWROG GUIDANCE

The staff has the following general comments regarding the URG.

- On page 1 of the URG, the BWROG states that the "probability of a DEGB in a BWR is extremely low (on the order of 1E-9 to 1E-12)". While the staff agrees qualitatively with the statement (i.e., that it is extremely low), it disagrees with the specific values cited in the URG. Both the NUREG/CR-6224 study, as well as 90% of the individual plant examinations (IPEs), including BWR IPEs, estimated these numbers to be several orders of magnitude higher.

- The terms bounding and conservative are used frequently throughout the URG, but are not clearly defined anywhere in the document. In addition, where these terms are used in the body of the text, the BWROG did not always discuss the basis for stating that the individual method described is "bounding" or "conservative." The staff does not believe that such terms should be used to describe an assumption made strictly on engineering judgment unless BWROG can provide a technical basis for the statement.

7.0 OVERALL CONCLUSIONS AND RECOMMENDATIONS

The principal strength of the URG is that it reviews important considerations of which licensees should be aware in estimating the quantity of debris generated and transported through drywell and wetwell to the strainer, as well as the head loss resulting from the debris bed buildup. The overall framework suggested for ECCS suction strainer evaluation is very similar to that developed during the NUREG/CR-6224 study. Moreover, the BWROG obtained valuable data that were lacking at the time of NUREG/CR-6224 study, including data regarding generation and transport. In addition, some of the analyses conducted by BWROG are technically sound and well-founded on good engineering judgment.

Nonetheless, the staff identified several identified instances in which the BWROG guidance was either unsubstantiated or developed using assumptions that lacked a sound analytical or experimental basis. In a few cases, the BWROG guidance can even be shown to result in erroneous estimates of the head loss, while in many cases their guidance could not be deemed either "conservative" or "non-conservative." This lack of confidence arose from the BWROG's use of inconsistent modeling assumptions or experimental data without sufficient technical justification for scaling to drywell operating conditions.

The staff has found that the data can be interpreted and a basis established on which to conclude that the URG guidance is reasonable and/or "conservative." Where possible, the staff has proposed some alternatives that licensees can use to improve their analyses. Licensees may wish to explore these alternatives. The staff notes that the suggested alternatives are a byproduct of the staff's review, not its objective. The following are the staff's key overall conclusions categorized by phenomena:

- **Selection of Breaks**: Licensees should evaluate a sufficient number of breaks to ensure that the most limiting breaks are analyzed. Possible locations of the breaks should include pipe sections or welds in the area of the drywell where the highest density of fibrous insulation is installed. Breaks analyzed in support of strainer sizing should meet the requirements of 10 CFR 50.46 and, therefore, should not be limited to breaks analyzed for compliance with GDC 4 (i.e., MEB 3-1 break analysis). This will determine the limiting break relative to ensuring adequate ECCS NPSH margin. The staff also concludes that it is reasonable for licensees to screen out medium breaks in their strainer analysis if they plan to use alternative strainer designs with deep crevices for debris capture (such as stacked disk or star strainers), provided that the strainer vendor can provide adequate assurance that head losses from combinations of debris loadings up to those consistent with a large-break LOCA are bounded by the large-break LOCA rather than any smaller break. Licensees (or strainer vendors) should also have strainer test data to support this conclusion.

- **Debris Generation**: The staff's findings are summarized as follows:

  — The staff identified errors in the P_{dest} factors provided in URG Table 1. The staff concludes that these values should be revised consistent with the values in Table B.1 of Appendix B to this SER. The staff's concerns on the use of JCL versus TAAP for insulations having high P_{dest} factors can be resolved on a plant-specific basis.

— The methodology used to develop destruction factors for calculations of fine debris is acceptable.

— Methods 1 and 2 are reasonable and appear to provide conservative bounds for the volume of debris generated.

— Method 3 should be applied with caution on a plant-specific basis, since it allows utilities to take credit for limited separation (restrained unrestrained and single-jet double jet). Licensees should consider that in the case of a main steamline break, flow would be from both ends of the pipe break until the MSIVs are closed.

— The URG provided insufficient information regarding Method 4 for the staff to reach any conclusions concerning the proposed methodology; therefore, the staff concludes that Method 4 is unacceptable.

— Damage to Calcium Silicate should be treated as erosion (as demonstrated by Swedish experiments).

- **Other Sources of Debris**: The staff concludes that the generic values provided in the URG for other sources of debris are acceptable. The staff provided guidance on methods licensees may use should they wish to evaluate these debris sources on a plant-specific basis. To avoid potential operability problems resulting from the ongoing NRC and industry efforts related to potential clogging of ECCS strainers by coating debris, the staff also suggests that licensees assume that all unqualified and indeterminate coatings are transported to the strainer surface, unless data is available supporting use of other assumptions.

- **Drywell Debris Transport**: The staff has found no evidence that transport fractions for Mark II containments should be any different than for Mark I and Mark III containments; therefore, the staff concludes that the same transport fractions) should be used for all three containment types. The staff also concludes that the combined debris generation/transportfractions provided in the URG for Mark I and III containments (e.g., for RMI, fine fibrous debris, and large fibrous debris below the lowest grating in the drywell, and so forth) are acceptable for use in all three containment types.

- **Suppression Pool Transport** The staff finds that this section is acceptable with no comments.

- **Head Loss**: The staff's conclusions are summarized as follows:

  — The staff agrees with the BWROG that the "thin bed effects" are not likely to be an issue for the alternate strainer designs tested.

  — The generic applicability of the URG head loss correlation is not acceptable for the following reasons:

    1) The correlations are based on data obtained for lower debris loadings than would be expected in many plants, and the correlations are not mechanistic to overcome this deficiency.

2) The RMI conclusions are specific to the strainer design tested and the type of RMI used in the test. No basis was provided for extrapolating to other RMI types and strainer designs.
3) The correlations are specific to the limited types of insulations tested.

— As a result of the staff's findings relative to the URG head loss correlation, the staff recommends that licensees use test data to support the head loss used in their plant analysis.

— The NPSH evaluation described in Volume II of the URG Technical Support Documentation, Tab 15, is not acceptable since it only addresses viscous loss. For RMI, this would yield erroneous results.

— The bump-up factors provide a "conservative means" for extending the fiber correlation to other debris, but can create severe design impacts if used.

- **Resolution Options**:

— Use of self-cleaning strainers is discouraged unless the licensee cannot reach adequate resolution with a passive strainer design.

— Backflushing is recommended only as a defense-in-depth measure (rather than a primary method of mitigating a LOCA).

- **Overall:** The staff's overall conclusions are summarized as follows:

— In general, the URG provides good guidance on how to evaluate the potential strainer clogging issue on a plant-specific basis, and provides acceptable methods for sizing of strainers. The staff has found certain portions of the URG unacceptable for use by licensees due to inadequate guidance or insufficient technical justification. Where the staff has not accepted a portion of the URG, the staff's concerns have been noted in this SER. If a licensee desires to use a methodology or resolution option not accepted by the staff, they should resolve the staff's concerns identified in this SER.

— In its response (Ref. 64) to the draft SER (Ref. 63),on the URG, the BWROG stated, "The BWROG requests that the staff consider issuing a supplement to NRCB 96-03 that provides blanket schedule relief to the licensees in reaching final technical closure on NRCB 96-03 until an NRC-accepted methodology is available that fully and completely addresses all the issues affecting the calculation of ECCS pump NPSH. The BWROG is not requesting blanket deferral for the installation of replacement strainers but only for final closure of the 96-03 technical response. Once the final NRC accepted methodology is available, licensees should be given adequate time to review their strainer designs, debris loading calculations, and the need for any further actions (e.g., license changes for containment overpressure credit) before closure of NRCB 96-03 is required." In particular, the BWROG noted the fact that the coatings issue is currently an open issue that could significantly impact the resolution of NRCB 96-03 for many licensees. The staff will consider issuing the requested deferral in a bulletin supplement.

8.0 REFERENCES

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2) "Technical Support Documentation Utility Resolution Guidance for ECCS Suction Strainer Blockage" (3 Volumes), BWROG, November 1996.
3) Facsimile Transmittal from T.A. Green to R.B. Elliott, "Summary Information Regarding URG Drywell Transport Methodology," November 25, 1996.
4) NRC Bulletin 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris," May 6, 1996.
5) Regulatory Guide 1.82, Revision 2, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," May 1996.
6) Draft Utility Resolution Guidance Document, Sections 3.1.4, "Backflush"; 3.2.1.1, "Postulated Break Locations"; 3.2.2.2, "Suppression Pool Transport and Settling"; and 3.2.3.4, "ECCS Pump NPSH Calculations," March 31, 1996.
7) Draft Utility Resolution Guidance Document, Sections 3.1, "Evaluation of Resolution Options"; 3.2.2, "Other Drywell Debris Sources"; 3.2.4, "Suppression Pool Debris Sources"; and 3.4 "Self-Cleaning Strainer," May 28, 1996.
8) Letter from C.H. Berlinger to R. Sgarro, "Comments on Draft Utility Resolution Guidance Sections 3.1.4, 3.2.1.1, 3.2.2.2, and 3.2.3.4," July 25, 1996.
9) Letter from C.H. Berlinger to R. Sgarro, "Comments on Draft Utility Resolution Guidance Sections 3.1, 3.2.2, 3.2.4, 3.4," August 20, 1996 (Accession number 9608260002).
10) Memorandum from R.B. Elliott to C.H. Berlinger, "Summary of August 19, 1996, Meeting with the Boiling Water Reactor Owners Group (BWROG) to Discuss Issues Related to the Potential Loss of Emergency Core Cooling System (ECCS) Capability Due to Clogging of the Suction Strainers by Debris Generated During a Postulated Loss-of-Coolant Accident (LOCA)," September 4, 1996 (Accession number 9609100214).
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14) Letter from M.J. Virgilio to R. Pinelli (no subject line), June 13, 1994 (Accession Number 9407010102).
15) Facsimile transmittal from J.H. Munchausen to A.W. Serkiz, "Plan for Testing Pipe Insulation Debris Generation Due to Simulated Pipe Breaks," August 9, 1994.
16) Letter from G.M. Holahan to R. Pinelli (no subject line), September 12, 1994.
17) Letter from T.A. Green to A.W. Serkiz, "BWR Owners' Group Program to Test Alternative ECCS Suction Strainers," March 15, 1995.
18) Letter from M.D. Lynch to R. Sgarro, "Request for Additional Information (RAI) Regarding the Strainer Test Program Being Conducted by the BWROG," June 22, 1995 (Accession Number 9507060112).
19) Letter from M.D. Lynch to R. Sgarro, "Second Request for Additional Information Regarding the Strainer Test Program Being Conducted by the BWROG (TAC No. M86925)," August 21, 1995 (Accession Number 9508240384).

20) Letter from C.H. Berlinger to R. Sgarro, "Request for Additional Information Regarding the Drywell Transport Program Being Conducted by the BWROG," dated April 22, 1996 (Accession Number 9608260002).
21) Facsimile Transmittal from M.L. Marshall, Jr., to A. Bilanin of Continuum Dynamics, Inc., "Transmittal of Questions and Concerns Regarding the BWROG Strainer Tests," August 14, 1995.
22) Letter from T.A. Green to R.B. Elliott, "Closure of BWR Owners Group Response to NRC 'Request for Additional Information Regarding the Strainer Test Program Being Conducted by the BWROG'," July 17, 1995.
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24) Memorandum from R.B. Elliott to C.H. Berlinger, "Summary of May 31, 1995, Meeting with the Boiling Water Reactor Owners Group (BWROG) to Discuss Issues Related to the Potential Loss of Emergency Core Cooling System (ECCS) Capability Due to Clogging of the Suction Strainers by Debris Generated During a Postulated Loss-of-Coolant Accident (LOCA)," June 13, 1995.
25) Memorandum from M.L. Marshall, Jr., to C.Z. Serpan and C.H. Berlinger, "Trip Report and Meeting Summary of September 27 and 28, 1995, Public Meeting with Boiling Water Reactor Owners Group in San Jose, CA Regarding the Resolution of the Boiling Water Reactor Suction Strainer Blockage Issue," October 6, 1995.
26) Memorandum from M.L. Marshall, Jr., to C.Z. Serpan and C.H. Berlinger, "Summary of April 4, 1996 Public Meeting Between the NRC Staff and BWROG Representatives to Discuss BWROG URG Document Concerning the BWR Suction Strainer Debris Blockage Issue and the BWROG Planned Drywell Transport Test," April 16, 1996.
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44) Letter from R.L. Seale (Advisory Committee on Reactor Safeguards) to L.J. Callan (NRC Executive Director for Operations), "Proposed Final Generic Letter, 'Assurance of Sufficient Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal Pumps'," June 17, 1997.
45) Generic Letter 97-04, "Assurance of Sufficient Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal Pumps," October 7, 1997.
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55) BWROG Letter OG96-321-161, Attachment 2, "Suppression Pool Sludge Particle Distribution Data - Average Distribution Calculation," September 1994.
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59) NRC Information Notice 92-85, "Potential Failures of Emergency Core Cooling Systems Caused by foreign Material Blockage," December 23, 1992.
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66) BWROG Letter BWROG-94157, from R.A. Pinelli to A.C. Thadani, "Interim Report of the BWR Owners' Group ECCS Suction Strainer Committee, Dated December 1994," December 15, 1994.
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9.0 LIST OF RELATED REPORTS AND DOCUMENTS IN THE PUBLIC DOCUMENT ROOM

The following table lists test reports and documents related to the ECCS strainer clogging issue that are available in the NRC's Public Document Room.

Technical Documents in Public Document Room		
	Document	**Accession Number**
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2	Murthy, P., Padmanabhan, M., and Hecker, G., "Tests of Particle Settling Velocity in Still Water," Alden Research Laboratory, Inc., Holden, MA, June 1994.	9511010046
3	Murthy, P., *et al.*, "Head Loss of Fibrous NUKON™ Insulation Debris and Sludge for BWR Suction Strainers," 124-95/M787F, Alden Research Laboratory, Inc., Holden, MA, June 1995.	9511010046
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Appendix A

Calculation to Check Estimates of Bulk Dynamic Pressures Computed by the BWROG

References:

A.1 URG, Section 3.2.1.2.3, Page 36, Line 1.

A.2 Letter from D.V. Rao to M.L. Marshall, Jr., "Debris Drywell Transport Study, Draft Phase 1 Letter Report," SEA Letter 96-3105-010-A:2, September 27, 1996.

A.3 Letter from T.A. Green to R.B. Elliott, "BWR Owners Group Response to NRC Comments and Questions Regarding NEDO-32686, Revision 0, 'Utility Resolution Guidance for ECCS Suction Strainer Blockage'," January 30, 1997.

Problem Definition: In Reference A.1, the URG includes the following statements:

- The bulk dynamic pressures in the drywell far from the break are lower than 0.02 psi.
- The licensee need not worry about damage to insulation located outside the jet's ZOI.

The staff performed calculations to evaluate these URG conclusions. The assumptions used in performing these calculations are as follows:

- LOCA Data:

  — Discharge from both ends of a pipe break will reach a maximum flow (M) of 8000 lbm/s, assuming a 24-inch DEGB with full separation (Ref. A.2). A higher flow rate is calculated if containment atmospheric pressure is considered.

  — Instantaneous containment pressure will be 15-40 psi. It takes several seconds for the containment pressure to buildup to 40 psi. The density of the steam and air mixture in the initial stages of accident (ρ) is 0.08 lbm/ft3 (Ref. A.2).

- Geometrical Information: The staff compiled the following geometrical information for an average size Mark I containment (Ref. A.2). Realistic equipment congestion was then used to estimate flow velocities and dynamic pressures.

Elevation Location	Total Area (ft^2)	Porosity	Net Flow Area (ft^2)
Neck	750	0.8	600
Upper Grating	1800	0.6	1080
Lower Grating	1550	0.57 ($\approx$0.6)	930

- Velocity and Dynamic Pressure: Assuming that a quasi-steady state break flow occupies 100% of net flow area (A_{x-s}) available for flow, the estimated flow velocities (V_∞) and dynamic pressures (P_∞) can be calculated as follows:

$$V_\infty = M/(\rho A_{x-s})$$
$$P_\infty = M^2/(2\rho A^2_{x-s} g_c)$$

On the basis of these assumptions, the estimated bulk dynamic pressures are as follows:

Elevation Location	Dynamic Pressure (psi)
Neck	0.24
Upper Grating	0.07
Lower Grating	0.10

These pressures are probably not large enough to inflict damage on properly installed jacketed fibrous insulation (such as those tested by the BWROG). Nevertheless, in the staff's opinion, these values are sufficiently large to inflict damage on improperly installed insulation (e.g., cut-to-fit partially exposed insulation blanket pieces some utilities may use to insulate hard-to-fit components such as valves) or insulation blankets that are not well maintained (e.g., partially torn insulation blankets that some utilities may not have replaced in the past). Note that in the event at Barsebäck, Unit 2, pressures in the same range generated substantial debris from aged unjacketed mineral wool blankets.

Conclusion: The BWROG underestimated bulk dynamic pressures for at least certain types of containments (e.g., Mark I). The staff is concerned that this error in the URG minimizes the potential for debris generation in the regions far from the break. As a result, there is a lack of emphasis in the URG on the importance of proper installation and maintenance of insulation blankets (especially at hard to reach places). The staff cautions licensees to consider the potential for generation of miscellaneous fibrous debris attributable to these elevated dynamic pressures that exist far from the break. The staff notes that the BWROG addressed this comment in Reference A.3 above. The staff concludes that this response adequately addresses this issue.

Appendix B

Analyses to Verify Values of P_{dest} for Selected Materials Reported by the BWROG and Suggestions for Development of Scaling Analyses

References:

B.1 URG Section 3.2.1.2.3.2, Page 38, Line 13, and Page 46, Table 2.

B.2 URG, Vol. II, Tab 3, CDI Report No. 95-06, "Air Jet Impact Testing of Fibrous and Reflective Metallic Insulation," CDI, September 1996.

B.3 URG, Vol. II, Tab 1, CDI Report No. 96-01, "Zone of Influence as Defined by Computational Fluid Dynamics, Revision 3," CDI, October 1996.

B.4 Jet Model fromANSI/ANS-58.2, "Design Basis for Protection of Light Water Nuclear Power Plants Against Effects of Postulated Rupture," ANSI, 1988.

Problem Definition: In the URG, the BWROG provided a table of destruction pressures (P_{dest}) for selected insulation blankets (References B.1, B.2, and B.3). This table, reproduced here for convenience, lists P_{dest} values for insulation blankets installed on 12-inch diameter piping.

Material	P_{dest} (psi)
Darchem DARMET®	190*
Transco RMI	190*
Jacketed NUKON® with "Sure-Hold" Bands	190*
Diamond Power MIRROR® with "Sure-Hold"	190*
Calcium Silicate with Aluminum Jacketing	160*
K-Wool	40
Temp-Mat with Stainless Steel Wire Retainer	17
Knaupf®	10
Jacketed NUKON® with Standard Bands	10
Unjacketed NUKON®	10
Koolphen-K®	6
Diamond Power MIRROR® with Standard Bands	4
Min-K	4

In addition, for insulation types where the P_{dest} values are marked by '*' in the table above, the BWROG suggested that the P_{dest} values for other pipe sizes can be estimated using the following relationship:

$$P^{D}_{dest} = P^{12}_{dest} (12 \text{ inches}/D)$$

The BWROG derived the P_{dest} values listed in the table above as follows:

- The AJITs were conducted at the CEESI facility using a 3-inch diameter jet nozzle and 12-inch diameter target pipe to determine the farthest location from a break at which a given insulation blanket will be damaged and dislodged from the target pipe. The results of these

tests are documented in Reference B.2. The location determined by the tests is defined as $(L/D)_{dest}$.

- The NPARC CFD calculations were used to determine the JCL pressure associated with $(L/D)_{dest}$. This pressure is listed in Reference B.1 as P_{dest}.

- The correction formula listed above is suggested to scale CEESI results to different target pipe sizes.

The staff notes that URG did not address any scaling issues relative to the applicability of test data using a 3-inch diameter nozzle from the CEESI facility to an MSLB in a full-size plant.

The staff and its contractor (Science and Engineering Associates, Inc. (SEA)) witnessed several of the BWROGs AJITs and carefully reviewed the documentation provided by the BWROG. The following paragraphs summarize the confirmatory analyses performed:

- **CEESI Test Facility and Experimental Procedure**: The experimental program carried out at CEESI appeared reasonable and tractable according to the NRC's quality assurance (QA) program. The staff reviewed the experimental data provided in Reference B.2 to determine the maximum distance from the jet (L/D) beyond which no noticeable damage was inflicted on the target. Column 4 of Table B-1 in this appendix lists these numbers. The staff made the following observations:

  — In the majority of the tests, the target consisted of a single piece of blanket (24-inches long) mounted on a 12-inch diameter target pipe. This allows for formation of a *non-prototypical* low-pressure region on both ends of the insulation blanket leading to air flow from the high-pressure mid-region to both ends. Such an air flow would inflict more damage than would be expected in a BWR plant, where the insulation blankets are continuous. As a result, the staff believes that the CEESI tests probably overestimate damage, especially in the case of fibrous insulation.

  — For some insulation types, the BWROG did not adequately explore the exact location at which damage first occurred. For example, in the case of stainless steel jacketed NUKON®, the URG reports damage at 50 L/D with 12% of insulation destroyed into fines and 29% into larger pieces. But the URG does not explore damage beyond 50 L/D. Similarly, in the case of unjacketed NUKON®significant damage occurred at 60 L/D and no damage at 119 L/D. No data points were reported in between. In view of such a lack of data, some of the conclusions stated in URG become questionable, especially considering that this information is later used to estimate the fraction of insulation transported.

- **BWROG Derivation of Damage Pressures**: The BWROG employed the NPARC code results presented in Figure 9 on page 18 of Reference B.3 to estimate the JCL pressures corresponding to $(L/D)_{dest}$ where damage was first recorded. These JCL pressures were then interpreted by the BWROG as the damage pressures. On the basis of a detailed review, the staff has identified the following deficiencies in the methodology used by BWROG:

— The URG may overestimate the JCL pressure at which damage first occurs. Although this is non-conservative, the staff considers this to be a minor deficiency because it was only noted for selected insulation blankets. For example, in the case of DPSC mirror insulation with Sure-Hold bands, the URG reported a damage pressure of 190 psid. The staff's contractor, SEA, used the same experimental data and NPARC code results provided in Figure 9 of Reference B.3 to estimate this value to be 150 psid. Several such discrepancies were found, and all of them are annotated in Table B-1 by '*'. In all cases, SEA estimated damage pressures lower than the URG values. The staff recognizes that interpretation of experimental data is often subjective, and this may explain these discrepancies. Nevertheless, the staff recommends the use of the values provided in column 4 of Table B-1 in this appendix.

— The staff's main concern relates to the simplifying assumption made by BWROG to equate the JCL pressure to the damage pressure. The rationale for such an assumption is unclear and not supported by experimental evidence documented in Reference B.2. In fact, this assumption is contrary to assumptions made in Appendix A, page 195 of Reference B.2. An alternative would be to use jet impingement load (force) as a scalable variable for characterizing damage, at least in the case of selected insulations. The staff performed the following analyses to explore this alternative:

a) The CEESI experiments clearly suggest that, in the case of jacketed insulation, damage occurs only after the outer casings on the insulation blankets (e.g., stainless steel sheaths) are separated from the blanket. Usually, the outer casings are secured by bands or latches of various types, ranging from simple latch and strike devices to "Sure-Hold®" bands with modified "CamLoc®" strikes. The BWROG notes (on page 182 of Reference B.2) that a typical failure mode of these devices involved deformation (or straightening) of the J-hook or destruction of the latch mechanism. In both cases, separation of the outer casing occurs when the load on the insulation blanket exceeds the structural strengths of the bands. Since the latch mechanisms or banding used were not typically located at the JCL in the AJITs, and they were failing, the staff believes that the banding or latches were failing at a pressure lower than the JCL. Consequently, the staff concludes that damage should be related to the total impingement force to which the blanket is subjected, rather than the maximum pressure over a small localized region[1]. The staff believes that the experimental evidence supports this in more cases than use of JCL pressures. In cases where the P_{dest} is low, then use of the JCL pressure would not significantly impact the calculated ZOI since the average pressure applied on the target insulation would not be significantly different from the JCL pressure on the target.

b) The difference in the choice of JCL pressure versus total force can be explained quantitatively by considering the radial distribution of pressures in an expanding jet illustrated in Figure B.1. As evidenced by this figure, at each L/D jet pressures are highest at the jet center-line and decrease rapidly with radial distance (R/D). For analysis purposes, Figure B.1 (of this appendix) uses a linear profile as suggested

[1] For example, would a ¼-inch diameter nozzle generate the same amount of debris as a 3-inch.

by the ANSI/ANS 58.2 Jet Model (Reference B.4) instead of a more realistic profile derived from more CFD calculations (e.g., Figure 11 of Reference B.3). Similar analyses may be conducted using more accurate radial profiles than those used in this study. Nevertheless, the net jet impingement load on the blanket is the sum of multiples of the local stagnation pressure in each radial zone and the area of that radial zone intersecting the blanket. As an alternative, one may choose to relate damage to target area averaged pressure (TAAP), which is essentially the ratio of jet impingement load on the target to the target area. Figure B.2 (of this appendix) compares maximum (or JCL) pressures and TAAPs as a function of axial distance from the nozzle exit plane. A blanket length of 24-inches was assumed to estimate these TAAPs. From Figure B.2, it can be seen that at an L/D of 10, the maximum pressure (or the JCL pressure) is 100 psid versus the TAAP of 40 psid, which is a large difference. For a particular insulation, if the first reported damage occurred at a L/D of 10, the URG shows an estimated damage pressure of 100 psid instead of the more realistic damage pressure of 40 psid.

This deficiencies could have considerable impact on the URG defined ZOI models for certain insulations having high P_{dest} values. This impact can be demonstrated by considering pressure isobars in an expanding jet (see Figure B.3 of this appendix). As shown in this figure, the 100-psid isobar includes much lower volume than the 40-psid isobar[2]. As a result, the volume of insulation destroyed would be higher if it were estimated based on drywell volume bounded by a 40-psid isobar as compared to that bounded by the 100-psid. As noted above, the staff believes that this comment is only significant for insulations with high P_{dest} values (e.g., where JCL pressure is significantly higher than average pressure on the target). The staff also notes that NPARC runs can be used effectively to provide a better estimate of target area averaged damage pressures than those estimated in this calculation using a simplified 1-D jet expansion model. Because of the limited number of insulations impacted, the staff believes this issue can be addressed on a plant-specific basis. The staff also recommends the use of the P_{dest} values listed in column 4 of Table B-1 herein.

[2] For a nozzle size of 24-inches, the isobars in Figure B.3 very closely represent "target area averaged pressures" at that location, assuming the target to be 24-inches long.

Table B-1 Results of CEESI Testing for Each Insulation Material.

Insulation Material	(L/D) Dest.[3]	URG Damage Pressure (psi)	JCL[4] Pressures Estimated in Confirmatory Analysis
Darchem DARMET®	5.0	190	190
Transco RMI [5]	5.0	190	190
Jacketed NUKON® with Sure-Hold® Bands	>11[6]	190	150*
DPSC MIRROR® with Sure-Hold® Band	8.5	190	150*
Calcium Silicate with Aluminum Jacketing	7	160	150*
K-Wool	15	40	40
Temp-Mat with stainless steel wire retainer	30	17	17
Knaupf®	60	10	10
Jacketed NUKON® with Standard Bands	>50	10	10
Unjacketed NUKON®	>60 ; < 119	10	10
Koolphen-K®	>80[6]	6	6
DPSC MIRROR® with Standard Bands	99	4	4
Min-K	>100[6]	4	< 4

- **Scalability of Results to BWR Drywells**: In the CEESI experiments, a 3-inch diameter nozzle was used to simulate a broken pipe, and a 12-inch diameter pipe was used to simulate a target pipe (Reference B.2). This raises the following concerns related to scalability of the experimental results:

  — How can damage pressures obtained for 12-inch target pipe be used to estimate damage pressures for a smaller or a larger pipe? Since all insulation blankets are attached to pipes of different diameters by identical straps, their failure occurs at same target load irrespective of the target pipe diameter (i.e., one should look for load conservation). Therefore, the following equation holds:

---

[3] The maximum distance at which damage or dislodgment is reported for the insulation type of interest.

[4] The jet-center-line pressure corresponding to $(L/D)_{dest}$. The JCL pressure was extracted from the CFD results of Reference B.3.

[5] Several different types of Transco RMI insulation was tested. However, the results presented here are for TPI 0.024-inch sheath solid end (stainless steel) with latch and strike closures. According to the URG, this insulation appears to be the most commonly found Transco RMI in BWRs.

[6] Exact number not known since testing did not go beyond the values listed for which significant damage was evident.

$$F^{d}_{dest} = F^{12}_{dest}$$

where,

F^{D}_{dest} = is the destruction load for a blanket installed on a pipe of diameter D
F^{12}_{dest} = is the destruction load calculated on the basis of CEESI experimental data for 12-inch pipe.

The force-pressure relationship is:

$$F^{d}_{dest} = P^{D,av}_{dest} * A_{jet\text{-}target}$$

where,

$P^{D,av}_{dest}$ = is averaged jet damage pressure (psi)
$A_{jet\text{-}target}$= is area of jet-target interaction (in^2).

For target pipes fully immersed in the jet, it can be easily shown that

$$A_{jet\text{-}target} = k(D+2t)L$$

where,

k = a constant of proportionality
D = Outer diameter of the target pipe (in)
t = insulation blanket thickness (in)
L = Length of the insulation blanket (in)

Substituting these variables into the force conservation equation above yields the following:

$$k*(D+2t)*L* P^{D,av}_{dest} = k*(12"+2t)*L* P^{12,av}_{dest}$$

or

$$P^{D,av}_{dest} = P^{12,av}_{dest} *(12"+2t)/ (D+2t)$$

A first-order approximation (within $\pm$ 25%) to the above equation is as follows:

$$P^{D,av}_{dest} = P^{12,av}_{dest} *(12"/ D)$$

This is the correction formula suggested by the BWROG. The staff believes it is adequate and can be used for certain types of insulation (i.e., steel encapsulated insulations, RMI etc.).

— How can damage pressures obtained using a 3-inch diameter nozzle be scaled for breaks associated with 22-inch diameter pipes or larger? This issue is pictorially illustrated in Figure B.4 (of this appendix) which shows that in CEESI testing, the blanket is not completely encompassed by the high-pressure region of the expanding jet, (especially for L/D values less than 5). Evidence to that effect can be found in some of the still pictures taken of damaged insulation cassettes (e.g., Figure 4-42 and Figure 4-43, Reference B.2) where damage occurred over a limited region. In BWRs, the broken pipes can be as large, if not larger than the target pipes. In such cases, high-pressure regions of the jet would completely encompass the insulation blanket, subjecting the entire front and side surfaces to high pressure. This raises questions related to scalability of CEESI results to BWRs. At least in part, this issue can be addressed if the damage is thought to be proportional to the total load, as follows.

  Consider that, in a BWR, a postulated LOCA involves a fully separated DEGB of a 24-inch MSLB. Now assume that an analyst is interested in quantifying the damage caused by the ensuing steam-jet impingement on a 24-inch diameter target pipe and located about 20 ft from the broken pipe (10 L/D). As a first step, one can use the ANSI/ANS-58.2 model to predict total impingement load on a blanket located on that target pipe. For a blanket that is 24 inches long, this load is calculated to be approximately 23,000 lbf, with an average pressure of approximately 40 psi (Note that load is calculated assuming the medium to be steam).

  Correspondingly, in CEESI air jet tests, the insulation blanket located on 12-inch target pipe also located 10 D (or 30 inches) from the nozzle would be subjected to an average pressure of 40 psi (see Figure 2). The net force it is subjected to however is only 11,520 lbf, not 23, 000 lbf computed for the BWR case above. As a result, licensees should exercise care to ensure that results from CEESI are not interpreted in terms of L/D values, but instead in terms of the impingement load.

  By contrast, in CEESI tests, an insulation blanket located on the same 12-inch target pipe but 5D from the nozzle would be subjected to a total force of about 22,752 lbf. A case can be made that damage observed at 5 L/D in CEESI air-tests is approximately equal to damage expected at 10 L/D following a 24-inch MSLB.

- **Fluid Medium of Experimentation**: Air used in CEESI testing obviously has different characteristics from high-temperature steam released following a LOCA. Once again, this difference can be accounted for if the analyst exercises care to think in terms of total load, not L/D. Through NPARC results (see Figure 9, Ref.. 3), the BWROG argued that air-based test results "conservatively bound" the damage expected in case of steam. The staff concurs that compressed air can be used to create high-pressure fields at a given L/D comparable to a steam jet of the same pressure.

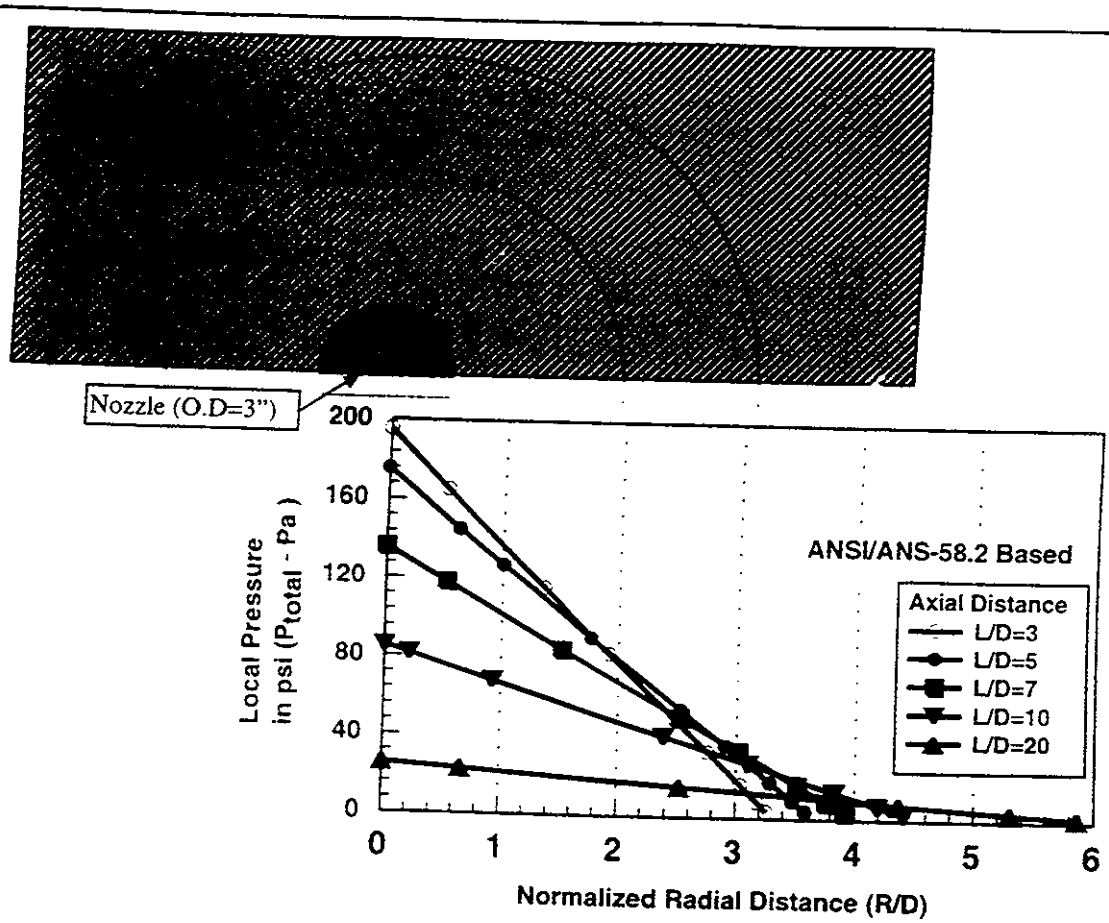


Figure B.1. Radial Distribution of the Stagnation Pressure in the Jet.
The actual pressure profile could be different from the linear profile assumed in the ANSI/ANS-58.2 Model.

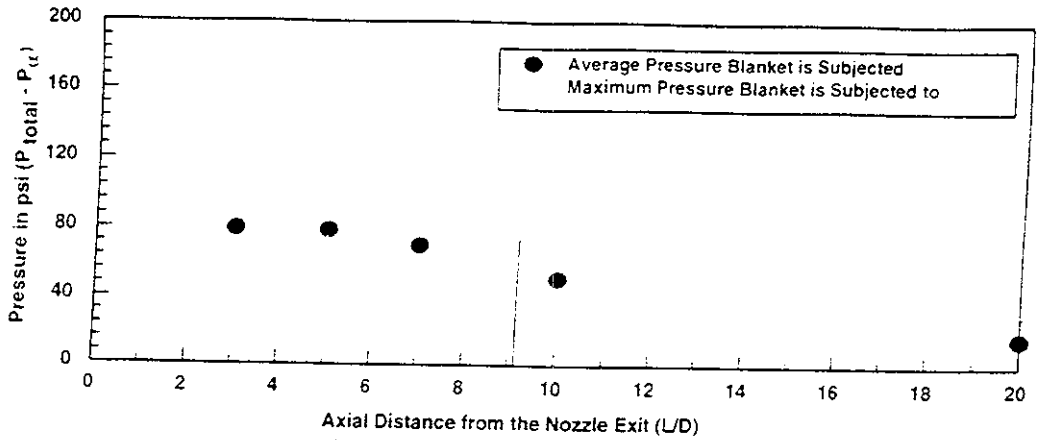


Figure B.2. Comparison of Average (SEA Suggested) and Maximum (BWROG_URG) Pressures on a 24" long and 3" thick blanket installed on 12" target versus its axial location.

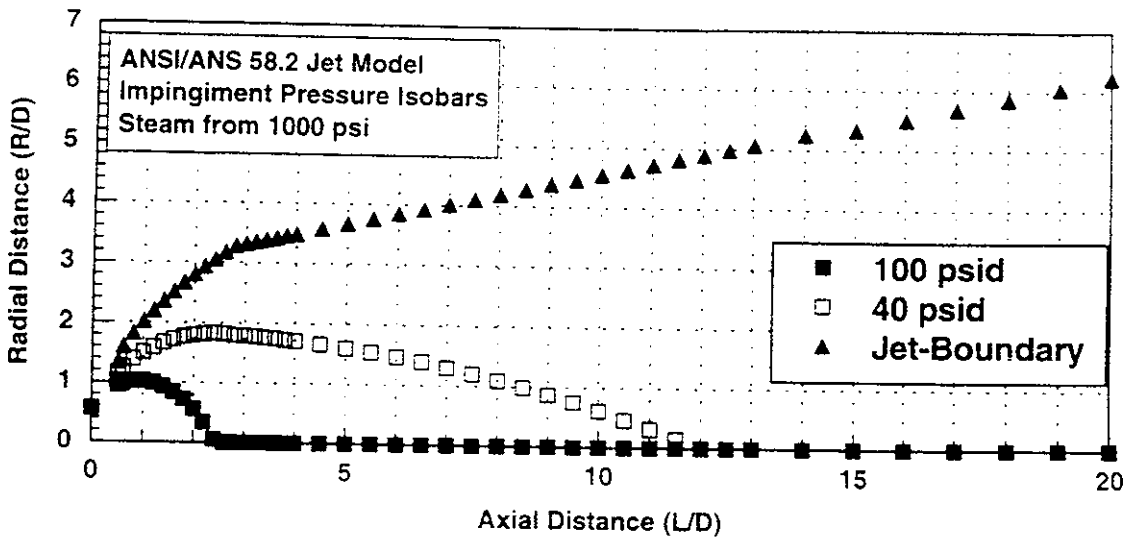


Figure B.3. Pressure Isobars for Steam Jet Expanding from a DEGB with Full Separation. Each Isobar Bounds the Volume of Jet in which Impingement Pressures are Higher than the Value Indicated in the Legend.

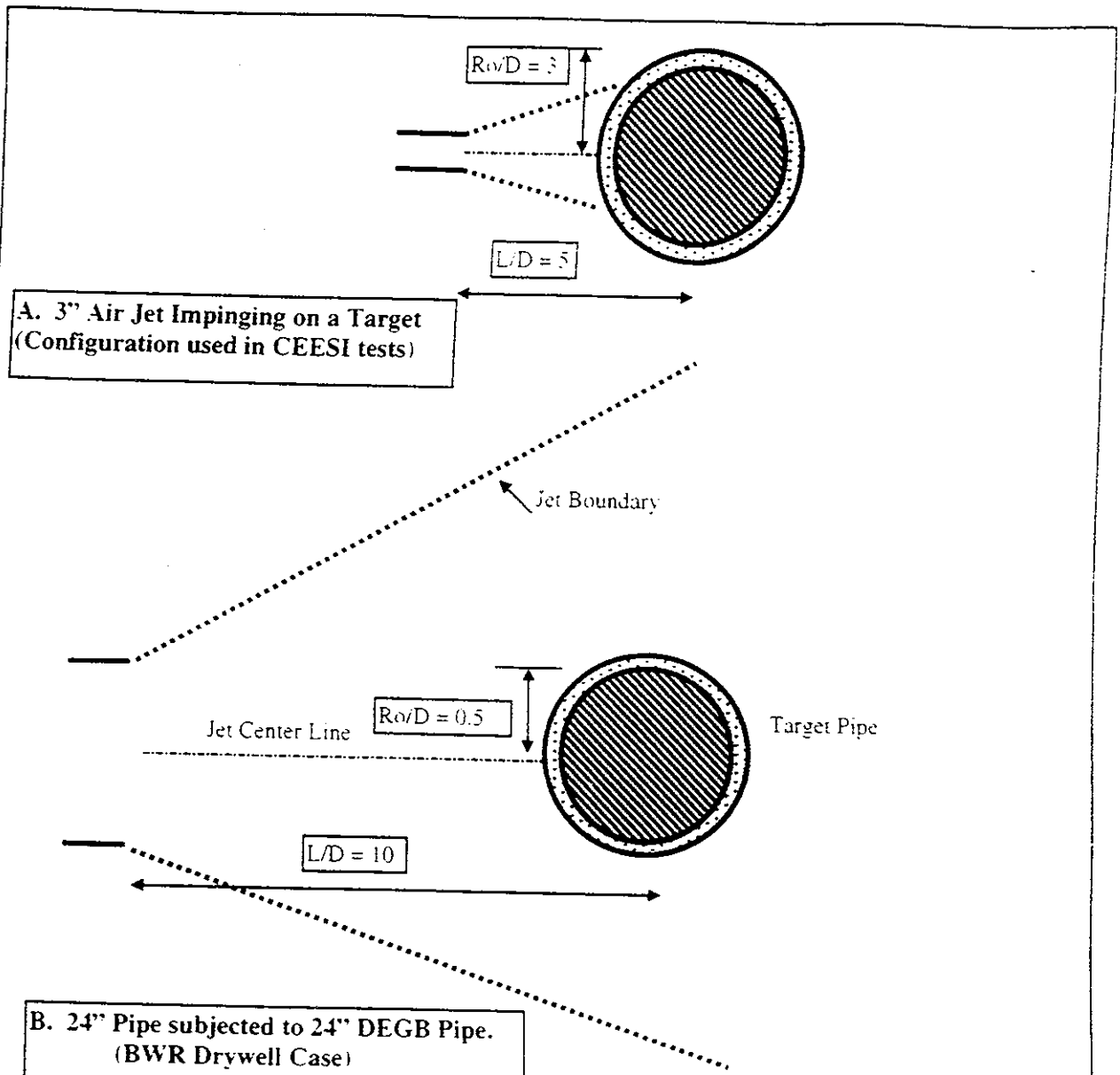


Figure 1. Schematic Illustration of CEESI Testing Versus BWR Drywell Steam Jet Impingement on Targets.

Appendix C

Calculations to Examine the Accuracy of Reported Jet Volumes Bounded by Selected Load Isobars

References:

C.1 URG Section 3.2.1.2.3.2, Page 38, Line 13 and Page 46, Table 2.

C.2 CDI Report No. 95-06, "Air Jet Impact Testing of Fibrous and Reflective Metallic Insulation," URG Technical Support Documentation, Volume II, Tab 3.

C.3 CDI Report No. 96-01, "Zone of Influence as Defined by Computational Fluid Dynamics," Revision 3, URG Technical Support Documentation, Volume II, Tab 1.

C.4 ANSI/ANS-58.2 Jet Model, "Design Basis for Protection of Light Water Nuclear Power Plants Against Effects of Postulated Rupture," ANSI, 1988.

C.5 EPRI NP-4362, "Two Phase Jet Modeling and Data Comparison," Electric Power Research Institute, 1986.

Problem Definition: In References C.1 and C.3, the BWROG reported volumes of jet regions enveloped by selected isobars (2, 4, 6, 10, 17, 40, 160, and 190 psid). These volumes were computed as a function of radial and axial offsets. The calculations used the NPARC computer code with thermodynamic properties of steam.

The staff performed calculations to evaluate the adequacy of the BWROG estimates using the ANSI/ANS-58.2 model (Reference C.4). These calculations are confirmatory and intended as a check of the BWROG calculations presented in Reference C.2. The staff believes that the NPARC computer code used in the URG to model steamline breaks is a more capable method to model steam jets than the ANSI/ANS-58.2 model. However, the ANSI/ANS-58.2 model has been thoroughly benchmarked with experimental data, and its accuracy (and limitations) are well established (Reference C.5). Furthermore, the ANSI/ANS-58.2 model also provides a good bounding estimate for recirculation line breaks which cannot be modeled with single-phase CFD codes such as NPARC.

Volumes of Jet with Pressures Higher than a Prescribed Damage Pressure: Figure C.1 of this appendix presents impingement load isobars for a postulated DEGB with full separation in main steamline and recirculation line breaks. Figure C.2 of this appendix presents similar plots for a DEGB with limited separation (no radial separation and an axial separation of 0.25D). These isobars were drawn on the basis of the model presented in ANSI/ANS-58.2. Careful examination of these figures reveals the following trends:

- The jets originating from MSLBs tend to remain focused around the JCLs for longer distances. For example, JCL pressure is higher than 1.5 bars (or 22 psid) at distances beyond 20 L/D. Note also that this value compares favorably with NPARC results for total pressure plotted in Figure 9 of Reference C.3. On the other hand, the radial extent to which the 22-psid isobar spreads is about 3D.

- The jets originating from recirculation line breaks diffuse to low pressures more rapidly than those from MSLBs. For example, in the case of a recirculation line break, the 22-psid isobar extends only up to about 7 L/D, instead of 20 L/D in the case of an MSLB.

- The main steamline results (especially JCL pressures) are in reasonable agreement with the NPARC results documented in Reference C.2.

The following conclusions can be drawn regarding breaks with limited separation:

- The MSLBs once again remain focused and go far beyond recirculation breaks of similar magnitude.

- In general, the jet expansion from a limited separation break is more modest in extent than a full separation.

The staff calculated the jet volumes enveloped by each isobar. Figure C.3 of this appendix presents these estimates for the following cases:

- a postulated MSLB as predicted by ANSI/ANS-58.2 model

- a postulated recirculation line break as predicted by the ANSI/ANS-58.2 model (Note that these values are applicable only to the sub-cooled blowdown phase.)

- the volume of a postulated spherical model (such as that used in NUREG/CR-6224), with increments in radius from 3L/D to 15 L/D

- a postulated MSLB as predicted by NPARC in the URG (Table 1, Page 46, of Reference C.1).

- a postulated recirculation line break as predicted by NPARC in the URG (Table 1, Page 47, Note 5, Reference C.1).

The comparison presented in Figure C.3 suggests the following conclusions:

- For impingement pressures larger than 40 psid, the volumes enveloped by the jet predicted in the URG are more conservative than the ANSI/ANS 58.2 predictions. As explained in Reference C.3, this is expected since the ANSI/ANS-58.2 model does not include shock dynamics and radial pressure distributions mechanistically. This comparison presents a good check of URG calculations.

- For impingement pressures between 25 and 4 psid, URG results and NPARC results are very close to each other. Once again, this comparison represents a good check for URG calculations.

- At pressures below 4 psid, the URG volumes are lower than the ANSI Model by up to a factor of 4. This result is not surprising because neither model is very effective at these low

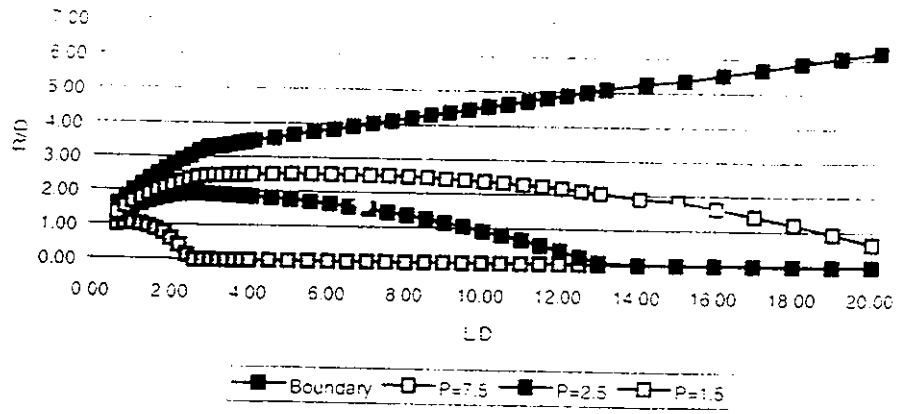
pressures. The staff notes that very few insulation types are significantly damaged at these low pressures.

- The multiplication factors provided for recirculation breaks appear to perform reasonably well for all pressures.

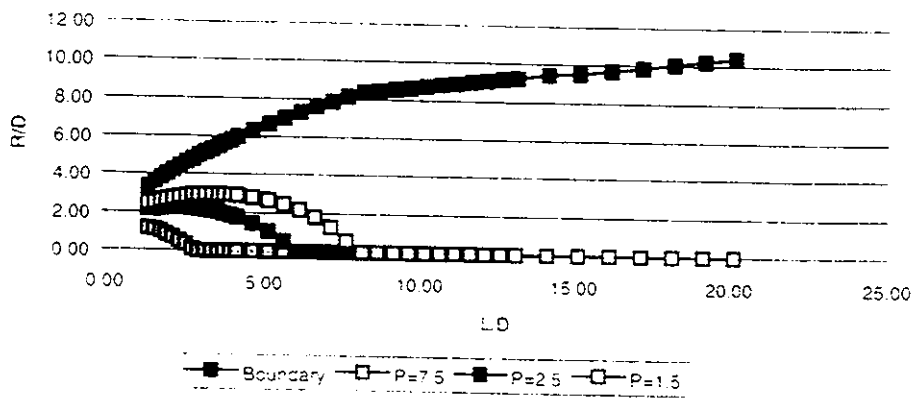
- Overall, it appears that a 17-psid isobar bounds a volume equal to that of a sphere with a radius equal to 7 L/D. Similarly, a 5L/D sphere was found to adequately bound the isobars with pressures larger than 150 psid.

Figure C.4 of this appendix presents a similar comparison for DEGB with no radial separation and an axial separation of 0.25 D. Once again, good agreement was observed between the ANSI/ANS 58.2 results and NPARC results at low pressures, while at high pressures, the NPARC results were conservative.

As a result of these comparisons, the staff concludes that the URG-predicted volumes are conservative or reasonable in the pressure ranges of interest, depending on the impingement load. Their use, if properly justified, is acceptable.



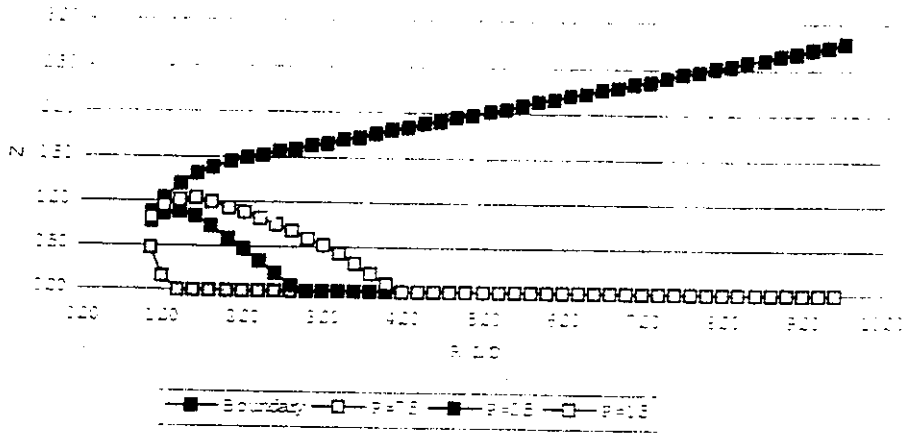
A. Main Steam Line Break. Full Separation



B. Recirculation Line Break. Full Separation. Sub-cooled blowdown

Figure C.1. Jet Impingement Loads Computed Using ANSI/ANS 58.2 Model for DEGB with Full Separation.

A. Main Steam Line Break
(0.25 D Separation)



B. Recirculation Line Break
(0.25 D Separation)

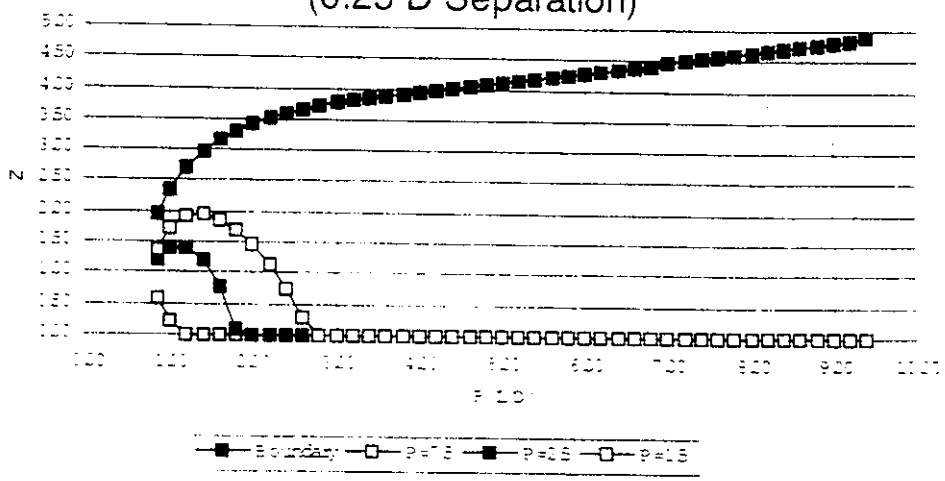


Figure C.2. Jet Impingement Loads Computed Using ANSI/ANS 58.2 Model for DEGB with Limited Separation.

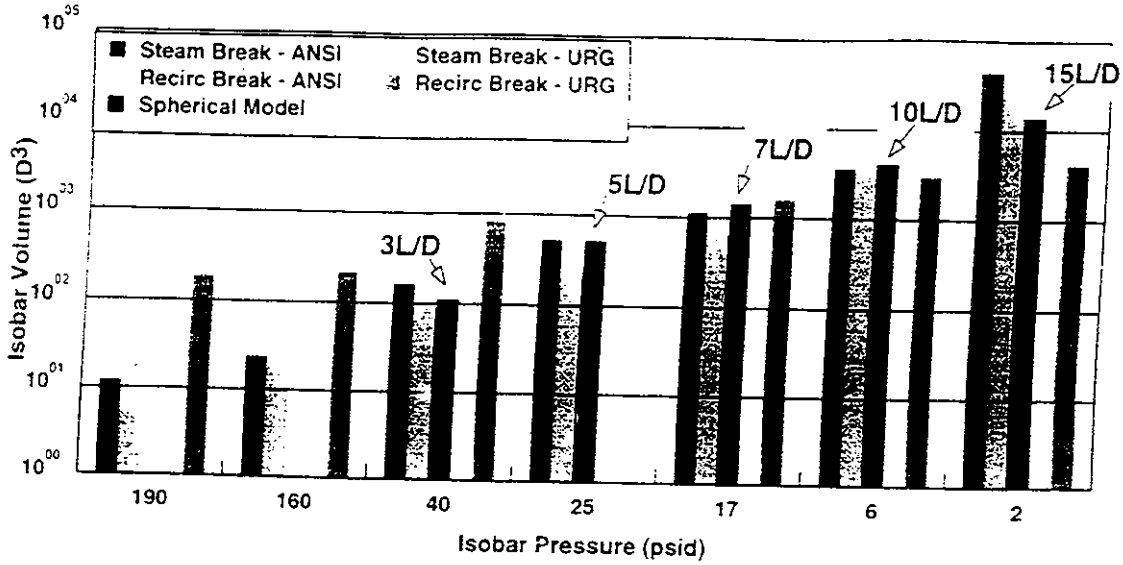


Figure C.3. Jet Impingement Load Isobar volumes for Fully Separated Steam Line and Recirculation Line Breaks. Bases: ANSI/ANS 58.2 and NPARC/URG

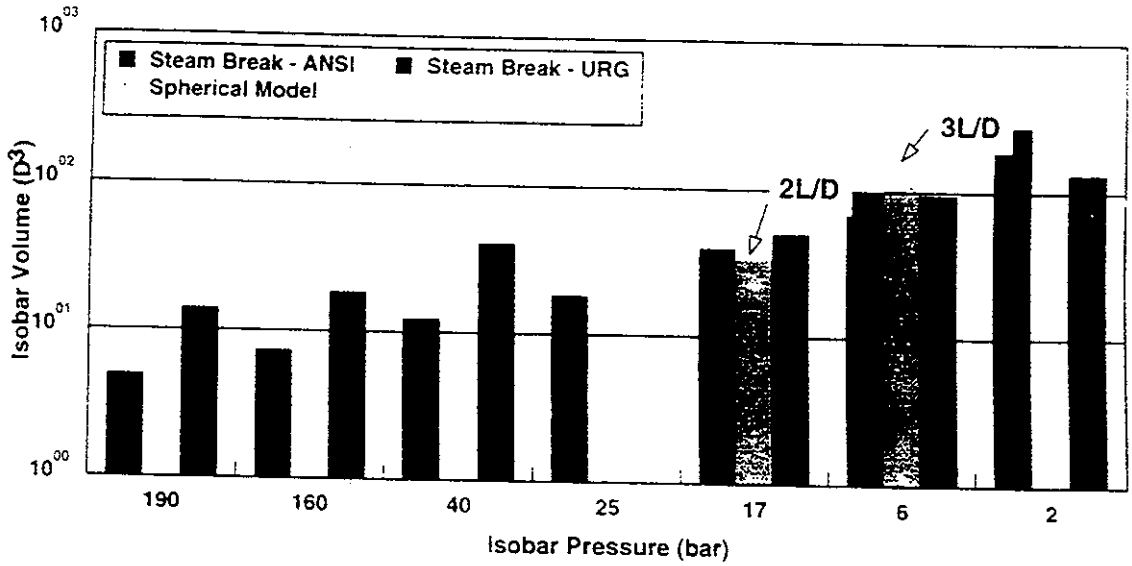


Figure C.4. Jet Impingement Load Isobar Volumes for Limited Separation Steam Line Breaks. Bases: ANSI/ANS 58.2 and NPARC/URG

Appendix D

Calculations to Examine Zone of Influence Models Proposed for Two-Phase Jets

References:

D.1 URG Section 3.2.1.2.3.2, Page 46, Table 2, and Page 47, Note 5.

D.2 CDI report No. 96-01, "ZOI as Defined by Computational Fluid Dynamics," Revision 3, URG Technical Support Documentation, Volume II, Tab 1.

D.3 GE Report DRF A74-00004, "Total Pressure Topography and Zone of Destruction for Steam and Mixture Discharge from Ruptured Pipes," URG Technical Support Documentation, Volume III, Tab 14, September 1996.

D.4 Jet Model from ANSI/ANS-58.2, "Design Basis for Protection of Light Water Nuclear Power Plants Against Effects of Postulated Rupture," ANSI, 1988.

D.5 EPRI NP-4362, "Two Phase Jet Modeling and Data Comparison," Electric Power Research Institute, 1986.

D.6 NUREG/CR-2913, "Two Phase Jet Loads," Sandia National Laboratories, 1983.

D.7 SEA 96-3105-010-A:2, "Debris Drywell Transport Study," Draft Phase 1 Letter Report, September, 1996.

Problem Definition: In Reference D.1, the BWROG proposed the following correction factors to account for reduction in jet volumes corresponding to the recirculation line break, as a function of the target load:

Insulation Destruction Pressure (psi)	Correction Factor for Recirc. Line Break
0-20	1.0
20-30	0.9
30-40	0.8
40-50	0.7
50-60	0.5
>60	0.4

The basis for developing this table is documented in References D.2 and D.3. The staff performed the following calculations to evaluate the appropriateness of these factors. The ANSI/ANS 58.2 model (Reference D.4) was again used as a basis for the calculations. The results are as follows.

Jet Volumes Corresponding to Subcooled Water Discharge: Immediately following a LOCA, subcooled water exits the break and expands into the containment. Past computer runs using the RELAP code (Reference D.7) suggest that subcooled blowdown occurs over a period of 5-10 seconds, during which exit quality of the break jet increases from 0 to 0.02 while the vessel pressure decreases from 1000 to 700 psi. Figures C.1 and C.2 in Appendix C of this SER show expanding jet isobars for flashing subcooled water discharged during this initial stage of a postulated DEGB in a recirculation line. Figures C.3 and C.4 from that appendix compare the volumes of jet bounded by each impingement load isobar for steam and recirculation line breaks with URG predictions provided in Reference C.1. Reference C.1

predictions are derived from the information presented in the table above. As shown in these figures, during subcooled water blowdown, the corresponding jets tend to be less energetic. For recirculation line break jets, the staff's confirmatory analysis estimated volume ratios consistent with the fractions listed above.

On that basis, the staff concludes that the values presented in Appendix A to Reference D.3, "Volume of Influence for Saturated Steam Versus Saturated Water," Revision B, are reasonable. The staff also notes that past debris generation data reported by European investigators also supports this finding.

Jet Volumes Corresponding to Two-Phase Mixtures: After initial blowdown, the exit quality increases steadily; thereafter, the blowdown at the exit plane consists of two-phase mixtures (Reference D.7). Jet impingement loads associated with such flows were experimentally measured in the Marvekian tests (Reference D.5). Moody has proposed a scaling scheme which justifies the use of this Marvekian test data to BWRs. The scaling criterion is acceptable, and as such that data has been widely used for similar purposes before (e.g., References D.5 and D.6). However, the URG does not explain in a tractable manner how the Marvekian test data are used to corroborate the correction factor table presented above. As a result, the following analysis was performed.

The pressures reported in the Marvekian tests can be tabulated as shown in Table D-1. A plot of JCL pressures (in column 9) versus L/D is presented in Figure D.1 for three types of blowdowns: subcooled liquid, steam/liquid mixture, and steam. A review of Figure D.1 suggests the following:

- Stagnation pressures near the nozzle would be higher for subcooled breaks over a narrow radial range.

- Far from the nozzle, for L/D > 4, the stagnation pressure is higher for steamline breaks as compared to both subcooled and saturated liquid breaks.

- However, mixture and steamline breaks look somewhat similar thereafter.

These trends are well established and have been explained using the K-FIX code in Reference D.5, and using the CSQ code in Reference D.6. Therefore, Figure D.1 can be used to conclude that mixture blowdown at a given stagnation pressure is no more severe than steam blowdown from the same stagnation pressure. Coupled with the fact that actual vessel stagnation pressure falls to about 700 psia before the onset of two-phase mixtures, this finding was used to compute the load isobars for mixture jet expansion during blowdown. Figure D.2 illustrates the isobars. Comparison of isobars presented in Figure D.2 with those presented in Figure C.1 would clearly establish that pressures associated with two-phase blowdown are considerably lower than steam blowdown.

Further calculations were performed to corroborate the correction factors listed above. These calculations support the conclusion that the correction factors cited above from the URG do conservatively bound the jet volumes. Therefore, the staff concludes that use of these correction factors is acceptable.

Table D-1 A Summary of Marvekian Test Data for Blowdown

Test	L/D	Time	Thermodynamic		Vessel Pressure		JCL	Ratio of
		(s)	Descrpt.	ΔT (°C)	Range	Average	(MPa)	JCI/Stag.
10	1.2	0-29	Subcool	0-23	4.3-3.1	3.7	3.7	1
		29-45	Mixture	x > 0.10	3.1-2.5	2.8	1.12	0.4
		52-55	Steam	x = 1.0	1.5-1.1	1.3	0.78	0.6
8	2	0-25	Subcool	0-23	4.3-3.2	3.75	1.875	0.5
		25-44	Mixture	x > 0.10	3.2-2.9	3.05	0.61	0.2
		49-55	Steam	x = 1.0	2.0-1.1	1.55	0.465	0.3
7	4	0-25	Subcool	0-23	4.4-3.2	3.8	0.38	0.1
		25-43	Mixture	x > 0.10	3.2-2.8	3	0.375	0.125
		48-55	Steam	x = 1.0	2.1-1.1	1.6	0.28	0.175

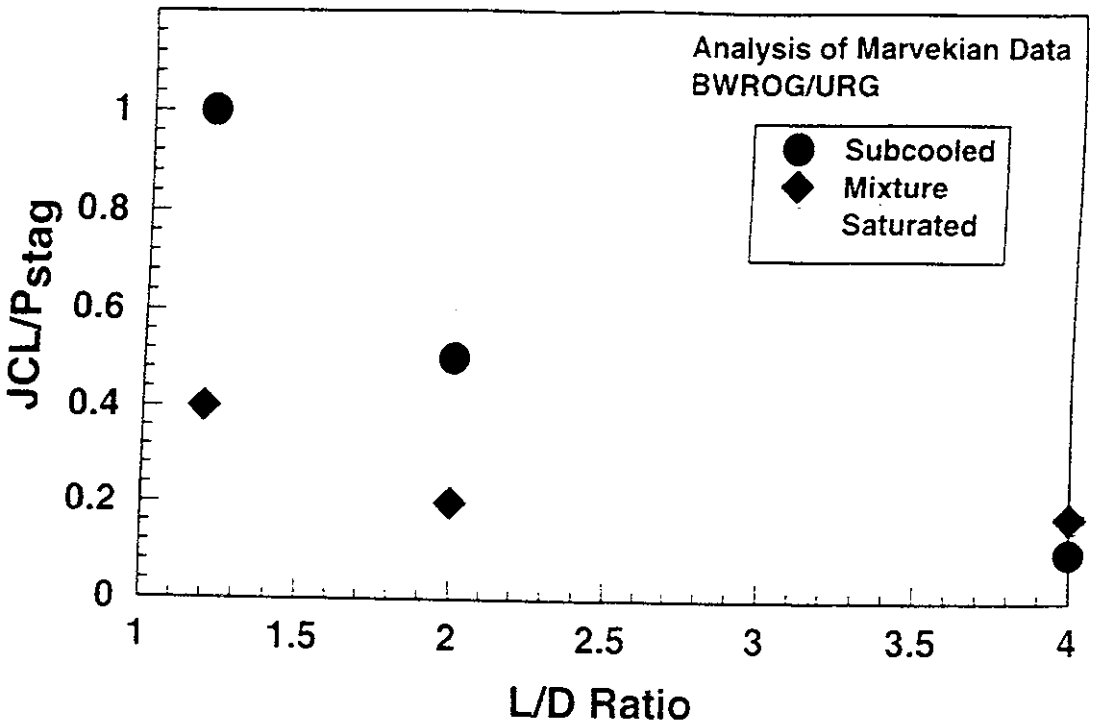


Figure D.1 JCL Pressure vs. L/D

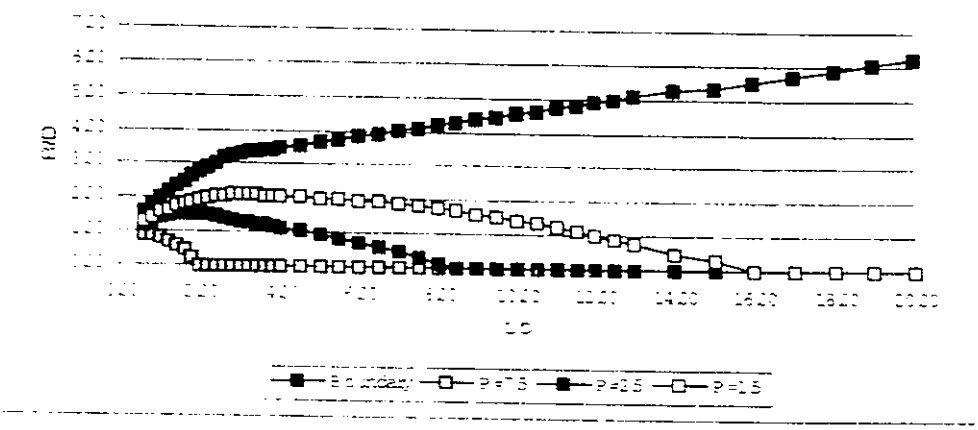


Figure D.2. Jet Impingement Load Isobars for Two-Phase Mixture Jets that Result During Late Stages of a Recirculation Break LOCA.

Appendix E

Calculation to Examine the URG Guidance on Thin-Bed Effect on Alternate Strainer Designs

References:

E.1 URG, Section 3.1.3, Page 16, Line 7.
E.2 URG, Section 3.2.1.1.1, Page 28, Line 12.
E.3 URG, Section 3.2.6.2.3, Page 117, Line 24.
E.4 Appendix I to CDI Report 95-09, "Testing of Alternate Strainers with Insulation Fiber and Other Debris," CDI, URG Technical Support Documentation, Volume I, Tab 2.

Problem Definition: In References E.1, E.2, and E.3, the URG presents the following statements:

- The thin-bed effect is an issue for semi-conical strainers, but not for stacked disc strainers or any other "alternate strainers."

- Therefore, licensees that propose to use alternate strainer designs need not analyze medium LOCAs, because they are not limiting relative to debris generation and transport.

As a result, the staff performed a series of data comparison analyses to evaluate the completeness and accuracy of the URG statements regarding thin-bed effects.

Results: The ability of thin fiber beds to trigger large pressure drops when combined with particulates (e.g., corrosion products, dirt, etc.) has been demonstrated by both the Perry and Limerick events. Studies by the NRC, European regulatory agencies and the BWROG have focused on characterizing the thin-bed effect. Figure E.1 provides a sketch of the "thin-bed effect" as it relates to head loss across the strainer. As shown in this figure, at very low thicknesses (<1/8") the strainer surface is partially covered by fibrous shreds. Corresponding to this situation, the head loss across the strainer is low. With a slight increase in the thickness, the strainer is more uniformly occupied and starts to filter out some of the particulate debris passing through the debris bed. However, as experimentally evidenced, these beds break down or undergo reconfiguration under the influence of the larger head losses caused by the particulate filtration (See NUREG/CR-6224, Appendix-E). This trend continues until the bed gains the strength necessary to sustain head losses. Thereafter, the head loss increases rapidly as the thin fiber bed continues to filter out a large fraction of the particulate debris. The resulting debris is characterized by a very dense, relatively impervious, particulate bed formed by a relatively small number of fibers. At higher fibrous debris bed thicknesses, this trend reverses because the debris bed starts to become more porous.

The thin-bed effect has been widely observed for flat-plate, cylindrical, and semi-conical (truncated cone) strainers. Table E-1 shows the URG data for semi-conical strainers demonstrating the effectiveness of thin-beds to introduce large head losses. As can be readily seen from this table, high head losses across the strainer are possible at very low insulation loading when coupled with large corrosion product (sludge) mass. These data confirm the high head losses reported in the Limerick and Perry events.

Proving existence or non-existence of a thin-bed effect in stacked-disk strainers is more complex. Figure E.2 illustrates the debris bed buildup on a stacked disc strainer surface. When the cavities of the strainer are partially filled, a substantial portion of the strainer surface is still open for particulate flow without being filtered. For these situations, the BWROG experimental data (see Table E-2) have shown that the thin-bed effect is not an issue. Even for the case when the cavities are nearly full, there has not been a drastic increase in head loss, in spite of large sludge-to-fiber mass ratios. However, this does not absolutely rule out occurrence of the thin-bed effect in stage 3 of Figure E.2. The BWROG has not reported any experimental data supporting their conclusion of "no thin-bed effect" during this stage, as all of the reported data in the URG apply to stages 1 and 2 of Figure E.2. Although Test P5 provides data for the case when the insulation goes beyond the cavities, it is one single data point and corresponds to a rather thick insulation layer (3-inch theoretical thickness).

Table E-1 Experimental Head Loss Data for Truncated Cones

Test ID	Insulation Mass (lbm)	Bed Thickness (inch)	Sludge Mass (lbm)	Mass Ratio	Head Loss (in H_2O)
6	0.5	0.14	500	1000	425
7	1	0.28	60	60	385
8	3	0.83	16	5	>500
		Strainer Surface Area = 18 sq. ft			
		Strainer Flow Rate = 5000 GPM			

Table E-2 BWROG Head Loss Data for Stacked-DisK Strainer.

Test ID	Strainer Type	Cavity Volume (ft3)	Insulation Mass (lbm)	% Cavity Occupied	Sludge Mass (lbm)	Head Loss (in H_2O)
21	Stacked-Disk #1	3.53	1	11.8	180	23
22	Stacked-Disk #1	3.53	3	35.4	180	65
22	Stacked-Disk #1	3.53	3	35.4	240	72
22	Stacked-Disk #1	3.53	4	47.2	240	250
23	Stacked-Disk #1	3.53	6	70.8	240	350
P2	Stacked-Disk #2	10	17	70.8	85	7
P3	Stacked-Disk #2	10	25	104.2	100	10
P4	Stacked-Disk #2	10	3	12.5	100	0
P5	Stacked-Disk #2	10	50	208.3	100	28
	In P5 the insulation goes beyond the cavities. The rest of the insulation forms a uniform layer 3-inch thickness.					

The staff performed additional exploratory calculations to evaluate the question of whether licensees who propose to use an alternate strainer designs (e.g., stacked-disk strainer) should

analyze MLOCAs. Calculations performed for NUREG/CR-6224 for an MLOCA postulated in the reference plant (BWR 4, Mark I) with an assumed drywell transport factor of 1.0 for transportable debris, resulted in an insulation debris volume on the strainer of 24 ft^3 (or a mass of 10 lbm). The BWROG data clearly suggest that both stacked-disk number (no.) 1 and stacked-disk no. 2 can accommodate such debris loads with sludge-to-fiber mass ratios of up to 30 without a noticeable increase in head loss (see data for Test P4). Therefore, the staff believes that MLOCAs can be screened out if stacked-disk strainers are used.

On the basis of the above analyses, the staff draws the following conclusions:

- The BWROG claim that thin-bed is not observed in alternate strainers is not adequately substantiated. The reported data apply to two strainer designs (stacked-disk and star). In addition, the data address a narrow range of experimental parameters.

- The existing data, however, suggest that licensees may screen out MLOCAs if they use stacked-disk strainer no. 2, star strainers, or other such strainers with large cavity (crevice) capacities for debris buildup (which prevent even debris bed buildup across the strainer surface at low fibrous debris loads) provided that the strainer vendor can demonstrate that debris loadings lower than the bounding large break LOCAs (e.g., loadings consistent with a spectrum of breaks from MLOCAs to large LOCAs) would not be limiting in terms of head loss across the strainer. Strainer vendors should have adequate test data to support this assurance.

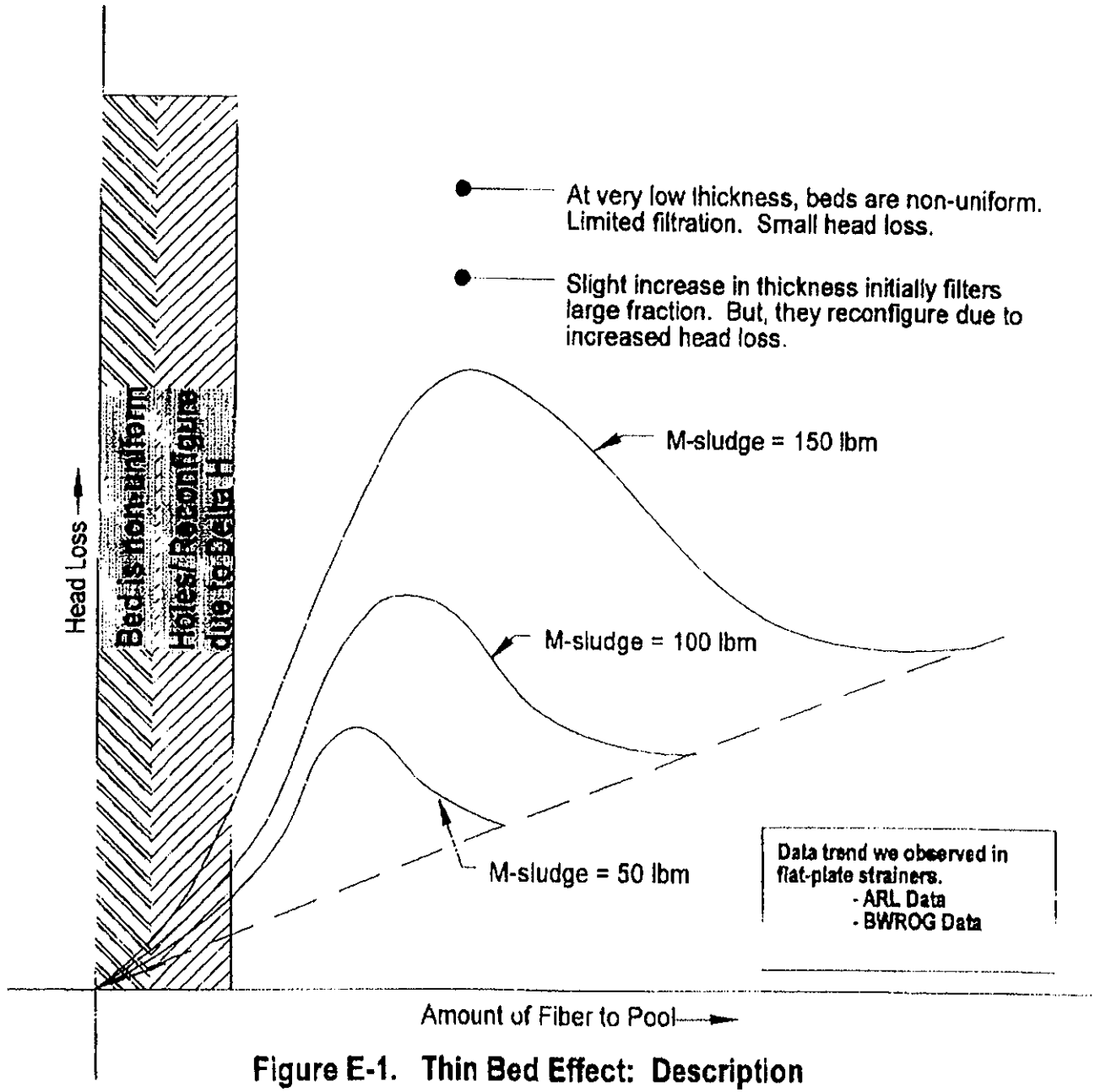
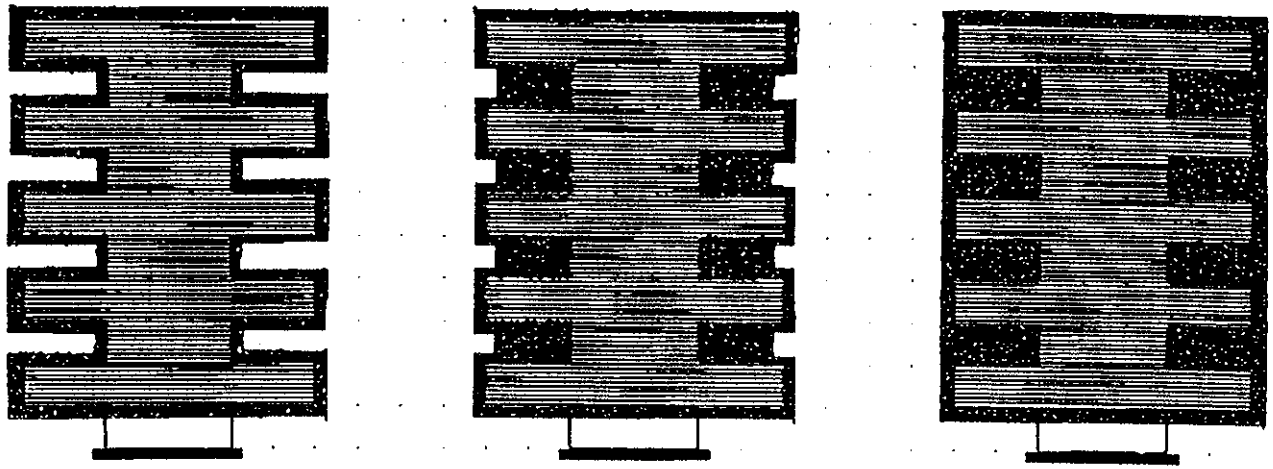


Figure E-1. Thin Bed Effect: Description

Figure E-2. Description of Debris Buildup on Stacked Disc Strainers



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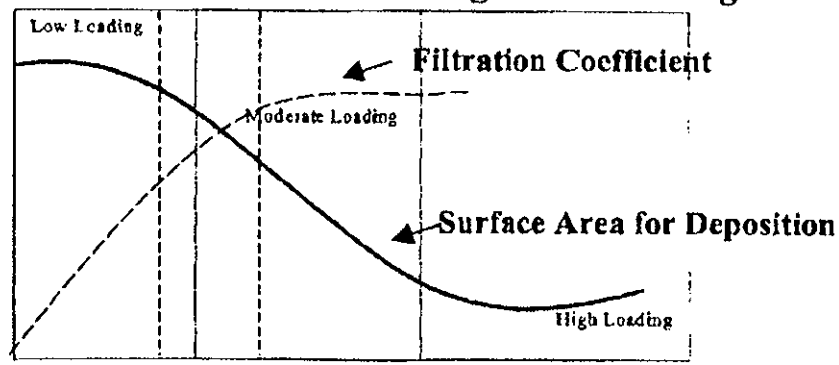

Fiber Volume

Appendix F

Mapping of the Zone of Influence

References:

F.1 URG, Section 3.2.1.3.2, "Method 2 - Target Based Analysis Using Limiting Size Zones of Influence."

F.2 CDI Report No. 96-06, "Air Jet Impact Testing of Fibrous and Reflective Metallic Insulation," URG Technical Support Documentation, Volume II, Tab 3.

Problem Definition: In Reference F.1, the URG stated that:

- A spherical ZOI should be used to define the geometrical region over which damage to the insulation blankets would occur.
- For fibrous insulation (e.g.,NUKON®), this region is as large as 10 break-diameters in radius.

Neither of these assumptions were fully substantiated by the BWROG. Furthermore, the BWROG stated that these assumptions would yield conservative estimates of the ZOI since the assumptions ignore the presence of pipes and other structural impediments. A series of computational fluid dynamic simulations of the jet expansion with and without structures were conducted to verify the adequacy of the BWROG recommendations.

Methodology: In the URG, information is provided related to experiments that were conducted to determine the failure pressure for NUKON® insulation cassettes; both encapsulated and non-encapsulated. These experiments reveal that damage is possible when the local total pressure exceeds 10 psi. Considering that downstream of shock-front, total pressure is made up entirely of the dynamic pressure, the local flow velocity that would be capable of inflicting damage can be calculated as follows:

$$P_{dynamic} = \tfrac{1}{2} \rho V^2 / g_c$$

Where,

ρ = gas (air) density at near-atmospheric conditions that exist downstream of shock (lb/ft3)
V = gas velocity (ft/s)
g_c = conversion factor (32.12 lbf/lbm)

After appropriate unit conversions, the velocity corresponding to damage pressure is

$$V^2 = (10)(32.12)(144)(2)/(0.067)$$ [7]

[7] The density was derived from the CFD calculations conducted as part of this study. This took into account the combined effects of lower than atmospheric pressures and temperatures in the jet.

V=1175 ft/s (or 358 m/s)

Thus, damage is possible whenever the jet velocity exceeds 1175 ft/s, although, more conservatively, damage can be assumed for velocities in excess of 985 ft/s (300 m/s).

The general method followed by the staff in this calculation is:

- CFD calculations were conducted to examine velocity fields in a freely expanding jet. These calculations were used to provide a reference case and also to compare the results with the BWROG results in References G.1 and G.2.

- Using the CFD calculations, the impact of adding structures in the pathway of the jet were examined, up to the congestion levels typical of BWR drywells.

Results and Discussions

Calculation no. 1: Define the spherical region dimensions in the ZOI as recommended by the BWROG?

For Steel Jacketed NUKON®:

P_{dest} for NUKON® in Table 2 of the URG = 10 psi
Extract A from Table 1 of the URG (as predicted by step #3): A = 4708
Volume of the ZOI; $V = 4708\ D^3_{Nozzle}$
D_{Nozzle} = 24 in. (or 2 ft.)
V = 37, 664 ft^3; which is about 25% of the drywell volume.
In terms of equivalent sphere: $R^3 = ½\ (4708*6/\pi)D^3$; $R = 10.4\ D_{Nozzle}$

The radius of the spherical region is 10.4 times the diameter of the break. These are large spheres compared to NUREG/CR-6224 and any other volumes previously used. This is used as the reference case for judging the conservative nature of BWROG recommendations.

Calculation no. 2: Check the adequacy of the pressure fields for freely expanding jet predicted using the BWROG methodology?

To examine this, the air jet originating from a 8-in (20-cm) diameter nozzle was allowed to expand freely into a 160-in (400 cm) diameter cylinder (20D), 160-in (400 cm) in length (20D). The inlet to the nozzle was air at a pressure of 600 psi and sonic velocity (965 ft/s or 300 m/s). The expanded jet flow fields are calculated using the following computational details:

ΔR = 3 cm; ΔZ = 2.5 cm; $\Delta\theta = 45°$ [8]
Typical time step = 10^{-5} to 2.5x 10^{-5} seconds (lower time step initially)
Typical Execution time = 12-14 hrs CPU for 0.15 seconds of real time

[8] ΔR, ΔZ, and $\Delta\theta$_radial, axial and angular nodal lengths used in the discretization.

The results of the CFD simulations are illustrated in Figure 2a of this appendix. As shown in this figure, freely expanding jets resemble semi-conical regions as described in NUREG-0897. The static pressure approaches atmospheric pressure within 1-2 break diameters and remains steady thereafter. The local fluid velocity increases initially reaching values as high as 2790 ft/s (850 m/s). However, this reduces to slightly above 985 ft/s (300 m/s) at a distance of above 10D and remains fairly constant up to and well beyond 20D. This confirms the behavior described in the URG. Thus, it is likely that high flow velocities would be maintained at very long distances for a freely expanding jet. Figure 2b of this appendix shows flow velocity isomers for a freely expanding jet. The dynamic pressures calculated in the present study are slightly below those in Figure 9 of Reference 2.

Calculation no. 3: *Examine the impact of adding a simple structure such as a grating in the jet path?*

To examine the impact of a single grating-like structure, a baffle plate is artificially introduced into the calculation domain. The structure was denoted to be with an area blockage of 20%, and pressure drop characteristics given by

$$\Delta P = 0.125\ (\rho V^2/g_c) \quad [9]$$

This case is shown in Figure 3a of this appendix, with the predicted flow fields shown in Figure 3b of this appendix. As shown here, the presence of a single grating can considerably alter the flow fields, such that flow velocities downstream of the grating are reduced well below the 985 ft/s (300 m/s) necessary to inflict damage. Thus, gratings can provide considerable "shadowing" effect. However, it is not clear, if the gratings can withstand such loads. (Note that gratings are not load-qualified structures.)

Calculations no. 4: *Examine the impact of pipes and I-beams arranged in a manner similar to those commonly encountered in BWR drywells?*

To examine this issue a total of five structures were introduced in the pathway of the expanding jet. As shown Figure 4a of this appendix, these structures include:

- A 8-in (20-m) diameter pipe located in the centerline of the break jet to simulate the effect of the other end of the broken pipe.
- Three pipes, each 20 cm in diameter and located in the pathway of the jet, considerably offset from the JCL.
- One pipe anchored on an I-beam; the pipe is 8-in (20-cm) in diameter and I-beam is 8-in (20-cm) in height.

At any given axial location, flow area averaged blockage is less than 40%. The degree of congestion is consistent with the values identified from a survey of BWR drywells. To

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[9] The value of momentum loss coefficient (0.125) was calculated from hand-calculations using approximations. This value, if at all, under predicts pressure drop and is, thus, conservative.

minimize computational effort, the pipes were not modeled in detail[10]. The results of the CFD simulation are shown in Figure 4b of this appendix. As shown in this figure, higher than 985 ft/s (300 m/s) velocities were observed at distances close to the break opening. However, farther from the break, flow velocities decreased considerably. Resulting velocities are well below the velocities required to inflict damage to the insulation blankets.

To further confirm this finding, the following variations were added:

- A cavity was added to create a narrow region that closely resembles the neck region of the drywell. This case was created to analyze breaks postulated in the neck region of the drywell. (See Figures 4.c and 4.d of this appendix)

- The boundary conditions were altered to simulate Mark II drywells. (See Figure 4.e of this appendix)

In all these cases, pipes and I-beams were found to have resulted in dispersal of the air jet over a substantially larger cross-section. The resulting flow velocities outside a spherical region 7D in radius were considerably lower than the 985 ft/s (300 m/s).

Conclusions: A series of CFD simulations were carried out to examine the impact of drywell structures on the ZOI. It is not the intent of these calculations to address this issue comprehensively. Instead, the focus had been to obtain order of magnitude estimates of jet dispersion when subjected to drywell structures. The results of the calculations described above should not be interpreted as "best-estimate" predictions. They were conducted for insights only.

These calculations suggest that use of a spherical ZOI is appropriate, since it tends to better approximate the jet expansion in a congested drywell volume. They suggest that presence of structures, such as pipes, I-beams and gratings would disperse the jet. As a result, the jet velocities outside the spherical ZOI with a radius of 7D are lower than those required to inflict damage to the insulation blankets. Thus, use of a 10D sphere by the BWROG (as shown in calculation no. 1 above) in the sample problem is considered conservative and appears reasonable.

It should also be recognized that conclusions reached are subjected to the following assumptions:

- Levels of congestion ("piping forest") is limited to a narrow region closer to the break. Addition of structures beyond this region would further reduce velocities.

- The structures were not modeled exactly using CAD drawings of the plants.

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[10] An additional computation suggested that this is not a major issue.

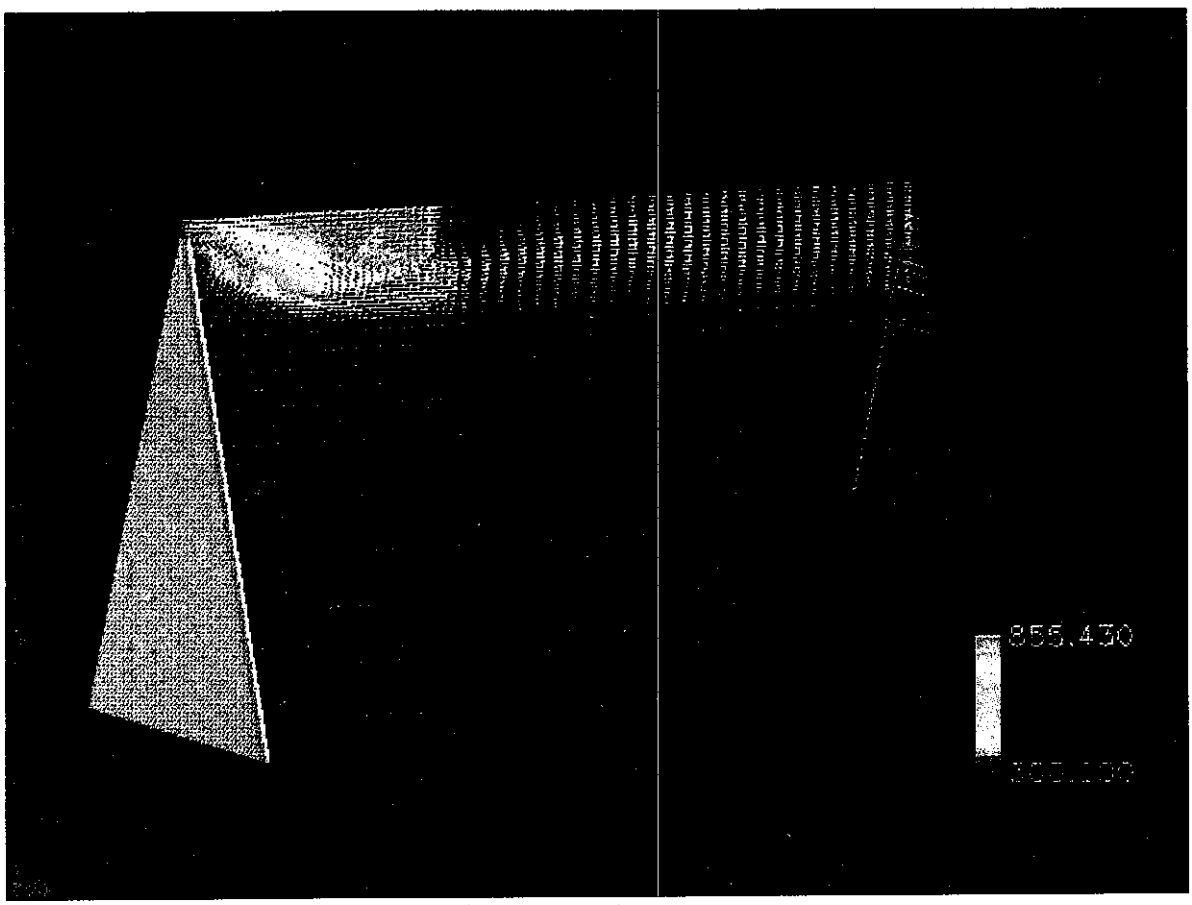

Figure 2a. Velocity Fields in a Freely expanding jet. [The Nozzle diameter is 20 cm. The volume of the computational area: 400 cm Diameter Cylinder, 400 cm in length. The time step 10^{-5} seconds. Reported flow fields are for a quasi-steady state. These are the flow fields most likely encountered in the BWROG Experiments at CEESI; High velocities far from the nozzle exit].

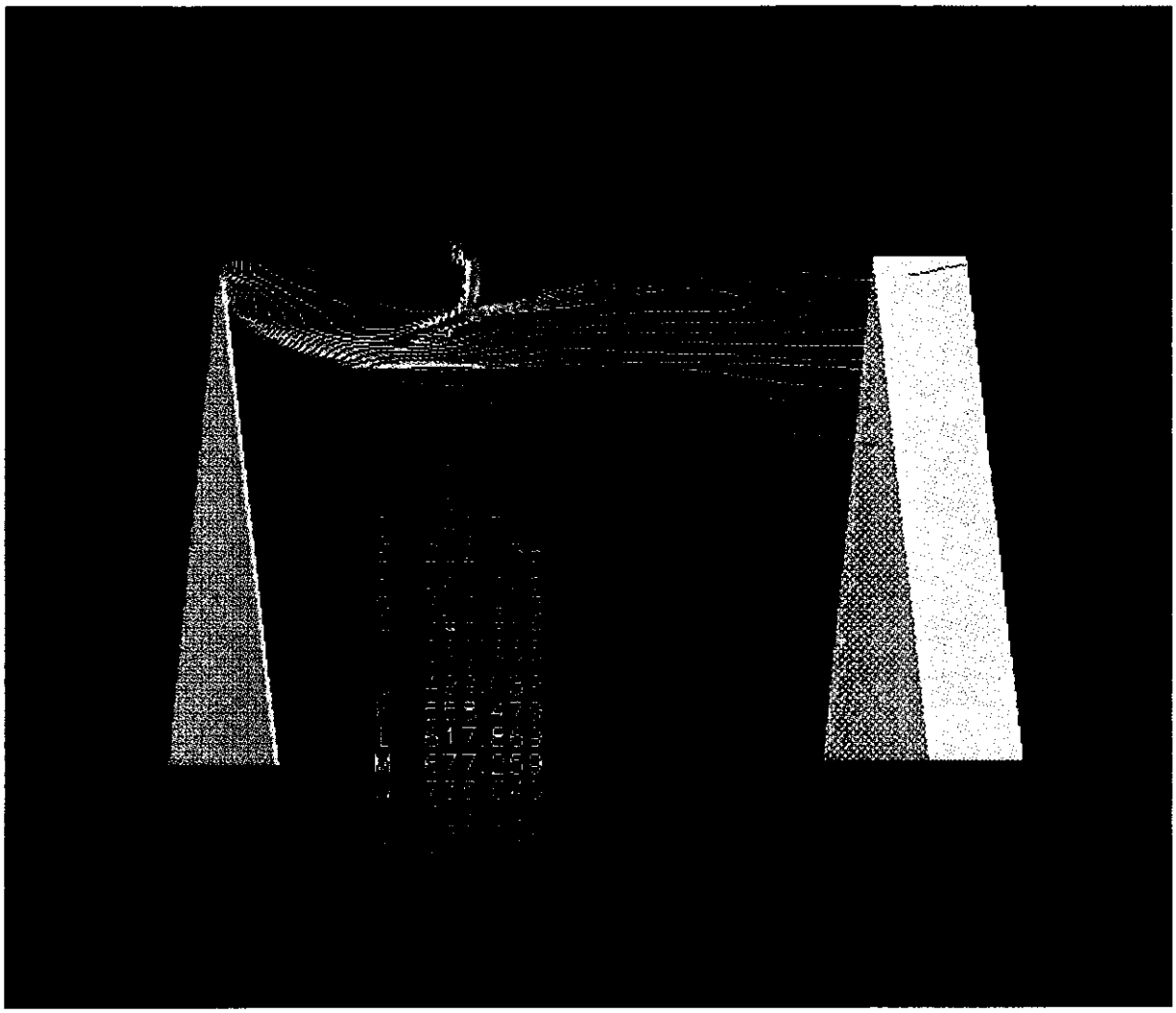

Figure 2b. Velocity contours in a freely expanding jet. [The associated dynamic pressure can be calculated as $P = \frac{1}{2} \rho V^2/g_c$. At a velocity of 380 m/s, the dynamic pressure is 10 psi; which is the damage pressure for NUKON. This calculation confirms that for distances beyond 20 D, the velocities within the jet would be fairly uniform, it covers the blanket completely, and pressures exceed 10 psid.]

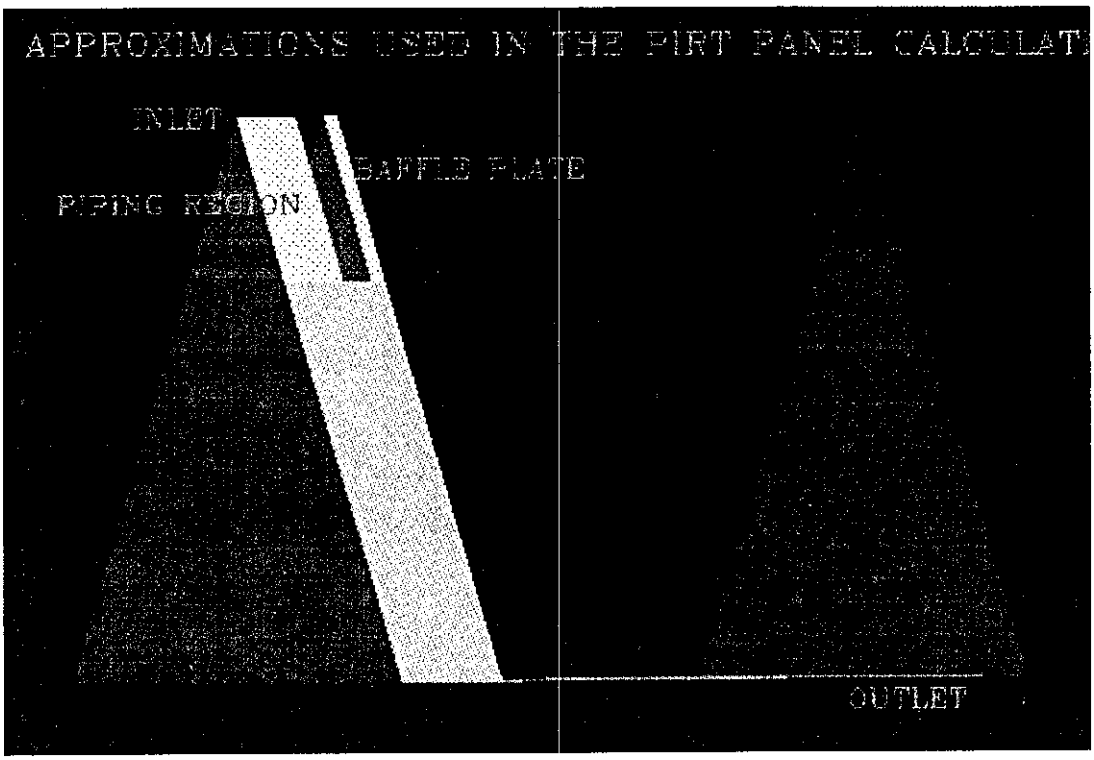

Figure 3a. Geometry used to simulate the effect of a single grating on the expansion of a air jet. The piping region was not used in these calculations. The Baffle Plate Approximation was used to simulate the floor grating. The baffle plate was assumed to have a blockage of 20% and a non-linear head loss coefficient of 0.125. The coefficient was chosen conservatively based on measured experimental data as well as hand calculations.

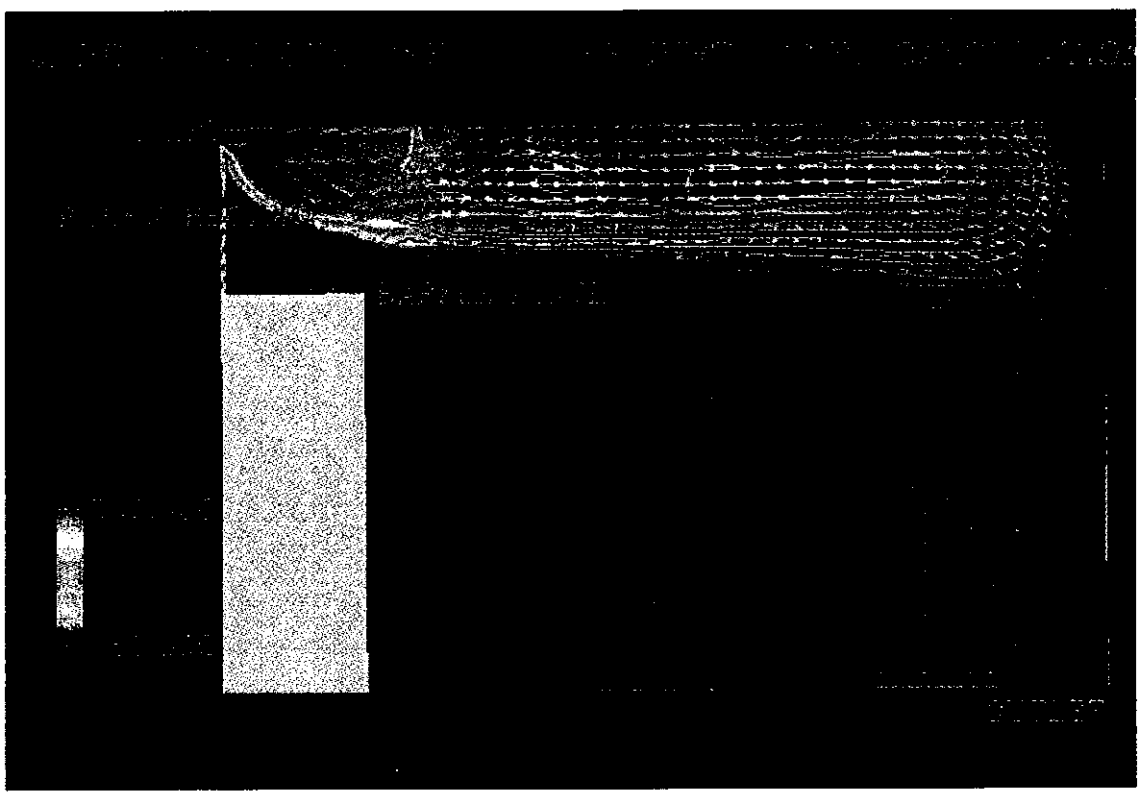

Figure 3b. Flow velocity fields and contours high lighting the impact of adding a baffle plate in the jet expansion pathway. As shown here, the flow velocities downstream of the baffle plate are less than 300 m/s. The velocities upstream are supersonic. The jet is wider. Comparison with Figure 2a would reveal that a single grating can substantially alter jet expansion, both upstream and downstream of the grating.

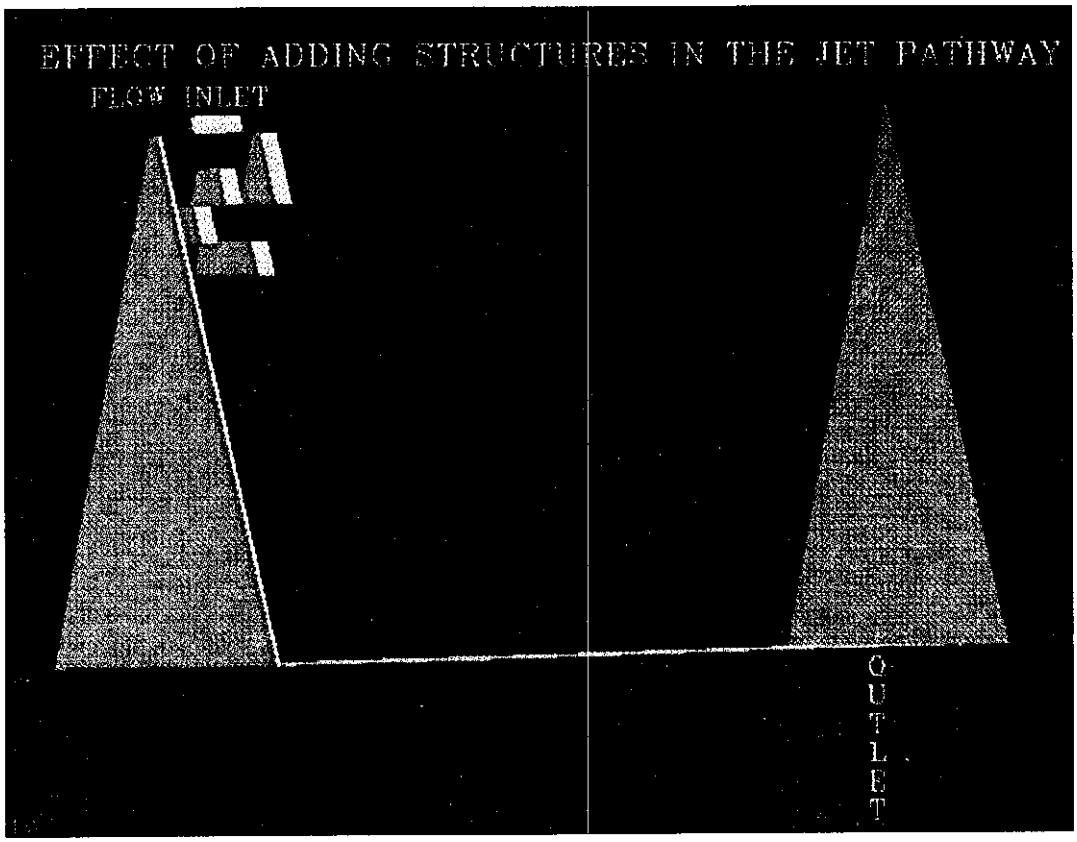

Figure 4a. A geometry used to study the impact of structural impediments to jet expansion. A total of five structures were added. The maximum blockage was 40%. These structures were assumed to have symmetry around jet center line. The flow outlet was assumed to be on the sides, to simulate a Mark I geometry.

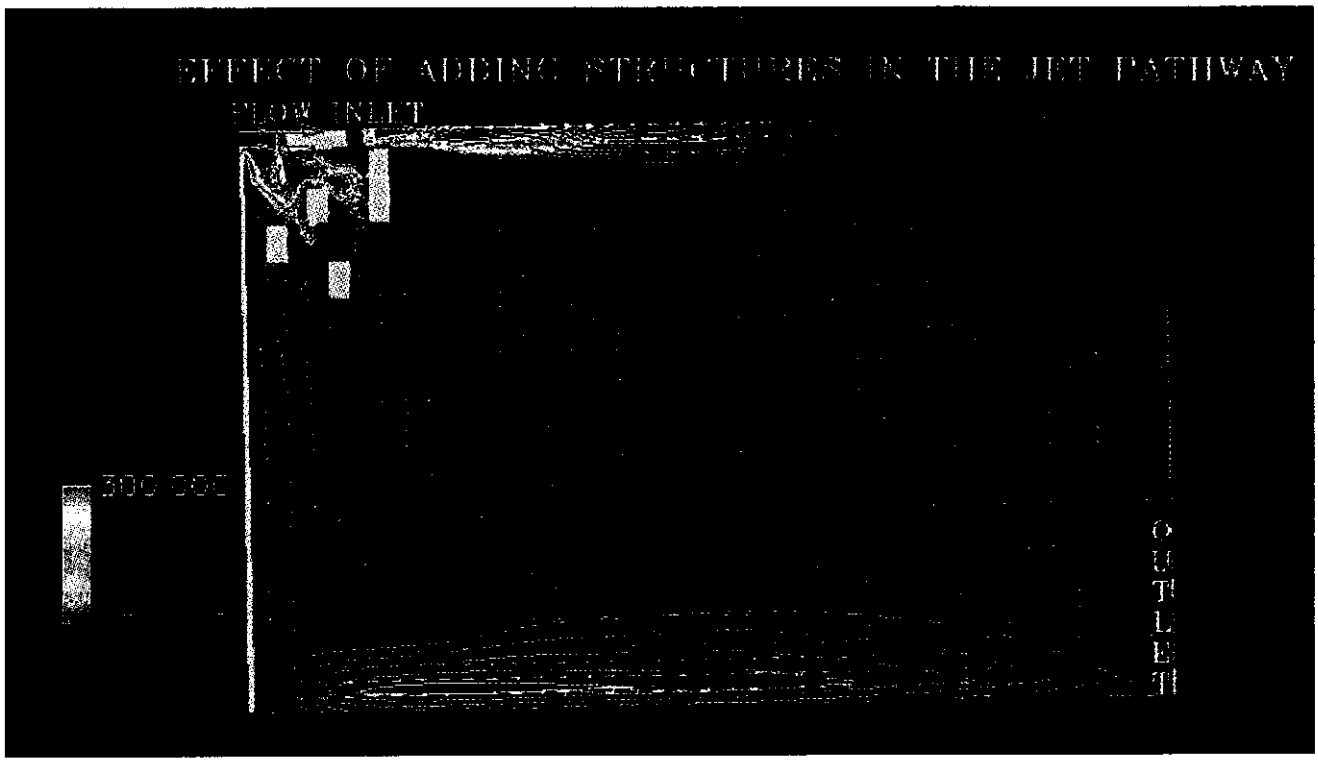

Figure 4b. Flow fields corresponding to geometrical case shown in Figure 4a. As shown here, local flow velocities much lower than 300 m/s characterize majority of the flow area. High flow velocities are confined to the 'piping forest' region. There also, some of the structures are not subject to high flow velocities, because of 'shadowing' effect.

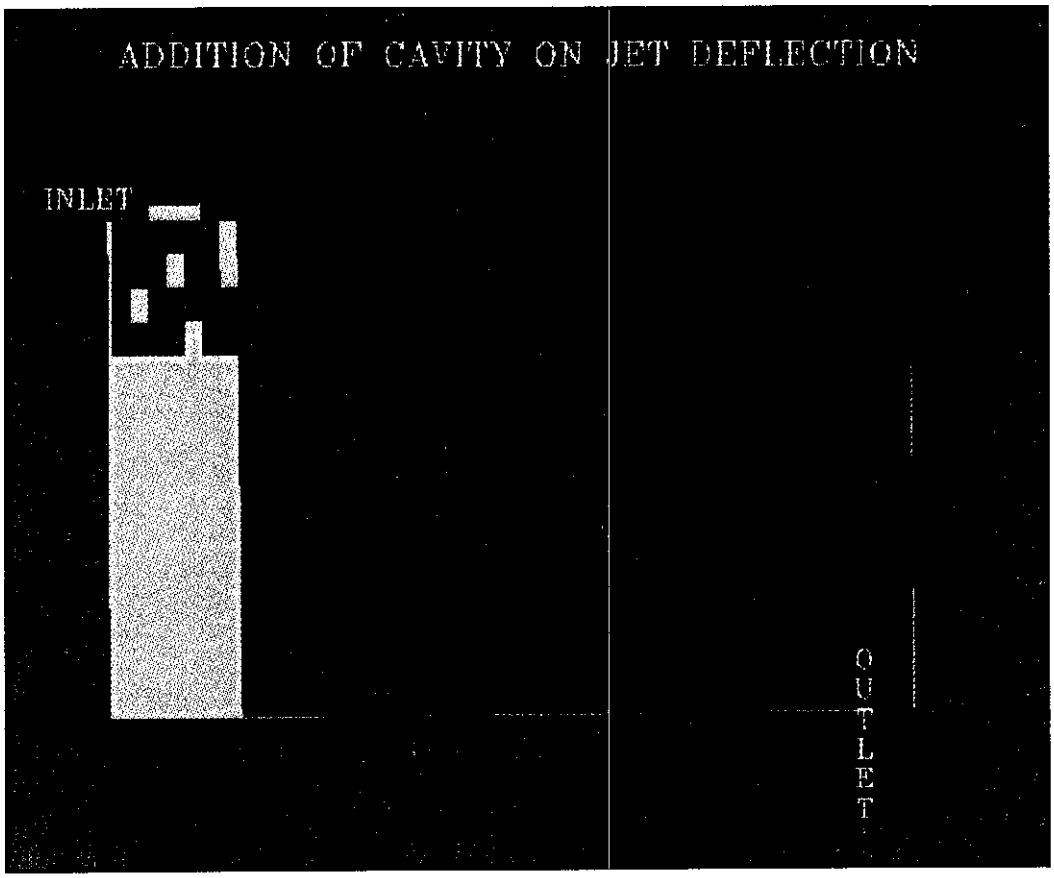

Figure 4c. The geometrical configuration used to simulate a postulated break in the neck region of a Mark I BWR containment. An axial cavity was added to the geometrical arrangement shown in Figure 4a to simulate the 'narrow' neck region. Otherwise, the geometrical arrangement is essentially same as Figure 4a.

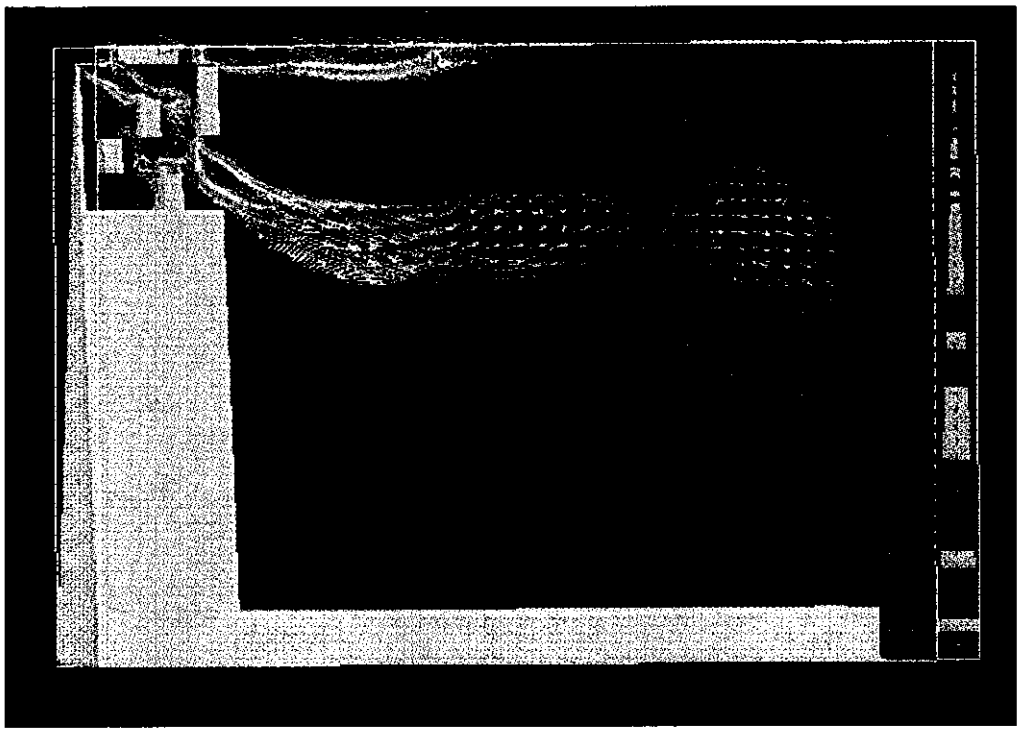

Figure 4d. Flow fields corresponding to geometrical case shown in Figure 4c. The flow outlet in this case is through the sides to simulate a Mark I drywell. Break is in the neck region.

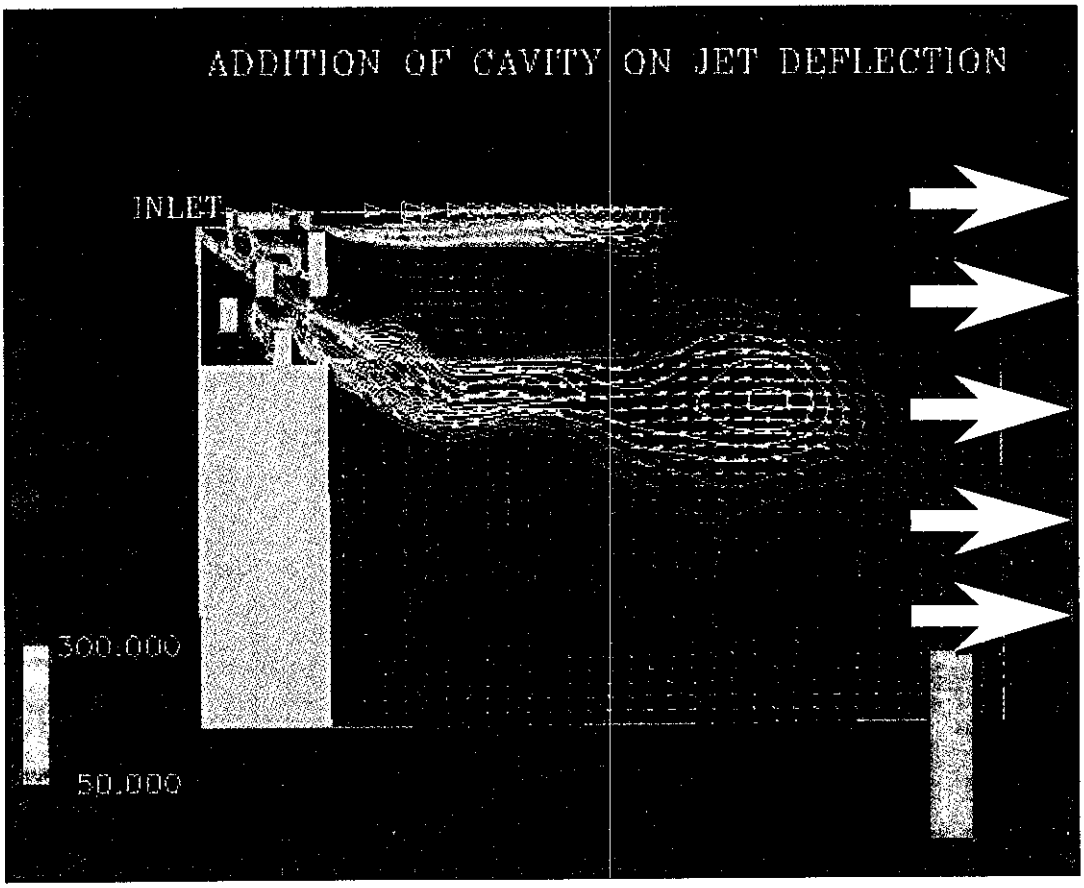

Figure 4e. Flow fields corresponding to geometrical case shown in Figure 4c. The flow outlet in this case is through the end to simulate a Mark II drywell.

Appendix G

Calculations to Evaluate the URG Methods to Estimate the Quantity of Fines

References

G.1 URG, Table 4, Page 71.

G.2 CDI Report 96-05, "Testing of Debris Transport through Downcomers/Vents into the Wetwell," URG Technical Support Documentation, Volume II, Tab 2.

G.3 WBE Report No. 796-001, "Evaluation for Existence of Blast Waves Following Licensing Basis Double Ended Guillotine Pipe Breaks," Science and Engineering Associates, Inc., 1996.

G.4 CDI Report 96-06, "Air Jet Impact Testing of Fibrous and Reflective Metallic Insulation," URG Technical Support Documentation, Volume II, Tab 3.

G.5 Appendix-B to this SER, "Analyses to Verify Values of P_{dest} for Selected Materials Reported by BWROG and Suggestions for Development of Scaling Analyses," 1998.

Problem Definition: In Reference G.1, the BWROG recommended a set of "destruction factors" that can be used by licensees to estimate the volume of fine debris generated by a postulated LOCA. These destruction factors were derived based on the experimental data obtained at the AJIT, and were provided for each insulation as a volume averaged quantity to facilitate ease of use by licensees. A series of analyses were conducted to examine the acceptability of the recommended values, with particular emphasis on determining whether or not the destruction factors would result in either "conservative" or "reasonable" estimates for the quantity of fines produced. The focus of the analyses was the production of fines from NUKON® blankets, although the conclusions reached are considered valid for other insulation types also. The staff's confirmatory analyses consisted of the following steps:

- Analysis of BWROG experimental data and comparison with NRC-sponsored test data.
- Analysis of effects from other phenomena (e.g.: jet deflection by various structures).

Analysis of Air Jet Impact Testing (AJIT) Data on Size Distribution: Table G.1 presents percentage of fines generated (by mass) for NUKON® blankets as a function of the target distance from the jet nozzle (L/D), blanket jacket status and blanket seam arrangement. The fraction of insulation not destroyed, termed as η_B by the BWROG, is plotted in Figure G.1 (of this appendix) as a function of L/D for NUKON®. This figure is identical to Figure G.1 of Appendix E in Reference G.2, with the exception that an additional data point obtained for NUKON® with Sure-Hold bands is included. Also shown in the figure is the linear fit for the data proposed by the BWROG. A close examination of the data reveals that:

- Irrespective of the type of encapsulation, the fraction of the fines contained in the debris is only a function of the distance from the jet nozzle as long as the jet is energetic enough to peel off insulation immediately upon impingement. For example, insulation with no jacket at 5L/D resulted in the same debris fraction as that which was covered with stainless steel jacketing secured on the target pipe by "Sure-Hold" bands.

- The fraction of fines is a strong function of the location of the blanket seam with respect to the jet nozzle. One data point obtained for seam arrangement described as 3 o'clock (i.e., the seam directly in front of the nozzle) yielded the largest η_B or, the least number of fines.

- The BWROG's linear regression is a poor fit for the data, and fails to explain all the trends. The data suggest that the fraction of fines initially increases as a function of L/D from the jet nozzle until reaching a maximum at 30 L/D. The amount of fines decreases thereafter as a function of L/D.

Table G-1 AJIT Experimental Data for NUKON® Blankets.
[Fines (%) is percentage of fines by mass. ς_b of Reference G.2 is 100-Fines (%)]

Test	Jacketed	Seam	L/D	Fines (%)	η_B [Ref. G.2]	Blankets
5-2	No	9	5	25.4	74.6	48.8
31-1	Y. "Sure-Hold"	9k	7	22.0	78.0	70.0
3-1	Y. Standard	9k	20	46.3	53.7	0.0
5-1	No	3k	20	7.1	92.9	35.6
5-3	No	9k	30	60.0	40.0	31.3
2-1	Y. Standard	9	50	25.3	74.7	32.6
3-2	Y. Standard	9k	50	11.9	88.1	59.1
5-6	No	9k	50	28.0	72.0	33.5
5-5	No	9k	60.5	6.3	93.7	30.3
6-2	No	9k	80	2.0	98.0	92.0
6-1	No	9k	115.5	0.0	100.0	100.0
5-4	No	9k	119	0.0	100.0	100.0

Comparison with NRC Sponsored Testing: As part of its drywell debris transport study, the NRC conducted a series of debris generation/transport tests at the same CEESI facility that was used by the BWROG for the AJIT. Although the intent of the NRC tests was not to generate data regarding debris generation, a by-product of these tests included insights into debris generation. The exploratory tests employed a 3.75-in (9.5-cm) diameter nozzle, instead of the 3-in (7.6-cm) diameter nozzle used in the AJIT tests described above. The following findings of NRC tests are in qualitative agreement with the AJIT test data:

- The direction of seam with respect to the jet is the key factor that determines the quantity of fines generated by a break jet. If the seams are directly facing the jet, then the blanket tended to be blown away, and suffer only limited destruction. Very little fine debris were generated. This confirms the results of the data in BWROG test 5-1. The BWROG conducted most of its tests with the seam in the 9 o'clock position maximizing potential debris generation. Thus, the data are conservative.

- Only rarely did the quantity of debris generated exceeded 50% of the target insulation, irrespective of where the blanket is placed (i.e., L/D value) and its seam alignment. Additional banding (which is non-prototypical) and end plates were required to keep the blanket in place in order to generate fines in excess of 50%. In spite of these engineered features, the maximum fraction of blanket destroyed into fines is 60%. Thus, a value of 50% forms a realistic upper bound for the destruction factor for typical insulation mounting configurations used by BWR licensees. It is very unlikely that higher than 50% is possible.

- The destruction factors (or the percentage of fines) vary considerably with distance from the jet nozzle. Increasing the L/D initially increased the destruction factors, until they reached a maximum. Thereafter, they decreased with distance. This is consistent with the data plotted in Figure G.1.

Although a linear fit of the data is an easy solution, it is not consistent with the trends exhibited by the data. The data exhibit the following three distinct characteristics:

- Minimum Fine Debris Generation Reached at 0 L/D: As can be seen from Figure G.1 (of this appendix), η_B reaches a maximum of 80% as L/D approaches zero. This implies that about 20% of the debris would be fines. However, the staff believes that this result can be attributed to the 3-in (7.6-cm) diameter nozzle size used in the AJIT. Initially, for L/D < 10, air jets from the nozzle tend to remain focused. For a blanket located at 5 L/D, Figure G.2 (of this appendix) illustrates the radial pressure distribution of the exposed target blanket [References G.3, G.4, and G.5]. In addition, Figure G.3 of this appendix [Reference G.7] illustrates the peak and average pressures on the target blanket. The average pressure suggests that the blanket remains on the target pipe only for a short interval. During this short time, destruction occurs in the localized region of the blanket which is subjected to high pressures. As evident from Figure G.2, high pressures (> 50 psi) are confined to a circular area in the middle of the blanket that is approximately 2.5-3.0 nozzle diameters (D_{Nozzle}) in radius. If one were to postulate that all the insulation contained in this high pressure area would be pulverized into fines, the fraction of blanket destroyed into fines can be calculated as:

Fines (%) = $1-\eta_B$ = (Area over which high pressure jet impinges)/(total blanket surface area)

where,

Total Blanket Surface Area = $\pi(D_{target} + t_{blanket}).L_{blanket}$
Area over which high pressure jet impinges = $\pi(2.5D_{Nozzle})^2$
D_{target} = Diameter of the target pipe (12 in.)
$t_{blanket}$ = blanket thickness (3 in.)
$L_{blanket}$ = Length of the blanket (24 in.)
D_{Nozzle} = Nozzle Diameter (3 in.)

After substituting all the values, the total fraction of insulation in fines can be estimated to be about 16-22.5% (depending on the choice of $2.5D_{Nozzle}$ or $3.0D_{Nozzle}$).

At 20 L/D, it can be shown that the predicted percentage of Fines using the same formulae above would be close to 50%, because the jet area envelopes the entire front surface of the blanket.

The implication of this analysis is that the 20% minimum value for fine debris generation at 5 L/D is a reflection of the 3-in (7.6-cm) diameter nozzle used in these tests. If in the AJIT tests, the nozzle diameter had been increased, the percentage of fines produced would probably increase over this region. This was observed in the NRC tests where a 3.75-in (9.5-cm) diameter nozzle was used.

- Maximum Reached At 30 L/D: As can be seen from Figure G.3 (of this appendix), the average pressure on the target blanket decreases with distance from the jet nozzle, reaching about 15 psig at 30 L/D. As L/D increases, the time the blanket would spend on the target pipe before being blown off by the jet (blanket residence time), which is inversely proportional to the average pressure, increases steadily. Larger residence times would imply that there is more time for the high pressure to penetrate the blanket and cause damage to the blanket. Apparently, at a point where a combination of peak pressure greater than 17 psid and an approximate average pressure of 13 psid occur, the target blanket destruction reaches a maximum. This suggests that if the target blanket is exposed to an average pressure of approximately 17 psid, maximum target blanket destruction is possible. In addition, this destruction may result in debris generation which is about 60% fine debris. Note: the 60% fine debris generation is only slightly larger than 50% (the fraction of insulation that is actually exposed to the jet with the remaining 50% being shadowed by the target pipe).

- Decrease in Fines(%) at L/Ds > 30: As the target distance from the jet nozzle increases beyond 30 L/D, the peak and average pressures the target is exposed to decreases. Although the residence time for the target insulation blanket also increases with distance from the jet nozzle, beyond 30 L/D the lower the destructive force of the jet leads to less debris generation. Ultimately, a point is reached where the peak pressure cannot penetrate the outer jacketing, preventing the jet from damaging the insulation. As the peak and average pressures continue to reduce, therefore, the fraction of fines also decreases.

Conclusions of the Comparison: Analysis of the experimental data and its comparison with NRC sponsored test data suggests that use of a linear fit to derive volume averaged destruction factors does not properly scale the experimental data to drywell conditions. Nevertheless, the method employed has the following conservatisms[11]:

- All the data included in the analysis was obtained for a condition in which blanket seams are arranged in the 9 o'clock position. NRC-sponsored testing found that seam position alone can significantly impact debris generation, and the 9 o'clock position maximizes generation of fines.

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[11] It should be noted that the BWROG incorporated the blast effects by assuming that all the debris located in a spherical zone 3 nozzle-diameters in radius would all be destroyed into fines.

- The method completely ignores the impact of targets present in the path of an expanding jet.

Quantification of Conservatisms in the BWROG Recommended Values: In order to evaluate the magnitude of conservatism involved in the BWROG recommended values for debris generation, a series of calculations were performed using the NUREG/CR-6224 (SER Reference 31) reference plant as the basis for the case study. In the reference plant, NUKON® is used as the insulation on all primary piping. The ZOI computed for that plant (also see Appendix F to this SER) using Method 2 of the URG is a spherical region 10.2 break diameters (D) in radius.

For a recirculation line break postulated in the most congested region of the drywell, the total quantity of insulation contained in a 10.2 D sphere is approximately 750 ft^3. The volume averaged destruction factor suggested by the BWROG for NUKON® is 0.23. Total quantity of fines generated is 172 ft^3.

An alternative method for calculating the debris generated would be to assume that :

- 100% of the insulation would be destroyed in a spherical region 3D in radius due to the blast effects from the postulated double-ended guillotine break. This conservatively bounds the possible effects of the blast wave. As discussed in Reference G.3, the blast effects would most likely be bounded by a spherical zone 3D in radius. For the reference plant the volume of debris contained in a 3D sphere is 35 ft^3.

- 50% of the insulation would be destroyed between 3D and the outer boundary where the dynamic pressures fall well below 10 psi. As discussed in Appendix F, due to the presence of structures, the dynamic pressures subside considerably within the 7D sphere. For the reference plant, the quantity of insulation contained between 3D and 7D is 191 ft^3. Using a destruction factor of 0.5, the quantity of fines can be estimated as 95.5 ft^3.

The total quantity of fines generated would be 130 ft^3. This value is about the same order of magnitude as that recommended by the BWROG. The latter number still has the following conservatisms:

- It does not take into consideration the orientation of the seam with respect to the jet direction.[12]

- It does not give credit for less than 50% damage observed at lower impingement pressures.

Based on this analysis, it is concluded that destruction factor recommended by the BWROG would result in reasonable estimates for the fines.

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[12] Discussions with the insulation vendors and contractors suggest that no particular arrangement is followed to align the seams in a particular orientation. They are randomly arranged with respect any postulated break.

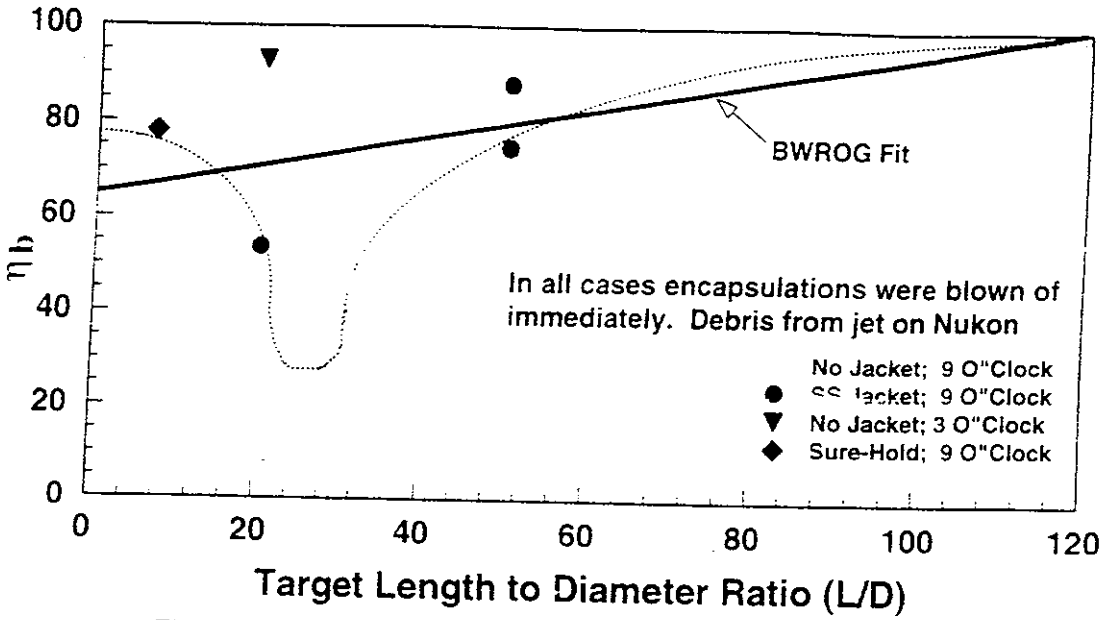

Figure G.1. Dependence of η_b on L/D Observed in AJIT [Ref. G.6]

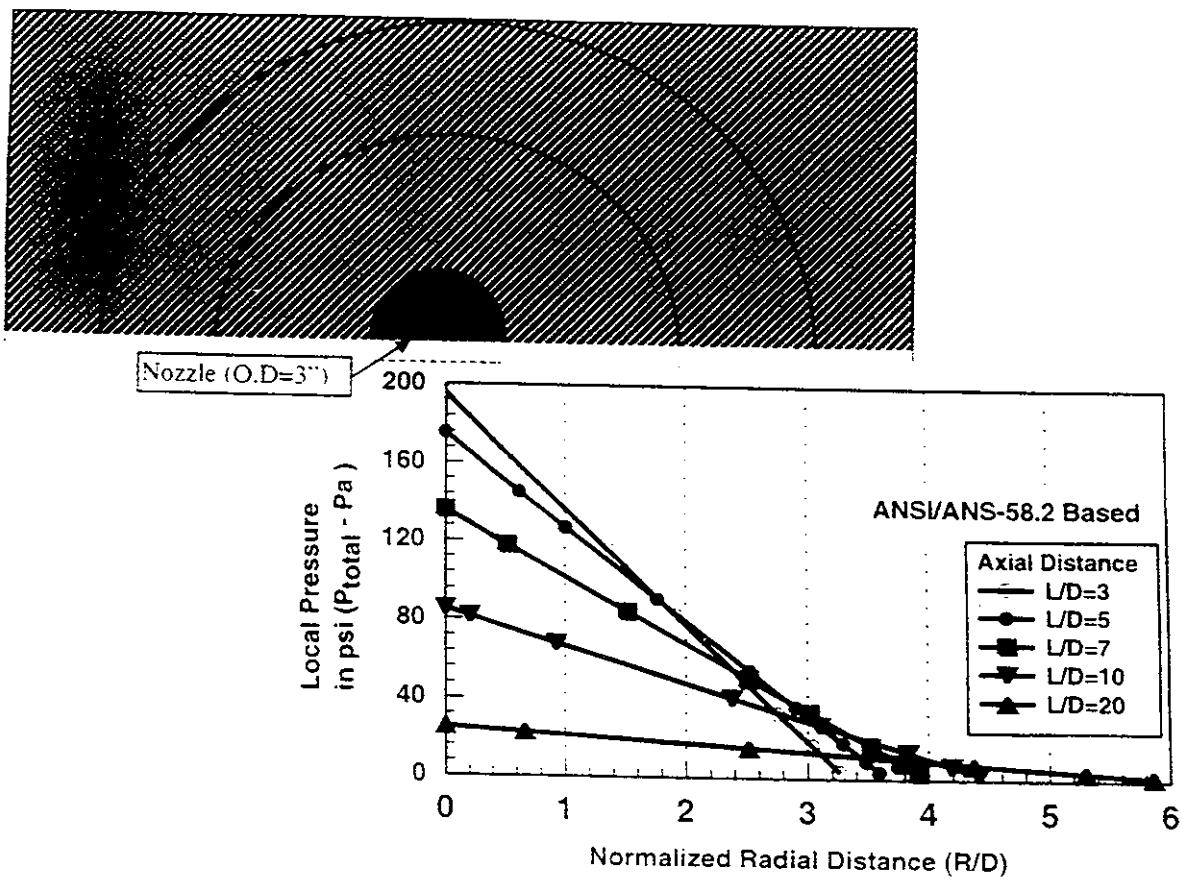

Figure G.2. Radial Distribution of the Stagnation Pressure in the jet. The Actual Pressure Profile Could be Different from the Linear Profile Assumed in the ANSI/ANS-58.2 Model.

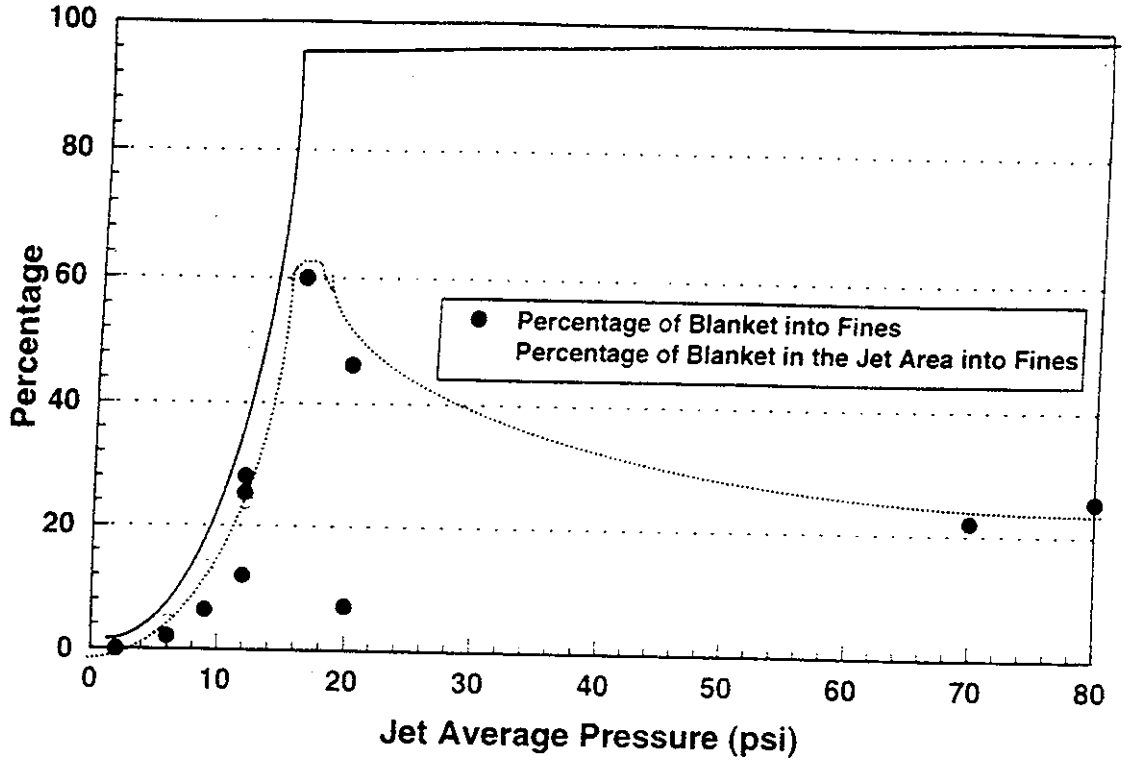

Figure G.3. Percentage of Blanket and Blanket in the Jet Area Destroyed into Fines as a Function of Jet Pressure. Analysis of AJIT Data [Ref. G.6].

Appendix H

Calculations to Examine the Accuracy of URG Drywell Debris Transport Factors

References:

H.1 URG, Page 75.

H.2 CDI Report No 96-05, "Testing of Debris Transport through Downcomers/Vents into the Wetwell," URG Technical Support Documentation, Volume II, Tab 2, November, 1996.

H.3 SEA 96-3105-010-A:2, "Drywell Debris Transport Study, Phase I Draft Letter Report," Science and Engineering Associates, Inc., September 27, 1996.

H.4 Letter from C.H. Berlinger to T.A. Green, "Second Transmittal of NUREG/CR-6369, 'Drywell Debris Transport Study'," dated April 8, 1998.

Problem Definition: The URG guidance assumes that only 50% of the fines would be transported to the suppression pool for a Mark II containment during steam blowdown. In addition, the URG provides transport fractions for Mark I and Mark III containments. The transport factors for Mark I's and II's were founded on the results of small-scale tests of downcomer/vent geometries. The Mark III factors were predicated on the more limiting conclusions drawn for Mark I containments. The staff performed the following analyses and experiments to evaluate the URG guidance:

- The staff sponsored four tests simulating steam flow in the lower region of the drywell of a Mark II. The tests simulated Mark II geometry where steam flow would enter the downcomers.

- Calculations were performed to estimate the steam velocities in the BWROG-sponsored testing documented in Reference H.2.

- The staff conducted a detailed drywell debris transport study (DDTS), which included testing and analysis to determine the key factors that affect debris transport from the drywell to the wetwell.

The staff's findings are summarized in the following paragraphs:

Confirmatory Experiments: The NRC sponsored experiments, both separate effects tests and integrated tests, to examine the impact of vent/floor arrangement on the transport of debris. In both cases, the vents were designed to simulate Mark II containment flows as close as possible, both at the vent entrance as well as at distances sufficiently farther from the entrance. (CFD and MELCOR results were used to design the vent geometry.) Tunnel approach velocities were close to 25 ft/s (7.8 m/s) and vent velocities close to 150 ft/s (46.6 m/s). These tests (Reference H.4) yielded the following results:

- The total insulation captured as a percentage of insulation arriving at the vent is 8-13% for classes 2-6. Classes 2 and 6 are markedly larger than the insulation shreds used in

the BWROG tests. In that sense, these values are expected to be larger than what would be anticipated for smaller debris.

- The capture percentage increases to 35% for classes 6+. Note that 6+ debris are typically larger than clearances in the gratings. For such debris, gratings are found to have a more significant impact on limiting debris transport. Large debris were deposited on the back wall equivalent to Mark II floor.

On the basis of these results, the staff concludes that an inadequate basis exists for the 50% credit for Mark II containments recommended by BWROG in the URG.

Scaling Uncertainties Associated with BWROG Testing: In the BWROG-sponsored steam tests conducted by CDI (Reference H.2), the blowdown was typically 2.45 seconds from a 0.25" orifice. Flows scaled according to the vent/downcomer flows are equivalent to those from a 17 inch diameter pipe break. In addition, the same flows scaled from the barrel diameter of the test facility to full scale are equivalent to a 12-14 inch pipe break LOCA. Thus, the velocities used are 50-60% lower than the velocities anticipated in the containment following a main steamline or recirculation line break LOCA. As calculated in Reference H.3, debris settling velocities are strong functions of the fluid velocity. No scaling rationale was provided in Reference H.2 as to how such a set of experiments can be extrapolated to BWR containments.

Comparison with the Guidance Provided in the URG: The major finding of the BWROG experimental program was that Mark II vents can retain up to 50% of the debris during both main steamline and recirculation line breaks. The NRC sponosored specific experiments to evaluate this as part of the DDTS. These experiments were conducted at conditions deemed to be typical of an MSLB. The data from the NRC-sponsored testing conducted in support of the DDTS study suggest that wet vent entrances do capture small debris. However, capture fractions are no more than 15% for small pieces, with the majority of that debris deposited on the floor. This value is much lower than the 50% proposed by the BWROG. Furthermore, it is likely that the ECCS flow from the break (in the case of a recirculation line break) would likely resuspend the majority of this debris and transport it to the vents. On the basis of these results, the staff concludes that the URG guidance is nonconservative for a MARK II containments.

For other containments, the URG guidance on page 75 of the URG is consistent with the upper-bound estimates of the DDTS, and consistently higher than the study's center estimate. While applying the URG suggested transport factors, licensees should take care to ensure that the underlying assumptions are consistent with the particular plant being analyzed. In particular, the following considerations should be addressed:

- All testing done by NRC and BWROG employed 4-in x 1-in x ½-in floor gratings. All of the results (e.g., capture efficiencies) were derived assuming that the grating occupies 100% of the cross-section with no chance for debris to bypass them. By contrast, if the utility identifies large discontinuities or gaps in gratings that would allow a fraction of the debris to pass through, the utility may wish to revise the transport factors accordingly.

- Implicitly, both studies assumed that unthrottled ECCS conditions exist for a maximum of 3 hours following a recirculation line break. If unthrottled ECCS operation is expected for more than 3 hours, the licensee may wish to revise the washdown fractions accordingly. NRC sponsored test results in Reference H.4 could be used to scale the washdown factor up.

Conclusions: The staff concludes that the BWROG provided transport fractions for Mark II containments (on page 75 of the URG) are not adequately supported. Mark II containments should use fractions similar to Mark I containments. However, the fractions provided for Mark I and III containments for the transport of fines are acceptable.

Appendix I

Analyses to Examine the Accuracy and Applicability of ECCS Strainer Head Loss

References:

I.1 CDI Report No. 95-09, "Testing of Alternate Strainers with Insulation Fiber and Other Debris," URG Technical Support Documentation, Volume I, Tab 2.
I.2 NUREG/CR-6370, "BLOCKAGE User's Manual," December 1996.
I.3 NUREG/CR-6224, "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris," October 1995.

Problem Definition: As part of the URG Technical Documentation, the BWROG provided the results of its head loss testing program conducted by the Electric Power Research Institute (EPRI) at the EPRI Non Destructive Examination (NDE) test facility in Charlotte, NC, as well as descriptions of the various cookbook approaches that can be used to estimate head loss induced by alternate and truncated cone strainers. This analysis was conducted to verify the adequacy of the proposed head loss estimation approaches.

Results of the Review: The staff has reviewed, and performed computations, to determine if the URG-proposed approach provides reasonable estimates of strainer head loss. Specifically, the staff applied the URG models to simulate the experimental data for a number of the tests for which data were included in the report. Time-dependent behavior was simulated by incorporating the URG models into a modified version of BLOCKAGE 2.5.

The debris bed head losses predicted by the URG models for selected test runs were compared to the experimental values in Tables C-1 and C-2 (Reference I.1) for fiber/particulate and RMI beds, respectively. Test runs were selected that indicated the head losses were approaching a steady-state value. The staff notes that one important criticism of the URG tests is that reasonable steady-state conditions were not achieved in a significant number of the test runs. This is important because the amount of debris on the strainer was deduced by taking the known quantities of debris introduced into the water tank and assuming that essentially all of the debris was deposited onto the strainer when steady-state head loss was achieved. Therefore, the debris bed composition was relatively unknown during transient conditions. It is believed that pool turbulence was sufficiently high to prevent debris from settling to the bottom of the tank. The results of four time-dependent simulations (for Tests P5, J28R, 4, and J6, respectively) are shown in Figures 1 through 4 of this appendix. These results lead to the following conclusions.

Stacked-Disk (PCI) Prototype No. 2 Strainer: Fiber/particulate simulations were performed for Tests P3, P5, and P8 for a range of flow rates, as shown in Table C-1 of Reference I.1. The URG model appears to yield reasonable or conservative predictions of strainer debris bed head loss for the ranges of conditions tested, as follows:

- fiber loadings range to 50 lbs.
- corrosion products to fiber mass ratios to 10
- approach velocities to 0.5 fps (on the basis of the circumscribed area)

- no miscellaneous debris

Note that head loss will be over predicted when the strainer surface area is not completely covered (as was obviously the case in Test P4), and miscellaneous debris was not considered in testing this type of strainer. There was insufficient data (see Table 6-5, URG Technical Support Documentation, Volume I) to determine with certainty that the strainer area was completely covered for the simulated test runs; however, it is likely that the coverage was complete, or nearly complete, since the average fiber debris bed thickness across the entire strainer area was 0.74, 1.5, and 0.30 inches for Tests P3, P5, and P8, respectively.

The time-dependent debris head loss for Test P5 predicted by the URG model is shown in Figure 1 compared to the head loss predicted by the NUREG/CR-6224 correlation and to the experimental test data. The strainer flow rate in the test was nominally 5000 GPM; however, it was varied from 2500 to 10000 GPM starting at about 70 minutes (see test data on Page C-102 of URG Technical Support Documentation, Volume I, Tab 2). The URG model did a good job of predicting the test. It over predicted early in time because of incomplete coverage of the strainer. Apparently, debris on the strainer shifted as a result of varying the flow rate because the head loss associated with 5000 GPM was less after the 5000 GPM flow was resumed than before the flow rate was varied. The shifting of debris by varying the flow rate was, of course, not predicted by the models.

The NUREG/CR-6224 correlation did not perform well when attempting to predict Test P5, as its predicted head loss at 5000 GPM was only about a third of the experimental head loss. Its poor performance is attributed to the fact that it was developed for a strainer with a uniform debris bed thickness and a uniform approach velocity, as would be expected for the truncated cone strainers. For stacked-disk and star strainers, the debris is apparently driven preferentially into their crevices resulting in distinctly non-uniform debris distributions and approach velocities. The NUREG/CR-6224 correlation may either require modification or the development of appropriate input guidance for it to be reliably applied to these non-uniform strainers.

Apparently, the only stacked-disk strainer design tested with RMI debris was the stacked-disk portion of the self-cleaning strainer (SCS-SDP). One of these tests, Test A1, was simulated over a range of strainer flow rates as shown in Table C-1 of Reference I.1. In all simulations performed for this strainer, the URG models conservatively over predicted the debris bed head losses by more than 100%.

Stacked-Disk (PCI) Prototype No. 1 Strainer: Fiber/particulate simulations were performed for Tests 20 and 22 at three flow rates, as shown in Table C-1 (Reference I.1). These results are similar to those for stacked-disk number 2; however, there was less test data to examine as reflected in the URG plot for non-dimensional head loss for the first prototype (see Figure 6-8, Page 70, Reference I.1). This curve was drawn with very limited data resulting in a straight line fit, which does not seem likely to be the case.

60-Point Star Strainer: The URG model generally under predicted the 60-point star strainer by 20 to 30%, as shown in Table 1, whenever the strainer surface area was

completely covered. (Coverage was determined by comparing the calculated nondimensional thickness associated with each debris loading with the required minimum nondimensional thickness reported.) The URG model over predicted two tests, J22 and J23, because the strainers were not completely covered. The ranges of conditions tested include:

- fiber loadings range to 25 lbs.
- sludge-to-fiber debris mass ratios up to 25
- approach velocities to 0.5 fps (based on the circumscribed area)
- either zero or "full recipe" (see Reference I.1) miscellaneous debris

Note that miscellaneous debris increases the experimental head losses for tests J28R and J23 by 24% and 116%, respectively and the URG model bump-up factors appeared to compensate appropriately.

Figure 2 of this appendix shows the time-dependent debris head loss for test J28R predicted by the URG model versus the head loss predicted by the NUREG/CR-6224 correlation, and the experimental test data. The strainer flow rate in the test was nominally 5000 GPM; however, it was varied from 2500 to 5000 GPM starting around the 40-minute point in the test. (See test data on Page C-188 of Reference I.1.) The URG model under predicted the test by 20 to 25% throughout the test. The NUREG/CR-6224 correlation did not perform well when attempting to predict test J28R, as its predicted head loss at 5000 GPM was only about 15% of the experimental head loss. Again, the NUREG/CR-6224 correlation's poor performance must be attributed to the fact that it was developed for a strainer with a uniform debris bed thickness and a uniform approach velocity, which is clearly not the case with this strainer design.

The URG model could be used to predict fiber/particulate debris bed strainer head losses for the 60-point star strainer if a reasonable safety factor is applied to compensate for the relatively uniform underpredictions shown herein, and provided that the conditions of the calculations are within the ranges of conditions listed above.

The 60-point star strainer was tested with RMI debris and one of these tests, J20, was simulated with the URG model for a range of flow rates shown in Table C-1 (Reference I.1). In all of these simulations, the URG models over predicted the debris bed head losses by 15 to 40%.

20-Point Star Strainer: Fewer test runs were simulated for the 20-point star strainer than for the 60-point star strainer, and all of the simulations except one over predicted the experimental head loss. Test run 11, which had fiber debris but no particulate, was under predicted by 47%. Two of the over predictions resulted from incomplete coverage on the strainer. The test run involving Kaowool rather than NUKON® was extremely over predicted by a factor of 259 which appears to be related to the fineness of its fibers (~2.5 microns in diameter) relative to the NUKON® fibers (~7.1 microns) for which the model was developed. In fact, all of the test runs checked involving Kaowool were way over predicted (i.e., by factors of 46, 259, and 14 for test runs J12, 35, and J30, respectively). It is likely that the

validity of the URG model as applied to the 20-Point Star strainer is similar to its validity as applied the 60-Point Star strainer; however, the uncertainty is higher.

Truncated Cone Strainer: The URG model is less reliable for simulating test runs using the truncated cone strainer design, which tend toward lower-fiber loadings with higher particulate-to-fiber mass ratios. Three of the simulated runs (6, 7, J6) had incomplete coverage of the strainer, and two of the runs (6, J6) had mass ratios larger than the upper limit of 120 for which the model was developed (see Figure 6-6, Page 68, Reference I.1). Using the URG model beyond this upper limit of 120 is non-conservative because the head loss beyond this limit increases by some unknown amount.

The primary reason that the URG model over predicted Run J6 was an excessively large and unrealistic bump-up Factor of 4.2. The bump-up factor accounts for the head loss contribution of the miscellaneous debris where the head loss without miscellaneous debris is multiplied by the bump-up factor to get the total head loss. The reason the bump-up factor is so large is the URG assumption that the fiber-to-particulate mass ratio used in calculating the bump-up factor must be limited to 4, whereas the actual mass ratio for this test was 360. This means that the miscellaneous debris contribution over powers the equation. This assumption was designed to guarantee that the head loss predictions would be conservative, but under certain conditions, it can render the URG model unusable.

The time-dependent head loss for Run 4 was predicted using both the URG model and the NUREG/CR-6224 correlation as shown in Figure 3 of this appendix. In this situation, the NUREG/CR-6224 correlation does an excellent job, whereas the URG model over predicts the head loss by about 40%. It was not surprising that the NUREG/CR-6224 correlation performed well for this test run because the correlation was specifically developed for the truncated cone strainer. Note that in Run 4, the strainer was completely covered with fiber debris and there was no particulate debris.

Another test, Run J6, was also simulated but with distinctly different results. In the J6 simulation, the NUREG/CR-6224 (Standard Simulation) grossly over predicted the head loss, as shown in Figure 4 of this appendix, whereas the URG model simply over predicted the head loss by a factor of about 2. The reason that the NUREG/CR-6244 correlation performed so poorly was that BLOCKAGE predicted that most of the particulate debris was on the strainer, when in reality, it most certainly was not. A second simulation (realistic simulation) where only about 5% of the particulate debris was allowed to accumulate on the strainer shows a much better agreement with the experiment. If all of the 180 lbs. of corrosion products were deposited onto this 18-ft^2 strainer, the entire surface area would have been covered with sludge to a depth of 1.8 inches, whereas the thickness of fiber debris (uncompressed) was only 0.15 inches; that is, it is highly unlikely that this thin layer of fibers could hold that much sludge in place and, if it did, the head loss would have been excessive as predicted by the NUREG/CR-6224 correlation (standard). The conclusion must be that the fiber bed became saturated with particulate debris, thereafter as much particulate passed through the fiber as was deposited onto the fibers. The NUREG/CR-6224 "realistic simulation" is considered the correct simulation of the experiment. Therefore, it must be further concluded that in at least one of the URG experiments, the

assumption that nearly all of the debris added to the system will be located on the strainer when the head loss approaches steady state is in error.

Using the URG model to simulate the truncated cone strainer given the test conditions for which the URG model was developed has been shown to be unreliable.

Conclusions: When used in the cookbook approach outlined in Appendices A and B of Reference I.1, the URG model is generally unreliable and incomplete for the following reasons:

- The URG model was developed for limited ranges of data (i.e., fiber and particulate debris loadings, velocities, and strainer design). Using the model beyond these limitations is especially risky because the models are non-mechanistic in nature.

- In many cases, the URG model has been shown to under predict the experimental data used to develop the model; therefore, each head loss prediction should be reviewed in detail relative to the applicable data to ensure a valid prediction. In many situations, such as the 60-Point Star strainer, a significant safety factor should be factored into the prediction.

- The bump-up factor used to account for the miscellaneous debris was developed with limited data (gravity head loss tests). In many situations, the bump-up factor has been shown to severely over predict the head loss. While this over prediction is conservative, it can render the use of the model impractical, especially with plants having low NPSH margins.

- Some of the test runs (e.g., J6) simply overpowered a thin layer of fibers with massive amounts of particulate debris so that the strainer debris apparently become saturated with particulate. Thus, the actual particulate debris loading on the strainer which was used to develop the model was not known. Instead, the total system inventory was assumed to be deposited onto the strainer when it likely was not.

- Debris such as duct tape, tie wraps, and plastic tags included in the recipe of miscellaneous debris was not included in the modeling effort. It is possible that this debris had only a minor impact on the overall head loss, but the report did not discuss this issue or what quantities of these debris types would be needed to significantly affect head loss.

- Extending the URG model to other types of debris, such as Kaowool rather than NUKON®, could be risky because the URG model was essentially developed for the NUKON®fibers. This review showed that the URG model tended to seriously over predict the head loss associated with test runs using the Kaowool. First of all, the over prediction may render the URG model unusable for predicting head loss associated with Kaowool. Secondly, the URG model could seriously under predict the head loss for some other type of fiber (i.e., in the opposite direction from the Kaowool). This could be the case for a fiber with thicker strands than NUKON®.

- The same NUKON® debris properties should be used as were employed in developing the URG model (i.e., densities and diameters). The fiber density of 2.4 lbm/ft^3 used in the URG study is the number generally assumed for the intact fiber insulation (sometimes referred to as the as-fabricated density), but there are data showing that the density of actual debris is considerably reduced by the destruction process. For example, fibrous debris used in the PP&L-sponsored tests conducted at ARL had an actual density of 1.3 lbm/ft^3. Employing this density rather than the as-fabricated density, the user would obtain a different fiber spacing distance, which would result in a different head loss than if the user actually used the as-fabricated density that is inherent in the non-mechanistic URG model.

- All of the test runs were conducted using a mass of corrosion products with the same representative size distribution (i.e., 83, 11, and 6% for size ranges represented by 2.5, 7.5, and 42.5 microns, respectively), and the URG model has not been validated for alternative size distributions. For example, one plant (designated as Plant J in URG Volume III) found that 27% of its particles were in the 10-75 micron range compared to the 6% of the representative study. It is likely that had the size distribution of Plant J been used in Run J6 rather than the representative distribution, the head loss would have been greater simply because fewer of the particles would have passed through the fiber bed than was apparent from the simulations performed for this review. In addition, the NUREG/CR-6224 head loss correlation has shown that the head loss is a function of the particulate-specific surface area, which is in turn a function of the particle diameters.

- Two types of RMI debris were used in the URG strainer debris bed head loss tests. Specifically, these include two different size distributions of the 2.5-mil stainless steel foils, and each size distribution was used over a different period of time. Thus, the tests for a specific strainer design are generally valid for only one type and size distribution of RMI debris. For example, the stacked-disk tests (stacked-disk section of the self-cleaning strainer) only used the RMI debris obtained from Diamond Power since all of these tests were conducted in August 1995. Therefore, the URG model, as it applies to the stacked-disk strainer, was developed only for this one type and size distribution of RMI debris. Furthermore, it must be assumed that the self-cleaning strainer is representative of stacked-disk strainers in general, since sufficient dimensions were not provided to determine if the size of the disks were the same as the two PCI prototypes (i.e., the spacing between the disks could well impact RMI debris loading).

- The URG model was developed from test data where a true steady-state condition was not generally achieved, implying the debris loadings used in the model development were somewhat different than the actual loadings on the strainers.

- The URG report did not provide model validation, parameter sensitivity, or uncertainty analysis leaving open the question of whether or not a particular combination of input parameters could cause the URG model to seriously under predict head loss.

In conclusion, the URG model must be used with care, not blindly plugging numbers into a cookbook step-by-step procedure as outlined in the report. Rather, each head loss prediction must be anchored into head loss data to ensure that it is reasonable and

conservative. For all of the reasons cited above, the staff recommends that vendor-specific test data be used to demonstrate the head loss assumed in a licensee's NPSH calculations.

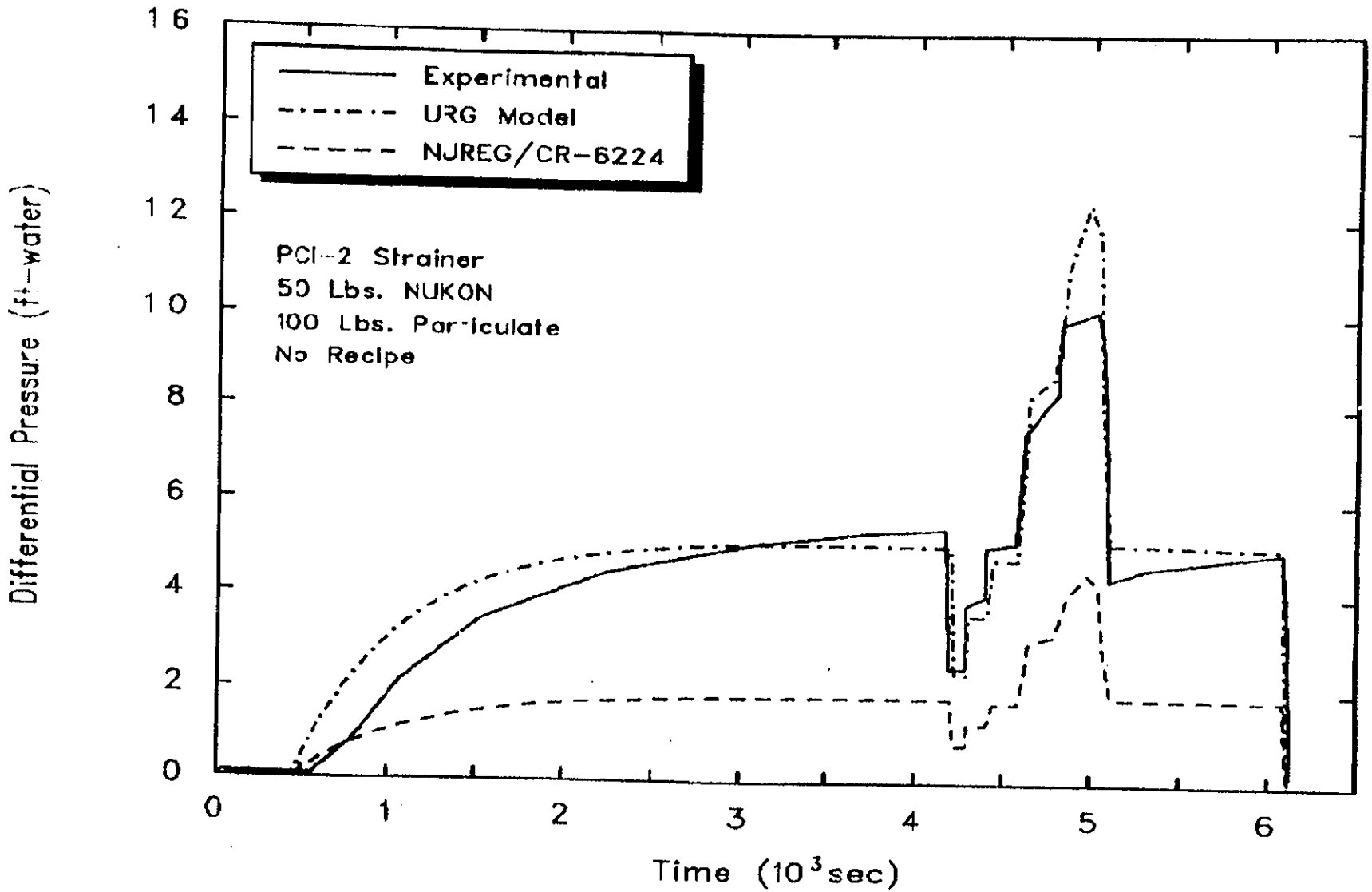

Figure 1: Debris Bed Head Loss for Run P5

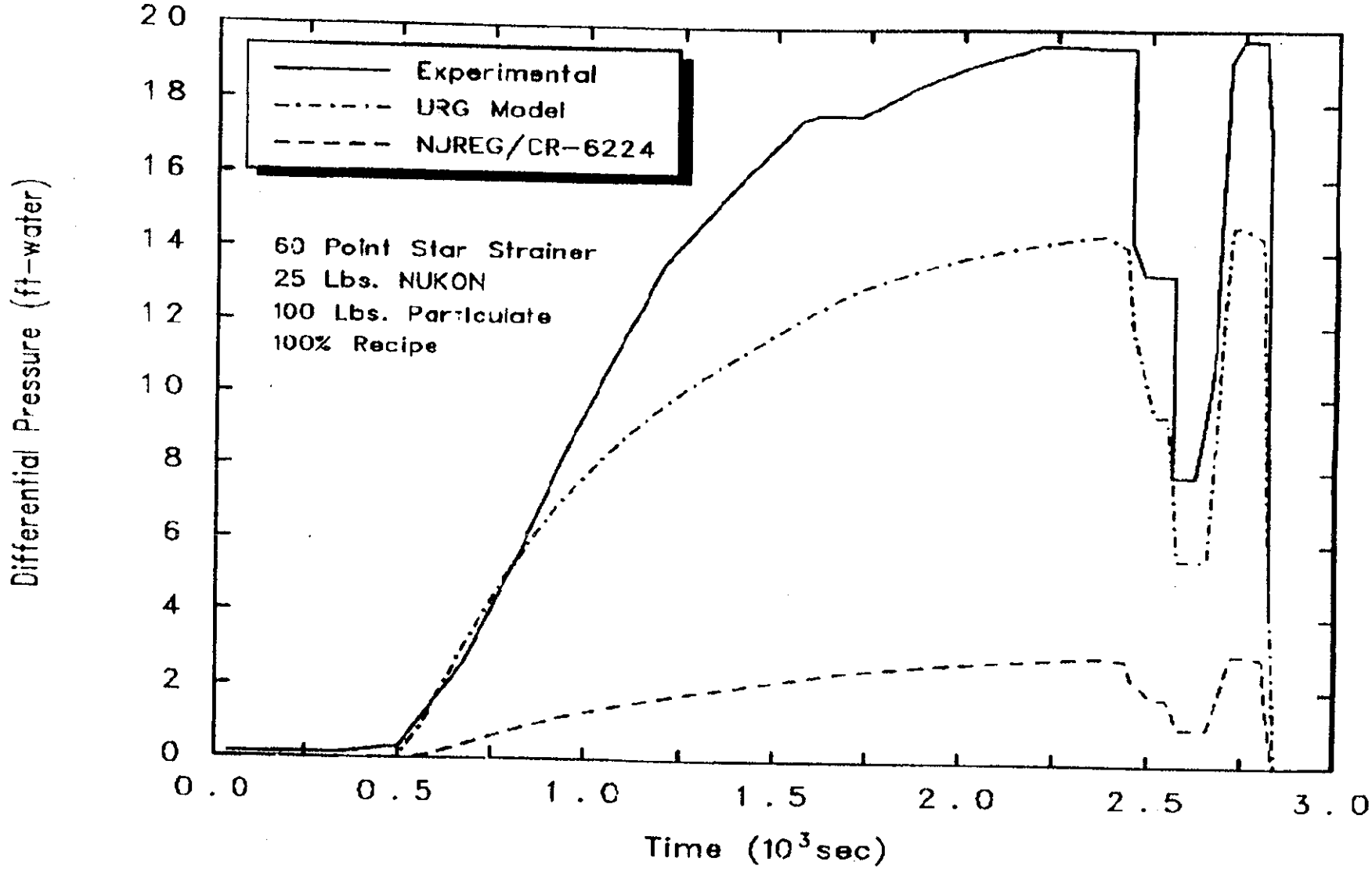

Figure 2: Debris Bed Head Loss for Run J28R

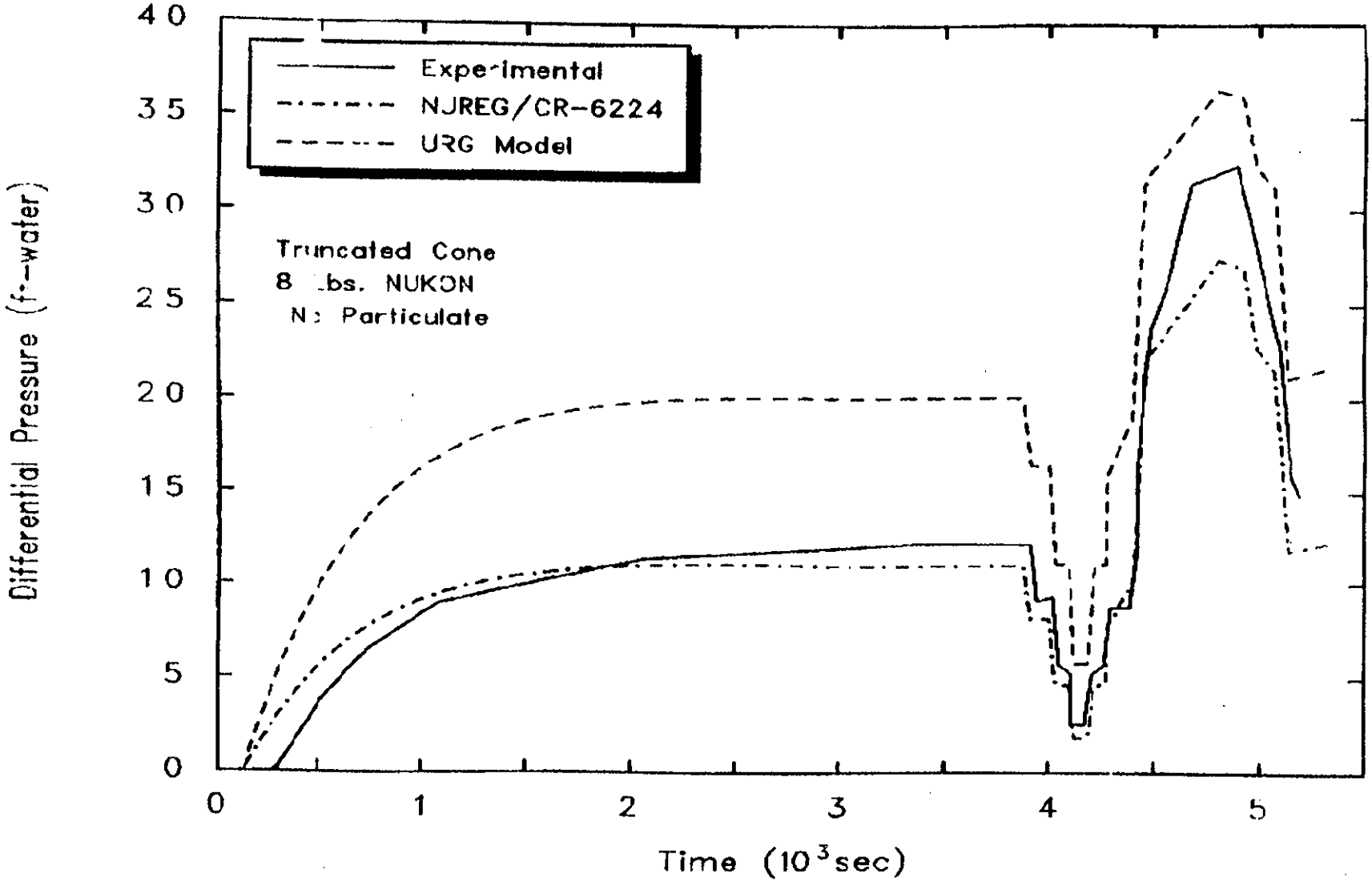

Figure 3: Debris Bed Head Loss for Run 4

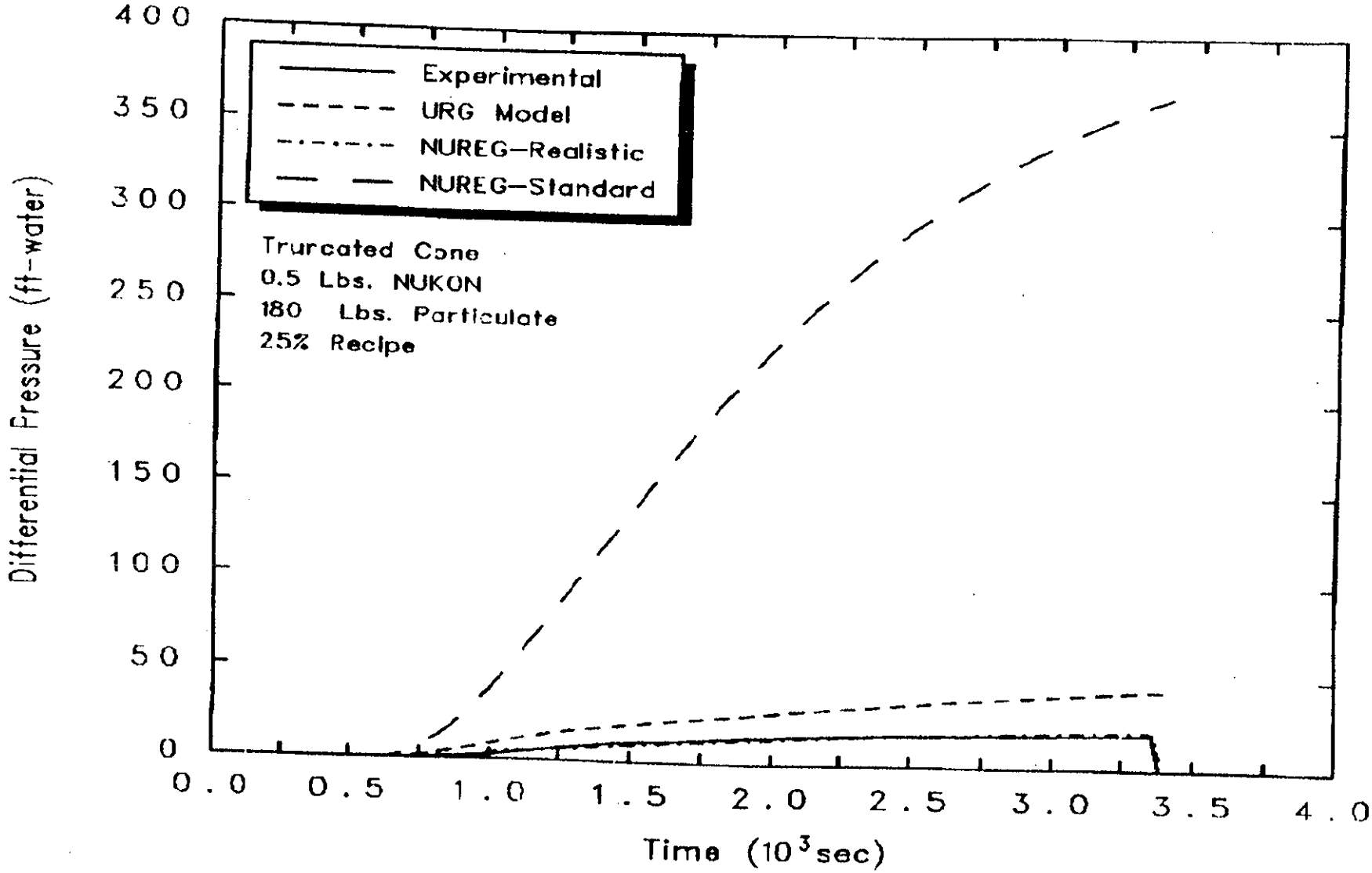

Figure 4: Debris Bed Head Loss for Run J6

Appendix J

Calculations to Examine the Accuracy of URG Sludge Generation Factors

References:

J.1 URG, Section 3.2.4.3.

J.2 BWROG Letter OG94-661-161, "BWR Owner's Group ECCS Suction Strainer Committee Suppression Pool Sludge Particle Size Distribution," URG Technical Support Documentation, Volume III, Tab 2, September 13, 1994.

J.3 Attachment 2 to BWROG Letter OG96-321-161, "Suppression Pool Sludge Particle Distribution Data - Average Distribution Calculation," URG Technical Support Documentation, Volume III, Tab 3.

J.4 BWROG Letter OG95-388-161, Attachment 4, "BWR Owners Group Suppression Pool Sludge Generation Rate Data," URG Technical Support Documentation, Volume III, Tab 4.

Problem Definition: In the URG, the BWROG provided guidance regarding the quantity of suppression pool corrosion products (sludge) that should be used in utility analysis of strainer blockage. A value of 300 lbm/year was recommended as the sludge generation rate, in lieu of establishing plant-specific sludge generation rates. The basis for the generation rate and characterization were provided in References J.2 and J.3, which the staff evaluated to determine the adequacy of the basis for the BWROG's conclusion.

Results and Discussions: The BWROG's survey information is provided in Figure J.1 of this appendix, which shows that in all of the plants but one (Mark I, II and III), generation rates are far less than 200 lbm/yr. From the NUREG/CR-6224 study, the staff is aware that the reference plant estimates were very conservative and were derived on the basis of wet sludge mass (not the dried sludge). Based on this, the staff concludes that the BWROG-recommended value of 300 lbm/year is reasonable and sufficiently conservative. Also, the URG provides comprehensive guidance for those utilities that do not wish to use the value of 300 lbm/yr.

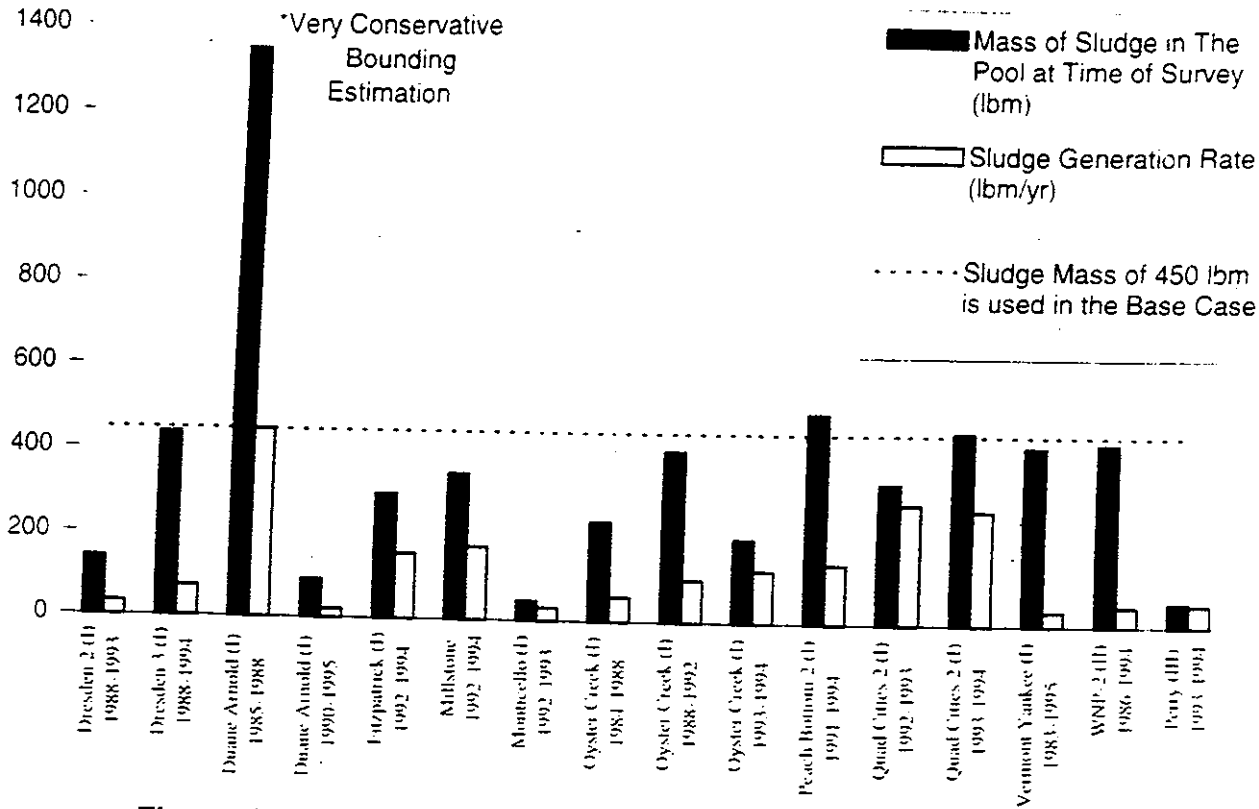

Figure J.1. Sludge Inventory and Sludge Generation Rate for Selected Plants

Appendix K

Analyses to Examine the Accuracy of URG Guidance for Primarily RMI Plants

Reference:

K.1 URG

K.2 CDI Report No. 95-06, "Air Jet Impact Testing of Fibrous and Reflective Metallic Insulation," URG Technical Support Documentation Volume II, Tab 3,.

K.3 CDI Report No. 95-09, "Testing of Alternate Strainers with Insulation and Fiber Debris," URG Technical Support Documentation Volume I, Tab #2,.

K.4 Letter from C.H. Berlinger to T.A. Green, "Second Transmittal of NUREG/CR-6369, 'Drywell Debris Transport Study'," dated April 8, 1998.

K.5 ARL Report entitled, "Head Loss of Reflective Metallic Insulation Debris With and Without Fibrous Insulation Debris and Sludge for BWR Suction Strainers," April 1996.

Problem Definition: In the URG, the BWROG also provided guidance for use by plants primarily having RMI insulation. This guidance included methods developed by the BWROG to estimate:

- The quantity of RMI debris generated by a postulated LOCA (i.e., destruction factors).
- The fraction of that debris that would be transported to the suppression pool (i.e., drywell transport factors).
- The total quantity of RMI debris that could accumulate on the strainers.
- The resulting head loss.

Various analyses were conducted, as documented in this appendix, to evaluate whether the BWROG guidance represents a adequate basis for strainer design. This appendix summarizes the important findings of the review effort. Finally, the last section of this report provides a brief discussion of insights gained from the LaSalle RMI test report, provided to staff for review in June 1998.

Guidance on the Zone of Influence: As indicated previously in this SER, the staff has concluded that URG methods 1, 2 and 3 (Pages 37 through 42, Reference K.1) are acceptable for calculating the debris generation ZOI from a pipe break. The staff believes that these methods would provide conservative estimates for the ZOI, and hence, the quantity of debris generated. However, some plants may not use ZOI calculations; instead focusing on estimating head loss on the basis of determining a "saturation thickness" of RMI debris that could get on the strainer surface. This "saturation thickness" is essentially the maximum amount of RMI debris that could physically accumulate on the strainer before the approach velocity would be too small to entrain more debris on the strainer surface.

Guidance on the Drywell Debris Transport Factors: The URG used experimental data to suggest that no more than 50% of the RMI contained in the ZOI gets destroyed into pieces that can be categorized as transportable. Therefore, the maximum volume of debris that

can be transported to suppression pool is 50% of the total RMI contained in the ZOI. A close review of BWROG AJIT test data indicates that use of 50% would result in a conservative estimate for the quantity of transportable RMI debris.

The BWROG relied on experimental data from CDI small-scale transport tests to derive the following drywell transport factors (Reference K.2):

Table K-1 Factors for combined generation and transport of RMI.

Containment Type	MSLB	Recirc. Break
Mark I	0.5	0.5
Mark II	0.05	0.03
Mark III	0.5	0.5

For Mark I and III containments, the URG concludes that nearly all of the transportable RMI debris would be transported to the suppression pool. In the case of Mark II, the URG concludes that the downcomer arrangement would "capture" nearly 90% of the debris approaching them. On this basis, the BWROG recommended a drywell transport factor of 0.05 for an MSLB, and 0.03 for a recirculation line break. It is the staff's opinion that the BWROG recommended drywell transport factors for Mark II containment are non-conservative, because:

- The CDI experiments were not properly scaled. In the CDI facility, steam breaks were simulated using blowdown from a 0.25-in (0.64-cm) orifice that typically lasted for 2.45 seconds. The intent of the CDI tests is to achieve the flow velocities at the entrance of the downcomer that are fairly representative of a real scale BWR. Due to experimental limitations, the actual flow velocities at the downcomer entrance are approximately less than half the flow velocity following a postulated DEGB. In the bulk of the barrel, where the majority of the debris settling was observed, the flow velocity is less than a quarter of the flow velocity expected in a real Mark II containment following a DEGB. Thus, the flow velocities simulated in the tests are extremely low compared to the real case. Therefore, debris settling noted in the CDI tests may not be representative of reality. In the staff's opinion, the results are most likely non conservative.

- The RMI debris used are stainless steel foils. All the tests were conducted using stainless steel RMI foils that are 0.0025 inch[13] in thickness (Diamond Power Mirror® insulation). The staff believes that direct application of these data to lighter debris such as aluminum RMI would likely result in non-conservative transport factors.

- Qualitatively, ARL's experimental data do not support low transport factors for Mark II. At ARL [Ref. K.4], a facility was built which more closely simulated flow velocities throughout the test section (in the barrel, at the entrance and in the down comer). This facility was used to measure transportability of various size fibrous shreds. For fibrous debris, this facility has shown that Mark II downcomers do not possess any special characteristics that would result in high capture fractions. Although no tests were carried out to study capture of RMI pieces

[13] The actual thickness may be substantially different from the nominal thickness of 2.5 mil.

by the Mark II downcomer, selected fiber tests can provide some insights[14]. In those fiber tests, very little capture was observed for small and medium fibrous debris that possessed weight and gravitational settling velocities close to those of aluminum[15]. Similarly, the capture efficiency was less than 40% for larger debris that are more representative of stainless steel debris[16].

Given these findings, the staff believes that the URG transport factors for RMI debris are non-conservative for Mark II containments. (Note that a similar conclusion was reached for fibrous debris.) Individual plants that do not intend address RMI issues using the saturation thickness approach should use same transport factors for Mark II as for Mark I and Mark III, unless the utility has data/evidence that support the use of another factor.

Guidance on Pure RMI Head Loss: Appendix B of Reference K.3 provides guidance for determining head loss due to accumulation of RMI debris on the strainer surface. This guidance directs the analyst to take the following steps:

- Estimate the maximum thickness of the debris layer on the strainer surface.
- Establish the relationship between the debris layer thickness and the foil surface area.
- Determine the head loss resulting from the accumulation of the maximum RMI layer on the strainer surface.

— *Capacity to retain RMI*: RMI pieces approaching the strainer surface would become attached to the strainer surface only if the drag on the debris due to flow is larger than the sum of gravitational forces and the turbulence drag. Otherwise, the RMI pieces would be dislodged from the strainer and will not considerably contribute toward head loss. As shown in Table K-2 below, the BWROG experiments have shown that 0.0025-inch thick stainless steel RMI debris are no longer retained on the strainer surface when the local approach velocity based on circumscribed area is less than or equal to 0.2 ft/s.

Table K-2 BWROG Experimental Data Establishing Point Where RMI No Longer Attaches to Strainer Surfaces

Geometry/Test ID	Flow (GPM)	Flow Area	Velocity (ft/s)
Truncated Cone/T7 and T8	1600	18 ft^2	0.2 ft/s
60 point star/A4	1250	14.52 (22 x 0.66) ft^2	0.2 ft/s

The value of 0.2 ft/s shown in the table above is approximately equal to half the gravitational settling velocity for 2.5-mil stainless steel RMI pieces (see Table 6-7 of Reference K.3). On this basis, the BWROG hypothesizes that RMI debris do not attach to the strainer surface if the local flow velocity is less than half the settling velocity of the RMI debris. In the URG, the BWROG suggests settling velocities listed in Table 6-7 be used in conjunction with Equation 6-9 to

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14 Because capture is driven by the weight of the debris and the flow velocity.

15 The measured settling velocity of small and medium debris in still water is close to 0.15-0.20 ft/s (see Reference K.4) as compared to the settling velocity of 1.5 mil-thick aluminum debris which is 0.25 ft/s (see Table B-1 of Reference K.3).

16 The measured settling velocity of class 6+ size fibrous debris is approximately 0.37 ft/s which is comparable to the measured settling velocity of 0.4 ft/s for 0.0025-inch stainless steel foil debris.

estimate the maximum thickness of the RMI layer. Equation 6-9 is produced here for convenience:

$$t_{max} = (DL/4)^{½} [(2U/U_s)^{½} - 1] \qquad (K.1)$$

Where,

D = the outer diameter of the strainer
L = the length of the strainer
U = the approach velocity on based on the circumscribed area of the strainer
U_s = the settling velocity of the RMI being analyzed

The experimental evidence as well as theoretical reasoning would clearly lead to the conclusion that RMI debris buildup would reach a "saturation point" or a maximum, beyond which local flow velocities would not induce sufficient drag to overcome forces imposed primarily by turbulence and secondarily by gravity. Whether or not the hypothesis that was being advanced by BWROG (specifically, $U_{local} \leq U_s/2$) to describe this equilibrium is accurate by itself is debatable. For example, one could argue that maximum thickness would be strongly dependent on both the residual turbulence and the shape and size of the debris, not just the shape and size of the debris as assumed by the BWROG. However, the staff has accepted the BWROG hypothesis. The rationale for staff acceptance is two-fold:

- It was staff's belief that turbulence levels in the EPRI tank are equal to or less than those expected in the BWR suppression pool during the high and intermediate energy phases of pool dynamics. Typically, high and intermediate energy phases only last few minutes following a large break LOCA. After that point, low energy recirculating water flow patterns exist in the suppression flow. Such flow conditions would allow for RMI debris fragments to settle down quickly (within 2 minutes for 2.5-mil SS RMI as demonstrated by ARL testing). On the other hand, the BWROG saturation thickness hypothesis is implicitly based on the assumption that higher energy turbulence would be present to enable debris accumulation until saturation conditions are reached. Thus, the saturation thickness hypothesis is considered to be conservative.

- To confirm this conclusion, the staff conducted a series of calculations aimed to determine maximum credible RMI debris loads on suction strainers following a LOCA. These calculations employed the BLOCKAGE computer code and applied ARL test data conservatively. For a generic BWR suppression pool, the BLOCKAGE analyses led to the conclusion that debris loads estimated using BWROG hypothesis were always larger than maximum credible loads expected on the strainer following a large break LOCA.

The conclusions presented above were based on assumptions that are supported by NRC/ARL experimental data. Although NRC/ARL data were obtained for 2.5-mil SS RMI, theoretical analyses were used to extrapolate the data to 1.5-mil aluminum RMI and 6-mil aluminum RMI[17]. Furthermore, the BLOCKAGE analyses assume a generic BWR suppression pool response as described in NUREG/CR-6224, Appendix-B.

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[17] Table 1 of Appendix-D to Reference K.2 suggests that US BWRs primarily employ three types of RMI on piping and components: 2.5-mil SS, 6-mil Al and 1.5-mil Al.

Individual utilities that plan to use the saturation thickness approach should ensure that the assumptions made by the BWROG in deriving Equation 6-9 are applicable to the strainer they propose to install, especially in conjunction with the type of RMI. This caution is intended to focus attention on the BWROG assumption that debris would be deposited spherically on the strainer surface. This assumption formed the basis for Equation 6-9 of Reference K.3 (reproduced above as equation K.1). Neither the pictorial evidence nor any analytical reasoning was provided in support of such an assumption. Some of the pictorial evidence suggest that debris accumulation resembles in some cases more of a cylinder (or a distorted cone) than a sphere. Equation 6-9 of Reference K.3 does not reflect this finding and can be proven to be non-conservative for certain designs (e.g., long strainers (e.g., where strainer length is much greater than strainer diameter), odd shaped strainers and for strainers which are closer to the torus wall).

To demonstrate that point, consider a strainer on which debris deposition is expected to resemble a cylinder (e.g., long cylindrical strainers). For such a strainer, a more appropriate equation to calculate t_{max} is:

$$t_{max} = D(1+D/(4L))/2\ [(2U)/U_s - 1] \qquad \text{(K.2)}$$

Where,

D = the strainer circumscribed diameter (ft)
L = the length of the strainer (ft)
U = the approach velocity (ft/s) calculated on circumscribed strainer area
t_{max} = the maximum thickness of the debris layer (ft)

While this equation is also not exact (because it assumes the debris deposition on the strainer to be semi-cylindrical), it is more representative of reality. For long strainers (e.g., girder-to-girder strainers) or for strainers in which both ends are blocked, the above equation further reduces to:

$$t_{max} = D/2\ [(2U)/U_s - 1] \qquad \text{(K.2a)}$$

In both equations,

$$U = Q/(A_{cs} + A_{end})$$

Where,

A_{cs} = the circumscribed area per the URG definition (πDL)
A_{end} = the end area of the strainer ($\pi/4\ D^2$); if blocked by wall or support plates A_{end} is equal to 0

Note that equation K.2 and K.2a are substantially different from Equation 6-9 of Ref. 3. The difference is attributable to the fact that Equation K.2 is derived assuming that debris layer builds up cylindrically, where as Equation 6-9 assumes a spherical deposition. To quantify this difference, consider a case in which a utility proposes to use a cylindrical strainer 4 ft long and 3 ft in diameter. The utility has stainless steel RMI with a settling velocity of 0.4 ft/s. Finally, the net ECCS flow through the strainer is 7500 GPM. For such a case, if an

analyst estimates the maximum debris layer thickness, Equation 6-9 predicts the maximum thickness to be 0.843 ft, where as Equation K.2 predicts this value to be 1.534 ft; a difference of 8.3-inches.

Several such cases can be created to demonstrate that Equation 6-9 of Reference K.3 for certain cases can yield non-conservative results. On this basis, the staff concludes the following:

- Universal use of Equation 6-9 (or for that matter K.2) would not accurately predict saturation thicknesses and can be non-conservative for selected strainer geometrical configurations. The staff suggests that each utility may wish to derive an appropriate equation that is best suitable for their strainer configuration.

- However, this does not negate applicability of saturation thickness hypothesis proposed by the BWROG. Instead, it is intended to alert utilities that more appropriate equations can be derived to suit a particular strainer type and design.

Determination of Theoretical Thickness: An alternative to determining the maximum capacity of a strainer is the theoretical thickness of the RMI bed formed on the strainer surface. Depending on the size and shape of the RMI debris, for a given foil area (or foil mass) the actual volume occupied by the debris can vary widely. A measure of porosity or "packing density" was represented by an empirical parameter K_t in Reference K.3. The exact definition of K_t is:

$$V_{RMI} = K_t A_{foil} \qquad (K.3)$$

Where,

A_{foil} = the RMI foil surface area (ft^2)
V_{RMI} = the actual volume occupied by the RMI (ft^3)
K_t = the empirical constant usually measured from experiments (ft)

The staff measured K_t values for stainless steel RMI fragments of various sizes. The measured K_t values varied widely with the size of the debris fragments. As shown in Table 1 of Reference K.5, for an RMI mass distribution of 0.81 grams per cubic cm (g/cc), the actual bed thickness measured in the experiments varied between 1 and 2.5 inches (2.5 and 6.4 cm) as debris fragment sizes were varied from ¼-inch (0.64-cm) to 4-inch (10.2-cm). Qualitative observations by the staff suggest that "the smaller sized RMI debris would form stiffer beds with lower void fractions originally (i.e., before being subjected to water flow) than the larger sized RMI debris." However, the difference in head loss between the two cases indicates little effect of RMI debris size on head loss. Typically, at lower velocities ($U < 0.75$ ft/s) the smaller debris resulted in a head loss that is 10-20% higher than the larger debris. At higher velocities, this trend reverses. In all cases, the observed differences are within the estimated experimental uncertainties.

The following K_t values were derived based on experimental measurements for the stainless steel RMI debris used in NRC-sponsored testing at ARL:

Table K-2 K_t Values Derived From ARL Test Results

Debris Type	Original Bed
¼ to ½-inch	0.007 ± 0.002
1 and 2 inch	0.008 ± 0.003
2 and 4 inch	0.013 ± 0.004
½, 1, 2 and 4 inch	*0.009 ± 0.003*

The majority of NRC testing was done using the last combination (i.e., *½, 1, 2 and 4 inch*). Some of the debris were provided to the BWROG for their testing. (The exact size distribution of the debris provided to the BWROG is unknown.) For those pieces, the BWROG measured a value of 0.015 for K_t as shown in Table 6-8 of Reference K.3. While the absolute value is higher than the values given above, it is possible that the BWROG may have measured it for larger pieces. The staff notes, however, that the experimental uncertainties in both cases could be large enough to preclude a definitive conclusion.

Upon further review, the staff finds that the values provided in Table 6-8 of Reference K.3 are slightly higher than corresponding NRC measurements. The staff notes that the NRC measurements were made after the debris was subjected to small amounts of flow required to configure the bed, while the BWROG measured dry samples dropped randomly into a pipe. Furthermore, the BWROG's values are representative of a size distribution of RMI debris used in the BWROG's tests. If a particular utility believes that the size of RMI debris expected to reach the strainer is different from that used by BWROG, the utility should measure the appropriate value for use in its plant specific analysis.

Settling Velocities: Another important factor relating to estimation of saturation thickness is settling velocity of the debris. Settling velocities reported in Table 6-7 of Reference K.3 are slightly higher than those measured in NRC-sponsored testing at ARL.

Table K-3 Settling Velocities of RMI Materials Measured in NRC-Sponsored Tests at ARL

Debris Type	NRC Data	BWROG Data
¼ to ½-inch	0.39 ± 0.07	
1 and 2 inch	0.40 ± 0.07	0.47
2 and 4 inch	0.45 ± 0.07	
½, 1, 2 and 4 inch	0.40 ± 0.07	

These values are within 20-25% of the BWROG's reported results. Once again, it is possible that BWROG's values are representative of the size distribution of debris selected for testing. If a particular utility believes that the size of RMI debris expected to reach the strainer is different from that used by BWROG, the utility should measure an appropriate value for use in its plant-specific analysis.

Head Loss across RMI beds: The BWROG provided the following generalized equation to predict head loss across RMI debris:

$$\Delta H = K_p U^2 t_{RMI} \text{ (or) } \Delta H = K_p K_t U^2 A_{foil}/A_c \qquad (K.4)$$

Where,

ΔH = the head loss (ft-water)
U = the approach velocity (ft/s) calculated based on the circumscribed strainer area
t_{RMI} = the larger of theoretical thickness and maximum thickness (ft)
K_p = the frictional loss coefficient (ft^3/s^2)
K_t = the empirical constant previously discussed above (ft)
A_{foil} = the foil surface area (ft^2)
A_c = the circumscribed area of the strainer (ft^2)

The K_p values were given in Table B-3 of Reference K.3 for different materials and different strainer geometries. The staff observed the following:

- On the basis of the gravity head loss test data, the BWROG derived a K_p value of 5.1 for the NRC's stainless steel RMI on flat plate strainers. As noted above, a K_t value of 0.014 was measured in NRC-sponsored test of stainless steel RMI debris provided to the BWROG. This would result in the following equation, normalized to foil area:

$$\Delta H = 0.0714 U^2 A_{foil}/A_c \qquad (K.5)$$

This equation did fit a sizable number of the NRC data points obtained for 2.5-mil stainless steel RMI debris beds. However, several NRC data points (especially those where bed compression and debris size is an issue) were above Equation K.5. The following equation was found to bound NRC data reasonably well:

$$\Delta H = 0.108 U^2 A_{foil}/A_c \qquad (K.5a)$$

Equation K.5a also takes into consideration factors such as experimental uncertainties and repeatability.

Although the difference between K.5 and K.5a is considerable (up to 30%), it is well within the experimental uncertainty of both experiments. In view of this, the staff believes that the uncertainties in any of the correlations should be identified and addressed in calculations by the individual utilities. This comment is particularly important for plants with small NPSH margin to start with. Because of the uncertainty associated with the head loss correlations provided in the URG, the staff recommends that utilities use vendor test data to support the head loss used in their NPSH calculations.

- In addition to gravity head loss tests, the BWROG conducted a series of semi-scale strainer tests. In these tests, the debris used was made of 2.5-mil SS RMI foils manufactured by CDI. One of the strainers used in the study is a truncated cone strainer. For that strainer, the BWROG reported experimental data for several RMI debris loadings. Table K-4 of this appendix summarizes these data along with the Test ID. Also shown on Table K-4 are the head loss values predicted using Equation K.5a. Clearly, the head loss can be explained rather well by this correlation. However, this analysis shows two apparent errors in the URG. First, the data plotted in the URG for the truncated cone should plateau out around

12 not 25 as shown in the figure. Secondly, Table 6-11 in the URG suggests that the head loss for truncated cone should be predicted by

$$\Delta H = 0.35\, U^2\, A_{foil}/A_c \qquad \text{(i.e, } K_t=0.014 \text{ and } K_p=25\text{)} \qquad \text{(K.6)}$$

This equation over predicts head loss from tests T3, T4, T5 and T6 considerably. In view of this, it is concluded that BWROG conclusions related to truncated cone are wrong, albeit they are very conservative.

Table K-4 Comparison of Equation K.5a Predictions with Head Loss Measured for Truncated Cone Strainers

Test ID	Flow	Head Loss	RMI	Eqn. K.5a
T4	7500	15	180	15.5
	5000	8	180	6.9
	2500	1	180	1.7
T5	7500	27	360	31.1
	5000	13	360	13.8
	2500	3	360	3.5
T6	7500	38	500	43.2
	5000	17	500	19.2
	2500	4	500	4.8
T3	7500	10	120	10.4
	5000	5	120	4.6
	2500	1	120	1.2

The BWROG's conclusions related to the stacked-disk and star strainers are incomplete and cannot be accepted for debris loads beyond which they were tested. The primary reason for this conclusion is that the BWROG test data were obtained for RMI debris loads that are substantially lower than those required to fill up the gaps and result in thick beds. Also, the correlations developed by the BWROG do not possess basic parameters that allow them to be extended to higher debris loadings. For example, all the stacked-disk strainer data were obtained for an RMI debris loading lower than 210 ft^2. It would take in excess of 1500 ft^2 of RMI to fill up the gap volume and start building a layer outside the gap.

In conclusion, the head loss for RMI debris beds should be based on individual plant (or vendor) experimental data. Although the BWROG obtained valuable experimental data, its applicability is limited to truncated cone strainers. For truncated cone strainers also, a more appropriate correlation is Equation K.5a which was found to adequately predict experimental data from the following sources:

- NRC/ARL experimental data obtained using a mixture of RMI debris generated by steam blast tests.
- CDI gravity head loss test data using the same insulation.

- CDI test data obtained using 2.5-mil stainless steel RMI debris manually generated by CDI.

Finally, CDI gravity head loss test data suggest that manually generated RMI debris would result in higher head loss than air blast generated debris. This fact could not be fully substantiated. Further research in this area is required before reaching such a conclusion.

Head Loss for Mixed Beds: In the URG (Section 3.1.2, page 14), it is stated that "the head losses which resulted from the tests with combined RMI, fiber, and particulate debris were bounded by those seen in similar tests for the equivalent loading of fiber and particulate without RMI debris." In a meeting with the BWROG on February 9, 1998, the staff and the BWROG modified this position as follows: "The head losses which result from combined RMI, fiber, and particulate debris can be **bounded** by the higher of RMI only bed or fiber and particulate bed."

The staff conducted a series of tests to investigate head loss resulting from RMI and fibrous debris accumulation on the strainer. The BWROG also conducted similar tests. In both cases, the data clearly suggest that in most cases, the revised position is accurate (Specifically, the head loss for mixed beds is bounded by higher of RMI or fiber plus sludge correlations.) This conclusion is clearly true when the bed is made of a large quantity of RMI and trace quantities of fiber (e.g., saturation thickness of RMI and 0.5 lbm of NUKON®). This conclusion is also true when the bed is mainly made of fibrous debris, with trace quantities of RMI. However in the intermediate range there is potential that mixed bed head loss would exceed individual contribution of the debris constituents. A more appropriate method for this region is to add the contribution of individual constituents to estimate the total head loss. An alternative would be for the individual utilities to obtain experimental data in support the head loss used in their NPSH analysis.

Impact of LaSalle Strainer Test Data: Commonwealth Edison Company (CECo) issued a report documenting experimental findings related to 1.5-mil aluminum (Al) RMI (used at LaSalle County Station, Units 1 and 2) debris accumulation on the stacked-disk strainer design being used at LaSalle. In the report, CECo states that "These conditions are directly relevant to the LaSalle replacemnet strainers and are not necessarily representative of conditions for other BWRs. Direct extrapolation of these results to other foil types and/or strainer approach velocities is not recommended." The staff concurs with this statement. However, the staff reviewed this report to determine if the data from the report would revise any of the staff's findings stated in this SER or any of its appendices. On the basis of this review, the staff concludes that none of the its previous conclusions would be changed by the information contained in the CECo report. The basis for this conclusion is as follows:

- Equation K.2 suggests that saturation thickness for 1.5-mil Al RMI debris (U_s=0.2 ft/s) is a function of velocity. At a strainer flow of 4000 GPM, the expected saturation loading would correspond to a bed thickness between 4 and 5 ft (depending on assumptions related to bed buildup). The equivalent foil area is about 20,000 ft^2. LaSalle conducted its tests with RMI loadings up to 2250 ft^2. Neither Equation K.2 above nor the BWROG equation predicts saturation at the LaSalle test conditions. Equation K.2 suggests that debris should fall off the strainer due to gravitational settling at a flow of about 1000 GPM. The LaSalle report

confirms this finding, although debris detachment appears to be more gradual than predicted by Equation K.2

- The head loss obtained in Tests 3 and 4 in the CECo report are readily predicted using a modified form of Equation K.5a. These predictions for 2250 ft^2 of 1.5-mil Al RMI would have been 40, 23 and 10 inches of water respectively, corresponding to strainer flow rates of 4000, 3000, and 2000 GPM. These results compare well with the experimental data for Test 4.

- The CECo data also does not negate the conclusion that mixed bed head loss can be estimated as a sum of constituent contributions. Instead, it supports this conclusion. The CECo report postulates that the increase in head loss for the combined debris bed (fiber plus RMI) is due to "synergistic effects" of RMI and fibers. The staff's review suggests that another plausible reason for the observed behavior relates to the location of fibrous debris in Test 5 (fiber plus RMI) versus Test 1 (fiber only). In Test 1, the fibrous debris was subjected to very low velocities in the proximity of 0.18 ft/s. In Test 5, due to the presence of RMI, the fibrous debris would now accumulate on the circumscribed surface. As a result, the fibrous debris in Test 5 would be subjected to a velocity in excess of 0.4 ft/s, approximately 2.2 times larger than Test 1. Consequently, higher head losses are expected in Test 5 than a simple sum of Test 1 and Test 4. On the basis of this assumption, the staff's calculates head losses far in excess of 100 inches at a strainer flow rate of 4000 GPM. This is consistent with the experimental data. At 2000 GPM, the NRC model would have resulted in a head loss estimate of approximately 50 inches-water as opposed to the measured value of 58 inches.

Clearly, the report sheds light on head loss for RMI debris beds other than 2.5-mil stainless steel in conjunction with stacked-disk strainers. The report raises several issues that should be addressed on a plant-specific basis. It also provides valuable data. However, it does not negate any conclusions stated in this SER or any of its appendices.

Overall Conclusions: On the basis of the its review, the staff reached the following conclusions:

- The URG guidance related to debris generation and zone of influence are reasonable and would most likely yield conservative estimates for the quantity of debris generated.

- The URG guidance on transportability of debris in Mark I and III containments are reasonable and consistent with NRC analyses. For Mark II, the staff disagrees with the URG recommendations and concludes that Mark II containments should use the same transport factors as Mark I and Mark III containments.

- The URG guidance on saturation thickness is reasonable. However, individual utilities should separately determine the applicability of URG Equation 6-9 to the specific strainer designs being considered.

- The URG guidance on settling velocities and 'K_t' values are slightly higher than those measured by USNRC for the same debris. However, these differences are attributable to experimental uncertainties and would not likely significantly alter the final strainer design.

- The URG guidance on head loss for special strainer designs (e.g., stacked-disk strainers) is incomplete, having been developed based on head loss data obtained for thin beds of RMI. The staff recommends that vendor-specific data be used in the plant-specific NPSH analyses.

- The URG conclusion related to head loss in mixed beds (specifically, RMI plus fiber and sludge) is not considered acceptable and is modified as follows: "The head losses which result from combined RMI, fiber, and particulate debris can be **bounded** by the higher of RMI only bed or fiber and particulate bed." As modified, the staff considers this assumption reasonable for two extremes: a) where debris is primarily made of RMI, with trace quantities of fiber, and b) where debris is primarily made of fiber, with trace quantities of RMI. For the intermediate conditions, the URG conclusions could not be substantiated. A more appropriate method for this region is to add the contribution of individual constituents to estimate the total head loss. Another acceptable option is for the individual utilities to obtain experimental data to support the head loss used in their NPSH analysis.

Appendix L

Staff Resolution of BWROG Comments on the Draft SER on the URG Dated December 31, 1997

By letter dated December 31, 1997, the staff transmitted the draft SER on the URG to the BWROG. The BWROG provided its response in a letter dated March 13, 1998. Table L-1 provides a summary of the BWROG comments and the staff's resolution of those comments.

Table L-1
Summary of BWROG Comments on the Draft SER on the URG

Com. No.	Draft SER Ref.	Draft SER Issue Description	BWROG Response	Proposed Staff Resolution
1	Overall	Compounded Conservatisms: The approach adopted by the staff in reviewing the URG results in comments on each area where, in several cases, the staff identifies a more conservative application than the method provided in the URG. Application of the more conservative application suggested by the staff *in each and every area* can result in an overall conservatism that is so great for some plants that it could require a passive strainer of a size that it could only be installed by re-opening the containment loads analysis, or through reliance on containment overpressure (not currently credited) when calculating NPSH. In the draft SER the staff does not provide a perspective on how the overall conservatism of the URG methodology will be considered when evaluating the acceptability of any individual portion of the analysis.	The BWROG recommends that the SER communicate an expectation that licensees will apply individual portions of the URG with a primary focus on the overall conservatism of their plant-specific application of the URG in determining strainer head loss and the resulting ECCS pump NPSH margin. The BWROG agrees that each licensee should evaluate its use of the URG to ensure that the plant-specific application of the guidance provides an overall conservative approach ensuring the new strainers comply with the requirements of 10CFR50.46. The BWROG urges the staff to include a discussion recognizing the overall conservatism of the URG approach in order to minimize the burden on both the staff and licensees in performing plant-specific reviews.	The staff believes that there is sufficient conservatism in the URG methodologies which the staff finds acceptable to allow certain portions to be used in spite of technical concerns cited in the SER. The staff SER has been revised to include a discussion on this conservatism in SER section 5.0. However, the staff still found many resolution options (such as banding) unacceptable due to the lack of sufficient guidance, supporting data, or adequate technical justification. Licensees desiring to use portions of the URG which the staff has rejected will still need to resolve the staff's concerns.
2	Overall	Open issues require deferral in closure of NRCB 96-03 responses: The issues identified in the draft SER and the possible actions which may be required once the staff completes their review of 1) the coatings issue (draft Generic Letter 97-XX), and 2) the NPSH information provided in response to Generic Letter 97-04, will likely impact the closure of licensee responses to NRCB 96-03. These issues, based on our discussions on February 6, are not currently projected by the NRC to be fully resolved prior to the issuance of the SER on the URG.	The BWROG requests that the staff consider issuing a supplement to NRCB 96-03 that provides blanket schedule relief to the licensees in reaching final technical closure on NRCB 96-03 until an NRC-accepted methodology is available that fully and completely addresses all the issues affecting the calculation of ECCS pump NPSH. The BWROG is not requesting blanket deferral for the installation of replacement strainers but only for final closure of the 96-03 technical response. Once the final NRC accepted methodology is available, licensees should be given adequate time to review their strainer designs, debris loading calculations, and the need for any further actions (e.g., license changes for containment overpressure credit) before closure of NRCB 96-03 is required.	The staff will consider the need following for a bulletin supplement following the completion of its review of the URG.
3	Overall	On Site Reviews and Inspection: During the 2/6/98 public meeting to discuss the draft SER the staff indicated that on-site reviews would be conducted by NRR headquarters staff for a small number of plants. The need for or mechanism for accomplishing on-site reviews and/or inspections for other plants is undecided pending the outcome of the initial on-site reviews.	The BWROG believes that because of the technical complexity and the demonstrated high knowledge level of the NRR headquarters staff involved with this issue, it is appropriate for the headquarters staff to conduct the initial on-site reviews. The BWROG is interested in how this broad and complex knowledge base will be translated into future inspection guidance. Accordingly, the BWROG requests the opportunity to review and comment on proposed NRC inspection plans and modules that would be used to guide inspection activities subsequent to the on-site reviews.	The staff concurs that it would be appropriate to share future inspection guidance with the utilities since it would clearly define staff expectations relative to 96-03 resolutions. The staff will attempt to do so as soon as the guidance has been developed.

Com. No.	Draft SER Ref.	Draft SER Issue Description	BWROG Response	Proposed Staff Resolution
4	Page 2, 2nd ¶ Page 8, 1st ¶	Actions Required for Portions of URG Not "Accepted" by the NRC: "Licensees desiring to use the portions of the URG not accepted by the staff should address the concerns cited herein in plant-specific submittals." "Since the staff lacked sufficient detail and supporting justification on many of the 'resolution options,' these were generally considered unacceptable without additional supporting justification or technical details being provided by a licensee or the BWROG. If individual licensees desire to make use of any portions (analytical or resolution options) of the URG that are not accepted by the staff, they should resolve the staff's concerns cited herein in a plant-specific submittal."	The BWROG requests that the staff reconsider this position based on the responses provided herein to their specific comments on individual resolution options. We have attempted to clarify where plant-specific responses are appropriate. If further information is required, the staff is requested to clarify the nature of such information.	In some cases, the staff has agreed with the BWROG recommendations made herein. However, in several cases, the BWROG's comment is inconsistent with the basic purpose of the URG which is to ensure a uniform industry response to NRCB 96-03. When no guidance or minimal guidance is provided in the URG, the interpretation of how to implement that option is left up to the individual licensees. The staff cannot, therefore, determine if safety concerns arise out of the implementation of options not reviewed. Blanket acceptance of this BWROG comment would imply staff acceptance of options which were not reviewed and would mislead licensees as to the scope of the staff's URG review. Therefore, no change will be made to the SER in response to this comment unless has sufficient information to reach a conclusion a given portion of the URG.
5	Page 11, 1st ¶ of "Staff Evaluation"	Minimal Fibrous Insulation: The BWROG should clarify what is meant by "minimal" amounts of fibrous insulation.	See URG, Page 117, Line 29..(1/8 inch coverage is "minimal")	The staff's comment was on the general guidance (on page 8) before any analysis work is done. The definition provided by the BWROG on page 117 is referring to strainer head loss calculations with no tie between the two. A licensee applying the URG on his plant is not likely to find the definition on page 117. This is somewhat confusing, but the staff believes that the definition is acceptable and has revised the SER accordingly.
6	Page 11, last ¶ continued on Page 12	URG Flowchart Doesn't Match With Text in Regards to Bounding Assumption on Debris	The BWROG agrees that the flowchart could be clearer. There are really two methods intended, either of which is acceptable. One method is to use a zone of influence that encompasses 100% of the material of interest in the drywell and 100% transport to the suppression pool. The second method is to take 100% of the material of interest in the drywell and then use the transport factors provided in the URG to determine the amount of insulation that reaches the suppression pool.	The staff agrees that either method is acceptable, and the SER has been updated accordingly.
7	Page 12, 2nd ¶	RMI Head loss Should be Added to Head Loss from Fiber + Particulates: NRC position is that the URG statement that head loss from RMI + fiber + particulates is bounded by head loss from fiber + particulates is incorrect. NRC wants RMI head loss added to fiber + particulate head loss.	From discussions during the 2/6/98 public meeting it appears that the staff concerns are focused on the URG statement that fiber + particulates "bounds" the head loss from fiber + particulates + RMI and that the staff believes there are potentially cases where the URG statement may not be valid. The BWROG concurs that for cases with extremely small fiber loadings, the RMI + fiber + particulates head loss may exceed that for fiber plus particulates without RMI. The intent of the URG statement was that for cases where the fiber plus particulate head losses exceed or are comparable to the head losses for RMI alone, the addition of RMI to the fiber plus particulate bed always results in a decrease in strainer head loss. This position is supported by the BWROG test data (see OG 97-010-161). The BWROG believes that this issue can be most readily addressed on a plant-specific basis by having the licensee assure the strainer vendor reviews the debris combinations of interest to the particular plant and confirm that the head loss from fiber + particulates + RMI does not exceed that of fiber + particulates. If this confirmation cannot be provided, appropriate corrections based on plant-specific conditions should be made to account for the increase in the head loss attributed to the RMI.	The staff concurs with the BWROG comment and has revised the SER based on the BWROG information and the results of further review by the staff.

Com. No.	Draft SER Ref.	Draft SER Issue Description	BWROG Response	Proposed Staff Resolution
8	Page 13, 1st ¶, last sentence	Hydrodynamic Loads: "The staff cautions that licensees making changes to hydrodynamic load calculation coefficients and/or methodologies should not do so without testing to demonstrate the validity of the revised calculations."	The BWROG believes that this is a plant-specific issue and is outside the scope addressed in the URG. The URG notes that the need to consider hydrodynamic loads but does not attempt to address appropriate methods for performing hydrodynamic load calculations as those issues are not related to strainer performance per se. The BWROG recommends that issues related to hydrodynamic loads be resolved on a vendor and plant-specific basis.	The staff concurs that hydrodynamic loads must be resolved on a plant-specific basis; however, the staff's caution still remains as it is appropriate caution to licensees considering changes to their licensing basis calculations. The staff does not consider this to be an open issue, nor is this considered the forum for addressing plant-specific hydrodynamic load concerns.
9	Page 13, 3rd ¶	Application of BWROG Test Data to Other Strainer Designs: "The staff finds that there is insufficient information as to how to apply the BWROG test results to other strainers." ..."For this reason, the staff recommends that licensees use vendor specific data based on the licensee's analyzed conditions as the basis for determining head loss across the strainer."	The BWROG is not aware of any licensee that intends to install a strainer of a design based solely on the BWROG test data. The BWROG concurs that licensees should use vendor specific data consistent with the licensee's analyzed conditions as the basis for determining head loss across the strainer.	No change required.
10	Page 13, 4th ¶ continued on Page 15	Use of Banding/Jacketing: "Due to the lack of information as to how a plant is to apply this option, the staff is unable to reach any conclusion regarding this option. In addition, the characterization of the effectiveness of insulation jacketing on this page is inconsistent with the test report (AJIT)"....""Without further detailed information on how to apply this option and the associated benefits achieved, and the technical basis supporting the use of this measure, the staff is unable to make a determination as to the acceptability of this option."	The BWROG notes that information on the use of jacketing and banding is provided in URG Volume II Tab 3, page 181-183, paragraph 5.1.1. The BWROG recommends that those licensees which intend to credit banding/jacketing in order to minimize debris generation should have available appropriate documentation on how the URG data was applied which support the technical basis for such credit.	The staff considers this recommendation by the BWROG to be unacceptable because it implies that the staff has approved this option for use, when in fact, insufficient guidance has been provided by the BWROG for its use, or for staff review. In addition, insufficient data exists supporting its use. For instance, debris generation tests were not conducted from different target to jet nozzle angles or with varying numbers of bands, angles of band installation, or duration of blowdown. Guidance is not provided on minimum construction standards, maintenance and surveillance requirements, minimum or critical mounting requirements, etc. Use of this option without further detailed review by the staff is not considered acceptable. The staff has, however, provided more detail in the SER relative to concerns that need to be addressed should this be an option a licensee wishes to pursue. The staff notes that the pages cited by the BWROG provide conclusions relative to testing of insulation with banding, but no generic guidance on how to apply the data.

Com. No.	Draft SER Ref.	Draft SER Issue Description	BWROG Response	Proposed Staff Resolution
11	Page 14, 2nd ¶	Pool Cleaning Frequency: "...the staff believes that regular inspections of the suppression pool and ECCS suction strainer, and cleanings when necessary, should be conducted every refueling outage until licensees have demonstrated over time the ability to control foreign materials."	The BWROG believes that licensees have taken significant steps to improve suppression pool cleanliness in response to Bulletins 93-02 and 95-02. The BWROG recommends that licensees ensure that assumptions made for debris source terms in sizing the strainers are appropriate given the plant-specific actions taken to remove and control foreign materials. One key element is the planned frequency of pool inspection and cleaning. However, the BWROG believes that requiring all licensees to perform inspections and cleanings every refueling outage adds an unnecessary burden to plants which have taken significant actions to control foreign materials, or which have used very conservative assumptions in strainer design.	The BWROG has grouped two arguments together which do not necessarily go together although they are clearly related. Inspections and cleanings are two distinctly different issues. Inspections are surveillances necessary to ensure operability of the ECCS. The staff believes that inspections of the suppression pool and ECCS suction strainers *must be* conducted every refueling outage until the licensee has demonstrated that a longer interval is appropriate. In no case does the staff believe that the interval should be extended beyond every other refueling outage. Operability of the ECCS must be verified on a regular basis. As with all safety system surveillances, it must be done regardless of the licensee's design or licensing basis assumptions to ensure that they are operating within their licensing or design basis, and are in compliance with the regulations. Since these inspections can be conducted with remote cameras or with a diver, the staff does not feel that any unnecessary burden has been place on licensees with this requirement. The staff points out that without inspections, the operability of the ECCS cannot be completely demonstrated until called upon to perform its safety function. Elimination of inspections by a licensee would also tend to establish a culture where the importance of maintaining pool cleanliness would be downplayed. This could lead to relaxation of FME vigilance by licensees workers. The staff's draft SER on cleanings only stated that they should be conducted when necessary. The staff does not believe that any unnecessary burden has been placed on licensees with this requirement. If inspections determine that the licensee is at risk of exceeding its licensing or design basis due to foreign material in the suppression pool, then the pool should be cleaned prior to startup. Common sense says that cleaning of suppression pools on a regular basis is a good practice to avoid potential problems associated with debris (e.g., minimizing the potential for particulates or sludge to cause wear on pump bearings, etc.). The staff has ensured that its position is clearly stated in the SER.

Com. No.	Draft SER Ref.	Draft SER Issue Description	BWROG Response	Proposed Staff Resolution
12	Page 14, 3rd ¶ continued on Page 15	Containment Overpressure: "The staff concurs that additional containment overpressure (other than the amount already approved by the staff for the existing licensing basis) should not be used as part of the resolution of this issue. The staff is evaluating its position on use of containment overpressure in calculating NPSH margin as part of its review of (GL 97-04)...."	The BWROG recommends that, if practicable, plants not credit containment overpressure in the resolution of this issue. However, the URG notes that in some cases various plant-specific factors may make it necessary to credit containment overpressure. The BWROG recommends that licensees intending to make a change to their licensing basis relative to crediting containment overpressure should perform the appropriate analyses to demonstrate the minimum amount of containment overpressure available. These analyses should be separately submitted for staff review and approval. The BWROG notes that the more conservative the requirements are in the areas of zone of influence, debris generation, transport, and head loss correlation the more likely that some licensees will need to credit containment overpressure in order to meet the requirements of Bulletin 96-03. Excessive conservatism should be avoided.	The staff concurs with the BWROG comment, however, no change to the SER is needed specifically in response to this comment.
13	Page 15, 2nd ¶	Reanalyze Suction Penetration Loads: The URG suggests use of more sophisticated techniques or reduction in conservatism of current design basis calcs without reopening the licensing basis for containment loads. "The staff's concerns regarding Section 3.1.3.1 are stated above and apply to this section of the URG also." (URG section 3.1.3.4.6, Page 21)	This is similar to the hydrodynamic loads issue. See response to Item No. 8.	See Staff response to Item No. 8.
14	Page 15, 3rd ¶	Re-evaluate for Worst Case when Changing Insulation: "...however, when using this option for a selected break, the licensee should go back and reassess other breaks to ensure that the licensee has not change the break which is the most limiting in terms of NPSH margin."	The BWROG concurs.	No change needed.
15	Page 15, last ¶ continued on Page 16	Defense-in-Depth: "The staff strongly encourages the enhancement of alternate water sources (including maintenance of crossover valves), operator training, and emergency operating procedures to ensure that operators can mitigate any situation involving loss of ECCS flow due to strainer clogging.....the staff concurred with the ACRS comment and agreed to 'place more emphasis on the need to improve, where appropriate, the procedures to better address core cooling from alternate sources of water.'"	The BWROG understanding of this language is that defense-in-depth is an "encouragement" but not a requirement. The BWROG recommends that the staff use language in the SER that clearly differentiates actual requirements from that of encouragements and prudent actions and suggested evaluation approaches. Doing so would avoid confusion with actual requirements.	The staff concurs and has reviewed the SER to ensure consistency in the language relative to where it is making recommendations or encouragements versus requirements as in the case cited here by the BWROG.
16	Page 16 Thru Page 18, 2nd ¶	Use of MEB 3-1 for Selection of Break Locations to be Evaluated:	We note for ease of analysis, BWROG licensees have typically chosen not to use the MEB 3-1 approach and instead used an approach that considers those breaks that would result in the maximum debris generation.	The staff notes that it knows of at least three licensees who attempted to use MEB 3-1 breaks without consideration of other non-MEB 3-1 pipe break locations. The staff maintains its position that the use of MEB 3-1 for this application is inappropriate, and more importantly, completely unnecessary.

Com. No.	Draft SER Ref.	Draft SER Issue Description	BWROG Response	Proposed Staff Resolution
17	Page 18, last ¶ continue on Page 20 Page 21, 2nd ¶	Thin Bed Effect - Medium LOCAs: "...the staff believes that licensees considering a solution option using an alternate strainer design should experimentally verify (or ensure using existing vendor or BWROG data) that the thin-bed effects is not an issue for the strainer design being considered using debris quantities which are consistent with a MLOCA for their plant. Otherwise, the licensee should consider the MLOCA when performing their plant analysis. If verified experimentally, the licensee would not need to analyze medium LOCAs with the largest potential particulate debris to insulation ratio by weight." "Licensees may screen out MLOCAs in performing their plant-specific analysis if they intend to install a strainer similar to the stacked disk number, star strainer, or another geometrically similar strainer with deep crevices sufficient to hold debris loadings consistent with a MLOCA for their plant."	The BWROG recommends that this issue can be most readily addressed on a plant-specific basis by having the licensee assure that the strainer vendor reviews the debris combinations of interest to the particular plant and confirm that the head loss from the maximum debris loading bounds that of lesser debris loads. The debris combination resulting in the highest strainer head loss for the expected flow rate should be used in the NPSH calculation for the ECCS pumps. This can be accomplished by parametric variation of the debris loads when performing head loss calculations. This approach is recommended because it avoids the burden of explicitly establishing the expected ZOI, debris generation and transport resulting from MLOCAs while still assuring the most limiting head loss case is considered. The BWROG believes that the stacked disk strainer designs typically being installed as replacements have sufficiently deep crevices that MLOCAs can be screened out of consideration.	The staff concurs; however, licensees should not screen out MLOCAs without assurance from the strainer vendor that lower debris loadings could not result in more limiting head loss across the strainer. The vendor should have sufficient data to support its position. The staff has revised the SER to make this position more clear.
18	Page 20, 1st ¶	Large LOCAs with Highest Particulate to Fibrous Debris by Weight: "Therefore, the staff concludes that licensees should still evaluate large LOCAs with the highest particulate to fibrous debris ratios by weight to ensure that those breaks do not become more limiting in terms of head loss than the breaks that produce the highest volume of fibrous debris."	The BWROG recommends that this issue be resolved in the same way as item No. 17.	The staff concurs; however, licensees should not screen out these breaks without assurance from the strainer vendor that higher sludge to fiber ratios could not result in more limiting head loss across the strainer. The vendor should have sufficient data to support its position. The staff has revised the SER to make this position more clear.
19	Page 21, 4th ¶	Alternative Evaluation Methods: "Each alternative evaluation method presented must provide reasonable assurance that the most severe ECCS suction strainer debris loadings (from drywell insulation sources) be suitably evaluated."	The BWROG concurs provided such alternative evaluation methods are consistent with the plant licensing basis.	10CFR50.46 is a part of all licensee's licensing bases. This rule is the basis for the staff's comment. No change to the SER required.
20	Page 21, 5th ¶	Bounding Analyses: "Bounding analyses, if used by licensees in lieu of specific pipe break location analyses, need to address all debris species (from insulation sources) which have not been addressed by the specific pipe break location evaluations."	The BWROG concurs.	No change required.
21	Page 21, 6th ¶	Breaks Inside bio-shield: "The URG guidance on pipe breaks inside the bio-shield wall is incomplete. ....the staff believes that additional guidance on the analytical considerations to be evaluated by the licensee would be beneficial and consistent with the BWROG's stated goal of providing a consistent industry response to NRCB 96-03."	The BWROG believes that the plant unique aspects of the amount and type of insulation inside the bio-shield will govern the most appropriate means of addressing this debris source. For many plants the amount of debris available inside the bio-shield is negligible relative to other debris sources and can be discounted. The BWROG recommends that this issue is best addressed on a plant-specific basis.	The staff concurs that this part of the analysis is plant-specific. The staff was recommending that the BWROG provide guidance on what should be considered in evaluating debris sources within the bio-shield wall and their potential impact on NPSH. The staff will allow this to be addressed on a plant-specific basis, but cautions that a sound technical basis for the licensee's resolution of this part of the analysis should be established and maintained. The SER has been revised accordingly.

Com. No.	Draft SER Ref.	Draft SER Issue Description	BWROG Response	Proposed Staff Resolution
22	Page 23, 2nd ¶	Bulk Dynamic Pressure: "The BWROG calculations underestimate bulk dynamic pressures in Mark I containments by a factor of 10 at some locations. However, the staff's analysis concludes that the bulk dynamic pressure would likely be insufficient to damage insulation materials such as those presently used in operational BWRs, if the insulations are properly installed and well-maintained. ....Licensees should ensure that the analysis is reflective of the actual plant conditions. In addition, the URG calculations for bulk dynamic pressure in a Mark I containment should be updated to be consistent with the BWROG's response to staff RAIs in Reference 13."	As noted by the staff, the BWROG previously addressed this issue in response to NRC RAI. A revision of the URG is not anticipated. Further, the BWROG notes that even if the bulk dynamic pressure was sufficient to remove insulation, no impact on the strainer performance would be expected given that loose insulation would come off as relatively intact blankets which, in accordance with the NRC Drywell Debris Transport Study, are not transportable.	The staff will change the SER to not require a change to the URG but will still note the technical error in the URG. The staff will also note the BWROG response to staff questions on the URG where this issue was originally resolved.

Com. No.	Draft SER Ref.	Draft SER Issue Description	BWROG Response	Proposed Staff Resolution
23	Page 23, 3rd ¶ Page 23, 4th ¶ continued on Page 24 Page 25, 5th ¶ Page 26, 3rd ¶	Jet Centerline Pressure (JCL) versus Target Area Averaged Pressure (TAAP): "The staff believes that a target area averaged pressure or jet impingement load are more technically correct bases for assessing potential damage. If this approach is not taken, the BWROG should provide a better rationale for selecting the local jet centerline pressure at the L/D location where incipient damage was first observed as the fundamental property that uniquely controls insulation damage." "The BWROG should develop a logical rationale which would also resolve the staff's concern (described in Appendix B) relative to applying the BWROG air jet impact testing results to full size BWR drywells." "The NRC concludes that the JCL approach would result in a smaller ZOI for insulations with a higher P_{dest} (i.e., DARMET, with Camloc strikes and latches, Transco RMI, Jacketed NUKON with Sure-Hold Bands, Diamond Power Mirror with Sure-Hold Bands, and CalSil with Aluminum Jacketing) than would a TAAP based analysis. The effect of JCL vs TAAP would be minimal on other insulation types (those with a lower P_{dest})." "These two methods (ZOI Methods 2 & 3) are then sufficiently conservative to compensate for weaknesses note above, and therefore are considered acceptable by the staff for use on insulation with low P_{dest} values. For insulations noted above with high P_{dest} values, the staff recommends that the ZOI be developed based on the "target area averaged pressures" instead of JCL pressures."	Suggesting that target area averaged pressure (TAAP) may be a more technically correct basis for assessing potential damage to insulation presupposes one understands the failure mechanisms of various insulation types subjected to impingement by a LOCA jet. It is not obvious that an impacting jet, which has a smaller diameter than the target diameter is not more destructive than a jet which is very wide compared to the target diameter. This is because the smaller jet may not remain attached about the target, and may redirect the momentum of the incoming flow at right angles to the flow direction. The larger jet on the other hand presumably remains attached, and the resulting drag forces could be less than that resulting from the smaller diameter jet. Unfortunately, the situation is technically complex, and in light of the application methodology, the jet centerline stagnation pressure was chosen as the metric to quantify the insulation destruction pressure. If one considers the fact that in a drywell where all piping is randomly oriented, the average target would be oriented 45 degrees to the jet centerline, use of jet centerline stagnation pressure, as the measure insulation destruction pressure is very conservative. The BWROG believes that, without a commensurate increase in safety benefit, the added complexity of the TAAP model is not justified and that imposing it as a requirement would cause unnecessary reanalysis. Further, as noted previously, the BWROG believes that the overall conservatism in the various phases of the analysis is adequate to address any concerns that may arise regarding the acceptability of a particular area. The BWROG recommends that the staff approve the JCL model for use on all insulation types tested by the BWROG.	In the staff's draft SER, it is demonstrated how TAAP explains the BWROG's AJIT test data. In the BWROG response quoted here, their justification does not explain their test data. For example, for NUKON, debris generation increases with distance from the jet nozzle up to 30 L/D (while the jet is getting larger, JCL pressure is getting smaller and velocity/momentum is getting smaller), and then decreases beyond that. If the smaller jet has more destructive power as the BWROG claims it may, then why does debris generation go up as distance increases from the break, and then go down after 30 L/D? At 30 L/D, a simple calculation demonstrates that this is the approximate distance at which the jet entirely engulfs the target. In addition, the percentage of fines generated equals the amount of target blanket which is exposed to the jet. Admittedly, the BWROG is referring to two different size jets at the same L/D, but the point still holds true. The BWROG data shows that a larger jet with less velocity and momentum is creating more debris. The NRC also saw this in the Drywell Debris Transport Study, where a 3.75 inch nozzle clearly generated more debris than a 3 inch diameter nozzle at the same L/D. However, upon further review, the staff no longer views this comment as being a significant concern because it only involves a limited subset of insulation types. There are essentially five types of insulation which are affected by this comment. First is Darchem and Transco RMIs. As long as a licensee is sizing their strainer based on saturation loading of RMI debris or using the debris generation/transport factors cited in the URG, this comment is inconsequential due to the level of conservatism in the analysis. In the staff's opinion, the conservative generation and transport assumptions outweigh the concern stated in this open item. The second two insulations are banded to reduce debris generation. Since the staff has not yet accepted banding as a resolution option, the staff recommends that related debris generation concerns for banded insulations be addressed on a plant-specific basis. In comment 27, the staff points out that Cal-Sil should be treated as eroding over time. BWROG debris generation tests were of short duration. The staff has agreed to allow this to be addressed on a plant-specific basis. The staff notes that the BWROG's response to the draft SER did not explain *why* JCL is an appropriate metric.
24	Page 25, last ¶ continued on Page 26	Single versus Double-Ended Flow from a Steam Line Break: "The staff recommends that utilities not take credit for a single jet in the case of a main steam line break inside containment."	The BWROG recommends that licensees be given the option to demonstrate on a plant-specific basis that the ZOI for a steam line break is less than that caused by assuming double-ended flow from the break. Alternatively, licensees may conservatively assume double-ended flow.	As stated in the draft SER, this was a staff recommendation only. It was also stated in the same paragraph that if single-ended flow was assumed by the licensee, they should account for the effects of double-ended flow up to the time the MSIVs close. The staff's comments do not preclude the recommendations made by the BWROG, so no change is required.

Com. No.	Draft SER Ref.	Draft SER Issue Description	BWROG Response	Proposed Staff Resolution
25	Page 26, 2nd ¶	URG Insulation Destruction Data Limited for Some Insulations: "As a result, the staff believes that utilities having materials where the data are limited should conduct additional testing for those materials unless they use a bounding approach to those materials."	The BWROG recommendation is, given the overall conservatism of the analysis previously discussed, that the staff should not impose requirements for additional testing of materials nor should they impose a bounding approach on those materials where there is limited data.	The staff concurs with the BWROG comment and has revised the SER to include a discussion on the conservatism in the URG analysis methodologies. See staff response to BWROG comment 1.
26	Page 26, last ¶ continued on Page 27	ZOI Method 4 Not Acceptable: "As a result, Method 4 is not considered acceptable by the staff without further detailed justification on a plant-specific basis."	The BWROG concurs.	No change required.
27	Page 47, 6th bullet	Damage to CalSil Should be Treated as Erosion: "Damage to calcium silicate should be treated as erosion as demonstrated by Swedish experiments. Table 2 should be revised to alter the failure criterion."	During the meeting on 2/6/98, the staff raised concerns about the limited number of BWROG tests of calcium silicate insulation, possible variations in results among different types of calcium silicate insulation and the effect of aging on the P_{max} of the insulation. Due to these issues, the BWROG recommends that licensees with calcium silicate insulation resolve this on a plant-specific basis.	The staff concurs and has added more detail to the description in the SER.
28	Page 29, 1st ¶	Periodic Inspections are Necessary: "As a result, the staff considers the following statement on page 51 of the URG to be unacceptable, 'Note that where use of an adequately conservative value is assumed for a particular debris species (e.g., dirt/dust), periodic inspections are not necessary.' It is the staff's opinion that periodic inspections are always necessary regardless of any baseline assumptions used in the ECCS analysis. The interval between such inspections should only be adjusted based on actual licensee performance and the amount of conservatism in the base assumption."	The BWROG notes that the intent of this URG statement is that inspections to quantify the amount of dirt/dust are not required. It was not intended to imply that general cleanliness inspections were not appropriate.	No change required. The BWROG's clarification has been noted in the SER.

Com. No.	Draft SER Ref.	Draft SER Issue Description	BWROG Response	Proposed Staff Resolution
29	Page 29, 2nd ¶	Assure URG Guidance is Applicable to Your Plant: "The staff notes that licensees should make every effort to ensure that the guidance in Section of 3.2.2, or any other section of the URG, is applicable to their plant before implementing that guidance on their plant."	The BWROG recommends that as part of the overall evaluation of the issues raised by Bulletin 96-03, each licensee should qualitatively consider whether the generic guidance contained in the URG is appropriate for their plant. It should not be necessary for licensees to conduct detailed quantitative evaluations to justify NRC-accepted values in the URG (e.g., dirt/dust, rust flakes, sludge distribution, etc.). Licensees may elect to use different values than those provided in the URG and, where less conservative than the approved URG values, should document an adequate basis for the values used.	The staff concurs with the BWROG as long as the built-in conservatism in the calculation described in SER section 5.0 is retained. If further analysis refinement is performed by a licensee, then the staff does not agree with the BWROG comment because the numbers for dirt, dust, rust, etc., used in the analysis by licensees are based on engineering judgement. The staff's acceptance is also based on engineering judgement. Since the staff considers these recommendations to be acceptable, the staff has removed the requirement to assess the applicability for each plant. However, he staff still believes that certain licensees may still wish to be prudent and perform an assessment to ensure that the numbers in the URG represent conservative numbers, and that they would not likely to exceed those values during normal operation. The staff has pointed out in its safety evaluation simple assessment methods that can be used to ensure that the numbers used are appropriate on a plant-specific basis. The staff believes that this would be a prudent practice by licensees regardless of whether they are refining their analysis or not. These methods are simple estimations, and would not constitute a significant burden on the licensee. The staff also points out that the results of any qualitative assessment performed by a licensee could focus the licensee on areas that require further detailed analysis. An example may be that a licensee assessing their qualified coatings determining that the condition of their qualified coatings (e.g., blistering, peeling during normal operation) is such that they now must make a detailed assessment to determine the impact of the coating condition on their analysis. Nevertheless, the staff believes that any values less conservative than the URG values to be used by any licensee should be based on detailed technical analysis, not qualitative assessments or engineering judgements.

Com. No.	Draft SER Ref.	Draft SER Issue Description	BWROG Response	Proposed Staff Resolution
30	Page 30, 2nd ¶ Page 32, 1st ¶	150 lbm. Dirt/Dust Value Not Adequately Supported: "The staff believes it would be prudent for utilities to verify this number through sampling. It would be relatively straightforward for the BWROG or an individual licensee to take samples of dirt and dust from the drywell and suppression pool areas, determine typical weight-per-unit area on collecting surfaces, and calculate a bounding value for all applicable surfaces. An allowance would have to be added for concrete dust generated by LOCA forces. ....In addition, consideration should be given to containment size, and the potential for additional dirt and dust accumulation over the operating life of the plant. While the staff does not believe that use of the URG 150 lbm assumption is inappropriate, the staff does believe that it would be prudent for individual licenses to conduct a more thorough evaluation." "Considerable time was devoted to the development of the NUREG/CR-6224 (Ref 31) study to develop conservative estimates of dirt/dust and rust. where provided, the values suggested in the URG are about the same or larger than NUREG/CR-6224 values. As a result, the staff concludes that use of these values is acceptable; however, the staff notes that the NUREG/CR-6224 study was conducted on a reference Mark I containment. For this reason and the additional reasons cited above, the staff believes it would be prudent for individual licensees to evaluate the recommendations of this section for applicability to their plant."	The BWROG understanding of this language is that the staff considers 150 lbm value to be acceptable. Further, the BWROG believes that this issue is adequately addressed given the recommendation in Item 1 for each licensee to consider the overall conservatism of their evaluation and, as described in Item 29, the appropriateness of the URG guidance to their plant. The BWROG believes that there is negligible safety benefit to be achieved by requiring (or encouraging) that each licensee explicitly verify this value and that the radiation exposure received in accomplishment would not be justified.	See staff response to BWROG comment 29.
31	Page 30, 3rd ¶	50 lbm. Rust Flake Value Not Adequately Supported: "This presents the same concern to the staff for this suggestion as for the dirt/dust value noted above. Again, the staff believes that a sound technical basis could be developed by sampling applicable drywell and suppression chamber areas combined with walkdowns to establish typical quantities of rust per unit area. ....As with the dirt and dust discussion noted above, the staff does not believe that use of the 50 lbm assumption is inappropriate."	See the BWROG response to comment 30. The BWROG understanding of this language is that the staff considers the 50 lbm. value to be acceptable and that verification is not a requirement..	See staff response to BWROG comment 29.
32	Page 31, 1st ¶ Page 32 2nd ¶	Coatings Impacted by the LOCA Jet Still an Open Issue: "The staff has not identified any current concerns relative to the conclusions in Reference 51 (Bechtel Report). However, the staff points out that the issue of coatings and their potential impact on the ECCS is an issue currently under staff review, and is the subject of a generic letter expected to be issued in early 1998. As a result, the conclusions of Reference 51 are still under staff review." "Consistent with the staff's guidance above, it would also be prudent for licensees to evaluate the conclusions of the Bechtel coatings report to ensure applicability of those conclusions to their plant."	The BWROG notes that because the staff still has this issue under review, many licensees may not be able to reach a conclusion on whether or not the replacement strainers will satisfy the requirements of Bulletin 96-03. The impact on the schedule for closure of the Bulletin 96-03 response is discussed in further detail in Item No. 2. See BWROG response to Item No. 29.	The staff will consider an extension for demonstrating compliance with 96-03 based on coatings related issues. However, the licensees should proceed with installation of the hardware. See staff response to BWROG comment 29..

Com. No.	Draft SER Ref.	Draft SER Issue Description	BWROG Response	Proposed Staff Resolution
33	Page 31, 2nd ¶ Page 31, 3rd ¶ Page 32, 3rd ¶	The NRC Disagrees that Unqualified Coatings are a Latent Debris Source: "The staff is particularly concerned because there is no basis for this statement, and in the staff's opinion, it is entirely inaccurate. In fact, there is no evidence that indeterminate or unqualified coatings would be latent debris at all. ....the there is no reason to assume that the turbulent environment of the reactor vessel blowdown could not cause the coating to detach and transport to the suppression pool." "In light of recent qualified coating events and the lack of substantive technical basis for the BWROG guidance regarding unqualified and indeterminate coatings, the staff does not have enough information to evaluate the adequacy of the BWROG guidance." "Most importantly, as noted above, the staff concludes that licensees should be cautioned to carefully evaluate the potential impact of unqualified and indeterminate coatings on ECCS suction strainer head loss. If in doubt, assuming the coatings reach the strainer surface would clearly be the conservative measure. This would provide the licensee with less risk relative to the coatings issue, and could lead to additional margin in strainer design if URG statements which minimize the potential impact of unqualified protective coatings are supported by the results of the staff's coating review."	See BWROG Response to Item No. 32. The BWROG has undertaken a testing program for unqualified coatings. The testing and associated analyses will be used to address the concerns raised by the staff. This is a separate effort that will not be addressed by the URG.	As noted above, the staff will consider extending the deadline for demonstrating compliance with NRCB 96-03 until the coatings issue is resolved.
34	Page 33, 5th ¶	Complete Insulation Destruction within 3 L/D: "In addition, the URG estimates assume that for NUKON, all insulation contained within 3 L/D of the break is destroyed into fines. It is not clear, however, that this assumption was made for all debris types."	100% destruction to 3 L/D was assumed for all debris types.	The staff finds this acceptable. It does not appear to be true for RMI, however.
35	Page 35, 1st ¶	Opening in Lowest Level Gratings: "Large debris generated above the lowest grating should not be discounted if the lowest floor grating is not continuous or has substantial openings in it through which larger debris could transport. In this case, an appropriate fraction of large debris from above the grating should be considered as transportable."	To resolve this issue, the BWROG recommends that the staff consider the overall conservatism in the BWROG approach as being sufficiently conservative to address this concern. The BWROG notes that there are multiple levels of gratings and other obstructions which would also be effective at preventing the transport of debris but they are not credited in the analysis. If the above approach is not adopted, the staff should clarify what constitutes "substantial openings" and "appropriate fraction of large debris" as these terms could lead to inconsistent regulatory interpretation.	Based on the staff's evaluation of the built-in conservatism in the URG methodologies, the staff has removed this requirement from the URG.

Com. No.	Draft SER Ref.	Draft SER Issue Description	BWROG Response	Proposed Staff Resolution
36	Page 35, 2nd ¶	Mark II Transport Values Not Acceptable: "Therefore, the staff finds the transport fractions for Mark II containments listed on pages 75 and 80 of the URG to be unacceptable. Fractions are also given on the same pages for fine fibrous debris transport and RMI debris transport in Mark I's and III's. The values given for Mark I's and III's assume that 100% of the fine debris will transport to the suppression pool. ...The staff believes that these same fractions should also be used for Mark II's.	The basis for the staff's current position not to accept the transport values for Mark II's is the results of testing conducted by the NRC. These tests are documented in NUREG-CR/6369 which has not yet been published. The staff completed these tests in the first half of 1997 and made a presentation of the results in July 1997. The BWROG has previously requested a draft of the NUREG so as to be able to review the details of the test setup, parameters and procedures. The staff has stated that they cannot release the NUREG until final publication. The BWROG requests the opportunity to defer their response to this issue until the NUREG is made available. Upon receipt, we will evaluate the impact of the test differences between the BWROG scaled tests and the NRC tests on the outcome of the results.	A copy of the NUREG was forwarded to the BWROG on April 18, 1998. The staff is waiting on any further comments from the BWROG that results from their review.
37	Page 35, 3rd ¶	100% Transport of Large Debris Below the Lowest Grating: "The staff concludes that insufficient technical justification has been provided for assuring a transport fraction less than 100% for large debris generated below the lowest drywell grating."	This issue was discussed with the staff and resolved at the February 6th meeting. In summary, the BWROG approach is to calculate a transport factor as a percentage of the total debris while the staff approach is to use a transport factor for transportable debris. The BWROG notes that in the NRC Drywell Debris Transport Study, the NRC interpretation of the AJIT test report is that 40% of the NUKON insulation within the ZOI is in the form of "canvassed debris" which is not transportable. Hence, the NRC position is that the maximum amount of debris which can be transported to the suppression pool from the lower portion of the drywell is 60% of the initial insulation within the ZOI, a lower number than the corresponding 78% of the URG. This provides further evidence that the recommended values in the URG support the BWROG position that the overall methodology is sufficiently conservative.	The staff concurs with the BWROG comment and has modified the SER accordingly. Regarding the BWROG's second comment, regarding the overall conservatism in the analysis methods in the URG, see the staff's response to BWROG comment no. 1.
38	Page 36, 4th ¶	Erosion from Unthrottled ECCS Flow: "if it does continue for more than three hours, then the licensee should determine an appropriate fraction to assume. Erosion of NUKON was shown to be linear in the NRC tests, so scaling of erosion of NUKON can be performed easily. Similar testing could be conducted for other insulation types, if necessary, to determine an appropriate fraction to assume for erosion."	The staff concern discusses the erosion rate but does not consider the conservative position taken in the URG on the amount of insulation material that would be exposed to erosion. Following the break, the fibrous debris generated will be distributed over the containment and only a small fraction will come to rest within striking distance of spill from the break. A portion of that which does reside in the spill area will be pushed aside by the flowing water as it splashes onto the drywell floor. Therefore, only a small fraction of the large fiber debris is subjected to wash down erosion. Despite this, the URG assumes that 25% of fibrous "large debris" (i.e., not fines) is exposed to the eroding affects of the spill from the break. The BWROG believes that any concerns regarding the effect of erosion over periods greater than 3 hours are more than offset by the conservative assumption on the amount of insulation that adopting the staff position could result in additional operator burdens and would require a change to emergency operating procedures which would be inconsistent with their symptom-based design. The BWROG recommends that erosion values consistent with those in the URG (e.g., 6.25% for NUKON fiber, 25% for Min-K, etc.) be accepted and that a time dependent factor not be introduced.	The staff concurs with the BWROG comment and has revised the SER accordingly. However, the staff takes exception to the absolute language in the BWROG comment. While it is unlikely in the staff's opinion that 25% or more of the insulation debris may land where it will be eroded by break flow, it cannot be said that the only possible scenario is that "only a small fraction will come to rest within striking distance of spill from the break. A portion of that .....will be pushed aside by the flowing water.....Therefore, only a small fraction of the large fiber debris is subjected to wash down erosion." In fact, AJIT testing and NRC testing showed that gratings in the break jet flow stream could filter and retain large debris. For a break in a vertically oriented pipe (such as a recirc line), then, it is possible to accumulate a significant amount of debris below the break.

Com. No.	Draft SER Ref.	Draft SER Issue Description	BWROG Response	Proposed Staff Resolution
39	Page 38, 1st ¶	New Destruction Values Needed for Some Insulations: "However, the staff identified that N_s values were obtained for several insulations based on a very limited set of experimental data. Examples are Temp-Mat, K-wool and some of the RMI. ....Therefore, the staff suggests that licensees with these insulations determine N_s values as follows: 1. Assume that all the insulation contained in 3D spherical region becomes destroyed into fines, and 2. Assume that rest of the insulation would be destroyed such that local N_s is equal to the lowest N_s value measured in the experiments."	The URG methodology assumes 100% fines (fiber) within 3 pipe diameters. Where test data was limited for some materials, the BWROG used curve shapes that were consistent with materials for which several data points existed. The volume averaged destruction factor is not significantly affected by the curve shape. Based on the overall conservatism in the ZOI methodology, the BWROG recommends that the guidance in the URG be accepted and that the licensees not be required to adopt the approach suggested by the staff in the draft SER.	See staff response to BWROG comment no. 1. Based on the overall conservatism, the staff finds this acceptable.
40	Page 42, Item 1	BWROG Head Loss Model is Unreliable and Incomplete: Use of cookbook procedure may lead to erroneous head loss predictions. The staff does not believe their previous comment on this topic has been resolved.	All BWR licensees intend to use the head loss model provided by the selected strainer vendor which is specific to the replacement strainer. Consequently, the issue is moot and further response is not provided. The BWROG does note that licensees should be sensitive to the issues raised by the staff regarding head loss correlations and should assure that, where applicable, these issues are adequately addressed by the strainer vendor.	The staff concurs. No change required.
41	Page 42, Item 2	Variation in Fiber Density: NUKON fiber density as manufactured (2.4 lbm/ft^3) is greater than as-destroyed (~1.3 lbm/ft^3)and the BWROG model does not address which could lead to inconsistent results.	See response to Item 40. The BWROG also notes that mass, not density, is typically used in head loss correlations.	No change required.
42	Page 42, Item 3	Limited Applicability of Model: Applying the BWROG head loss prediction model to plant conditions that differ markedly from tested conditions could lead to erroneous head loss predictions. These limitations should be clearly stated.	See response to Item 40.	No change required.
43	Page 43, Item 4	Head Loss Model Not Applicable to Thick Beds: The test data and correlation were based on low debris loadings on the strainer surface. The staff's opinion is that the equation and the procedures are not applicable to thick combination fibrous/particulate debris beds. "As a result, the staff recommends that licensees utilize vendor specific test data demonstrating the strainer head loss for various debris loadings up to and including the licensee's limiting debris load."	See response to Item 40.	No change required.
44	Page 43, Item 5	Thin-bed Effect: "The experimental data is neither complete nor was it supported by sufficient quantitative analytical reasoning to support the URG statement that the thin-bed effect is not a concern for alternate strainers. ....It is reasonable to state that medium breaks will not result in large head losses that are not bounded by large breaks, but a statement that no 'thin-bed effect' was observed is incorrect."	See response to Item 40.	No change required.

Com. No.	Draft SER Ref.	Draft SER Issue Description	BWROG Response	Proposed Staff Resolution
45	Page 43, Item 6	Use Licensing Basis for Operator Actions: "In calculating NPSH, licensees should ensure that their calculations are consistent with their licensing basis. For instance, typically, no operator action is credited for the first 10 minutes during a postulated LOCA. Therefore, NPSH should be evaluated at runout flow until the plant licensing basis allows otherwise."	The BWROG concurs.	No change required.
46	Page 43, Item 7	Temperature Correction is Unacceptable: Reference 31 in the URG (CDI Memo 98-13 Effect of Temperature on NPSH Including Strainer Head Loss) is considered as an unacceptable methodology by the staff for determining minimum NPSH. The staff finds this methodology unacceptable because it incorrectly assumes that head loss across the strainer will be governed by laminar flow."	From the discussions during the meeting on 2-6-98, it was learned that the staff position is that the temperature correction methodology is not applicable to RMI debris beds. The BWROG concurs that it is not applicable to RMI beds but that the URG methodology is applicable to fiber beds.	The staff has clarified the SER.
47	Page 41, Item 5	Particulate Mass Not Accurately Accounted for in the Debris/Head Loss Correlation	See response to Item 40.	No change required.
48	Page ES-3, last sentence	Submit Analyses for Pipe Separation/Single Ended Blowdown: "Licensees desiring to take credit for limited separation of the broken ends due to pipe restraints or single ended blowdown should conduct supporting analyses and submit them for further review before their use."	The BWROG recommends that the staff revise this position and not require that licensees submit supporting analyses for pipe separation or single ended blowdown for staff review prior to their use. Instead, licensee should assure these analyses are available for review during inspection.	The staff concurs and has revised the SER accordingly.
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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

October 13, 1998

Mr. Rocky Sgarro
Pennsylvania Power and Light
2 North Ninth Street
Mail Code A6-1
Allentown, PA 18101

SUBJECT: CORRECTION TO PAGE B-5 OF THE STAFF'S FINAL SAFETY EVALUATION ON GENERAL ELECTRIC TOPICAL REPORT NEDO-326896, REVISION 0, "UTILITY RESOLUTION GUIDANCE FOR ECCS SUCTION STRAINER BLOCKAGE" AND CLARIFICATION OF THE STAFF'S POSITION ON EROSION OF CALCIUM SILICATE INSULATION

Dear Mr. Sgarro:

By letter dated November 20, 1996, the Boiling Water Reactor Owners group (BWROG) transmitted General Electric topical report NEDO-326896, Revision 0, "Utility Resolution Guidance for ECCS Suction Strainer Blockage," (URG) to the NRC staff for review. The staff completed its review of the URG, and issued its final safety evaluation by letter dated August 20, 1998.

In a public meeting with the BWROG on September 8, 1998, the staff was made aware that Page B-5 in the safety evaluation has typographical errors which could significantly impact a licensee's use of the URG. A corrected page is attached. Please remove Page B-5 from the staff's safety evaluation transmitted by letter dated August 20, 1998, and replace it with the attached page (Enclosure 1).

During the September 8, 1998, meeting, it also became clear that some licensees were confused by the wording on Page 26 of the safety evaluation regarding the erosion of calcium silicate insulation (Cal-Sil). In the first paragraph on Page 26, the staff states "The fifth affected insulation is calcium silicate (Cal-Sil) which the staff notes should be treated as being eroded over time by the break jet." The staff is not referring to erosion by ECCS water flow. "Break jet," in this case, refers to the blowdown phase of the accident. The staff position is that for the entire duration of the blowdown, jet impingement from the break jet would continue to generate debris from Cal-Sil insulation located within the zone of influence. The staff believes that the BWROG debris generation tests for Cal-Sil did not adequately demonstrate how much debris would be generated from Cal-Sil insulation because the tests were based on short duration (approximately 5 seconds) blowdowns. Therefore, the staff concludes that the amount of Cal-Sil debris generated should be calculated by scaling the test data to the full duration of the postulated blowdown.

If you have any questions about the corrected SER page or the clarification of the staff's position concerning the erosion of calcium silicate insulation, please call Mr. Rob Elliott, at 301-415-1397.

Sincerely,

Thomas H. Essig, Acting Chief
Generic Issues and Environmental Projects Branch
Division of Reactor Program Management
Office of Nuclear Reactor Regulation

Project No. 691

Enclosure: As stated

cc w/enclosure: See next page

Table B-1 Results of CEESI Testing for Each Insulation Material.

Insulation Material	(L/D) Dest.[3]	URG Damage Pressure (psi)	JCL[4] Pressures Estimated in Confirmatory Analysis
Darchem DARMET®	5.0	190	190
Transco RMI [5]	5.0	190	190
Jacketed NUKON® with Sure-Hold® Bands	>11[6]	190	150*
DPSC MIRROR® with Sure-Hold® Band	8.5	190	150*
Calcium Silicate with Aluminum Jacketing	7	160	150*
K-Wool	15	40	40
Temp-Mat with stainless steel wire retainer	30	17	17
Knaupf®	60	10	10
Jacketed NUKON® with Standard Bands	>50	10	10
Unjacketed NUKON®	>60 ; < 119	10	10
Koolphen-K®	>80[6]	6	6
DPSC MIRROR® with Standard Bands	99	4	4
Min-K	>100[6]	4	< 4

- **Scalability of Results to BWR Drywells**: In the CEESI experiments, a 3-inch diameter nozzle was used to simulate a broken pipe, and a 12-inch diameter pipe was used to simulate a target pipe (Reference B.2). This raises the following concerns related to scalability of the experimental results:

  — How can damage pressures obtained for 12-inch target pipe be used to estimate damage pressures for a smaller or a larger pipe? Since all insulation blankets are attached to pipes of different diameters by identical straps, their failure occurs at same target load irrespective of the target pipe diameter (i.e., one should look for load conservation). Therefore, the following equation holds:

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[3] The maximum distance at which damage or dislodgment is reported for the insulation type of interest.

[4] The jet-center-line pressure corresponding to $(L/D)_{dest}$. The JCL pressure was extracted from the CFD results of Reference B.3.

[5] Several different types of Transco RMI insulation was tested. However, the results presented here are for TPI 0.024-inch sheath solid end (stainless steel) with latch and strike closures. According to the URG, this insulation appears to be the most commonly found Transco RMI in BWRs.

[6] Exact number not known since testing did not go beyond the values listed for which significant damage was evident.

Project No. 691
Boiling Water Reactor Owners Group

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3

Attachment 2

United States Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Division of Engineering Technology
Generic Safety Issues Branch

FACSIMILE SHEET

DATE: December 23, 1996

TO: Mr. Tom Green, Senior Technical Project Manager
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FROM: Michael L. Marshall, Jr., Task Manger
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Fax #: 301-415-5062 Phone #: 301-415-5895

Number of Pages (excluding cover sheet): 7

SUBJECT: TRANSMITTAL OF NRC STAFF'S INITIAL COMMENTS ON URG

The attached list of comments is not a complete or final list of staff comments on the URG. Also, none of the comments should be construed as an official NRC position regarding the BWR suction strainer debris blockage issue or any other issue. The purpose of the list is to document the most significant comments by the staff on the URG. The staff originally presented these comments during the 12/17/96 public meeting with the BWROG. If you have nay questions regarding these comments please contact R. Elliott or M. Marshall.

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Initial Staff's Comments and Questions on URG

Suggested Solutions

1. Throughout the URG, there is a great deal of references and discussion on several different potential licensing basis changes a utility may wish to pursue in determining a resolution to the BWR Strainer Clogging issue. The staff position on these types of amendment requests is that it is unwilling to consider scheduler extensions because a licensee decides to request a license amendment. The staff strongly encourages licensees to develop a resolution that stays within their current licensing basis, if possible. If a utility needs a license amendment in order to complete its resolution of the issue, then it should get such requests to the staff as early as possible in order to facilitate a timely turnaround by the staff, and it should factor the staff review time into its schedule.

2. Page 22, Section 3.1.3.4.7, "Partial Replacement of Fibrous Insulation with RMI:" This section requires substantially more detail in order for the staff to understand how a licensee would utilize this potential solution/partial solution. In addition, there is no guidance for the utility to follow. The staff is concerned that utility may only evaluate a limited set of potential break locations (but enough to comply with 10 CFR 50.46), conduct partial replacement of insulation for those selected breaks, and then ignore other potential breaks where large volumes of fibrous insulation could be generated.

3. Page 16, Section 3.1.3, "Plants With Significant Amounts of Fibrous Insulation," Last Paragraph (continues on Page 17): What is the purpose of this paragraph? It seemingly counsels utilities to take no action (not even conducting their 50.59 evaluations) until the NRC approves the URG. Licensees should be doing as much as they can during the time the staff is reviewing this document, especially their 50.59 evaluations.

Pipe Break Locations

1. Page 27, Section 3.2.1.1, "Pipe Break Locations:" The staff's position on the use of SRP Section 3.6.2 is misrepresented on this page. The staff points out that NUREG 0897 summarizes the staff's technical findings relative to the resolution of USI A-43. It does not constitute a regulatory position. The forward to NUREG 0897 on page xiii states that "It should also be clearly noted that this report is not a substitute for requirements set forth in General Design Criteria 16, 35, 36, 38, 40, and 50 in Appendix A of Title 10 of the Code of Federal Regulations Part 50, nor is it a substitute for guidelines set forth in NRC's Standard Review Plan (SRP, NUREG-0800), Regulatory Guides, or other regulatory directives."

   As pointed out to the BWROG in the staff's letter to R. Sgarro dated July 25, 1996, "10CFR50.46 states in part, that ECCS cooling performance "must be calculated for a number of postulated loss-of-coolant accidents of different sizes, locations, and other properties sufficient to provide assurance that the most severe postulated loss-of-coolant accidents are calculated." There is no language in the rule that implies only the most probable break locations need to be evaluated." The staff goes on to say that while SRP Section 3.6.2 "may be a good starting point from which to start an analysis, it does not by itself appear to be sufficient to meet the intent of the rule. The Standard Review Plan

(SRP), Section 3.6.2 and Branch Technical Position (BTP) MEB 3-1 was developed for looking at dynamic and environmental effects of an LOCA (e.g., pipe whip), and are not considered sufficient for meeting the requirements of 10CFR50.46 for the ECCS suction strainer clogging issue.
SRP Sections 6.3 and 15.6.5 deal with evaluation of the ECCS, and more specifically, the adequacy of ECCS performance. The review procedure of 15.6.5 specifically requires reviewers to ensure that "A variety of break locations and the complete spectrum of break sizes were analyzed." This is clearly the intent of 10CFR50.46. Regulatory Guide 1.82, Revision 2 (RG 1.82) Regulatory Position 2.3.1.5 states the following: "As a minimum, the following postulated break locations should be considered. (a) Breaks on the main steam, feedwater, and recirculation lines with the largest amount of potential debris within the expected zone of influence, (b) Large breaks with two or more different types of debris within the expected zone of influence, (c) Breaks in areas with the most direct path between the drywell and wetwell, and (d) Medium and large breaks with the largest potential particulate debris to insulation ratios by weight." The staff believes that the RG provides a more complete scope of breaks needed to meet the intent of 10CFR50.46."

The staff also points out that neither SRP Section 3.6.2 nor BTP 3-1 references 10 CFR 50.46, or in anyway discusses compliance with that rule.

2. Page 32: The URG provides no guidance on how to evaluate pipe breaks inside the bio-shield wall. It's not even clear if they consider it necessary to do so. When the URG leaves it up to an individual utility to decide if, or how, to perform some part of the analysis, it is impossible for the staff to draw any conclusions as to the adequacy of the proposed methodology.

3. URG 3.2.1.1 embodies guidance found in RG 2.3.1.1, but not all guidance found in RG 2.3.1.5 - "Medium and large breaks with the largest potential particulate debris to insulation ratios by weight." Even though the URG did mention this break location criterion, in the section that gives clear directions, this criterion seems to be neglected. The staff is aware of the BWROG claim that the above criterion is not a problem for alternate strainers, but the URG does not limit itself to providing guidance for alternate strainers.

Debris Generation

1. Page 36, Section 3.2.1.2, "Zone of Influence:" What is the basis for the calculation shown and its applicability to all containments? It appears that the inputs for M and A for a Mark II are incorrect. The staff is concerned that this calculation underestimates bulk dynamic pressure.

2. Pages 37 and 38, Sections 3.2.1.2.3.1 and 3.2.1.2.3.2, Methods 1 and 2 for calculating Zone of Influence: These methods provide no information on size distribution of debris, so it is not clear what the basis is for not assuming 100% transport to the suppression pool. Also, please explain how Method 2 will be applied to a full size containment?

3. It is not clear if/how the CEESI AIJT tests were scaled to represent larger pipe breaks. The staff is concerned that a larger break will generate a different debris distribution (i.e., more fines) than the distribution measured during the AIJT program.
The staff believes that the size of the nozzle in a debris generation experiment may affect the percentage of debris fines that are generated. Consequently, a large break is likely to generate a higher percentage of fines than a smaller break which could substantially impact the amount of debris transported. The BWROG data is developed based on one nozzle size. What is the basis for scaling that to a large break in a plant?

4. During past meeting with the staff, the BWROG has conceded that the insulation on the break will be destructed into fines. If is not clear from the debris generation section how the debris on the ruptured pipe is included in the estimation of fine debris.

5. Debris generation (specifically debris distribution) should in part be a function of distance from the break. While comparing the category 1, 2, and 3 debris classes by distance from the break, the staff discovered that fewer fines (by mass) were generated in tests where the target was closer to the break than in tests where the target was located further from the break (see attached figure). These results appear to be counter intuitive. One would expect more fine debris closer to the break. How did the BWROG explain these results? Were all the tests valid?

6. Because the words used to described debris size are subjective (e.g., fine, shred, large, etc.) a more quantitative description should be included in the body of the URG. For instance in NUREG/CR-6224 fine fibrous debris is classified as Class 1 which is small single strand of fiber glass, but the URG characterizes fines as Category 1 which is fibrous debris that is smaller than an adult male open hand (this definition is not explicitly stated in the URG).

7. The conclusion that: "The amount of debris that might be generated by unqualified coatings that are close to a line break location is expected to be small compared to the bounding estimates for the jet impingement debris" runs contrary to the failure of unqualified coatings made on page 28 of 33 and is not supported by information in this section. Examination of HDR post-blowdown pictures in Appendix C of NUREG/0897 Rev. 1 (e.g., Figures C-4 and C-5) which show walls in compartments distant from the jet nozzle chamber stripped of wall paint do not support this conclusion.

8. The abstract notes that insulation removal has been shown when the fluid stagnation pressure exceeds a certain value, "which has been shown to typically range from several psi to about 50 psi for fibrous insulation materials." From my review of the CEESI experiments in the URG supporting Volume II, I find this statement misleading. Severe destruction of unjacketed fibrous insulation targets occurred at stagnation pressures on the order of 12 to 20 psig. This statement is also not supported by the values set forth in Table 2, page 39 of the draft URG.

Drywell Transport

PCI NUKON CEESI Tests

URG Support Vol. II

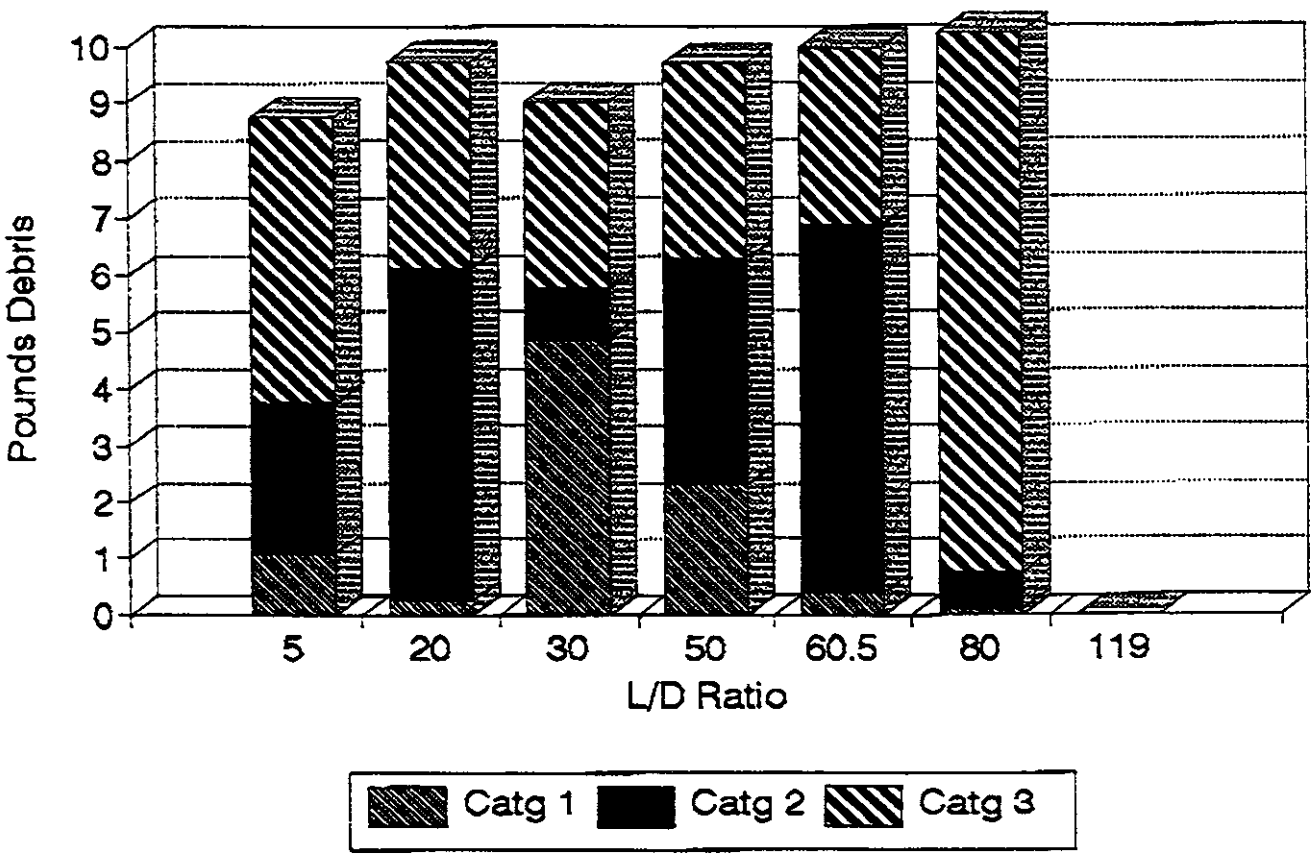

Figure 2

1. The staff is interested in how transportability (i.e., transport fractions) of materials other NUKON and RMI was determined. The tests at CDI seem to focus on NUKON and RMI. The staff is interested in knowing if enough data was collected during the BWROG test program to access the transportability of materials other than NUKON and RMI.

2. How should/are results shown in Figure F1 in Volume II, Tab 2 on Page E-2 adjusted for ZOI that are smaller than 100D. The staff is concerned that transportable debris will be under predicted if these results are not adjusted for smaller ZOI.

NPSH Calculations

1. Page 121 lines 14 through 19 states, "it may be acceptable to evaluate NPSH at reduced ECCS flows during the period of peak temperature, reducing the head losses at the strainer and again increasing NPSH available. If the NPSH analysis credits reduced ECCS flow through the strainers in order to meet pump NPSH requirements, appropriate operating and emergency procedures should be in place and operator training conducted so there is assurance that the operators will reduce pump flow at the appropriate point in the accident progression."

   Additionally, page 124 lines 22 through 24 states that "care should be taken to ensure that changes in ECCS flow rates are consistent with the inputs and assumptions used in the evaluation model required by 10CFR 50.46 to calculate the ECCS cooling performance."

   The staff is not aware of any licensing basis that credits reduced ECCS flow to meet NPSH requirements. If this is the case, it is not clear to the staff how reduced flows would be modeled in the LOCA analysis. LOCA methodology generally requires the input of ECCS design flows. This approach does not appear to be conservative.

2. On page 122 in the BWROG Guidance section, step one states that the "calculation of pump inlet conditions should follow the methodology described in Section 3.2.3 of NUREG-0897, Revision 1 with the following exceptions:

   c) the methodology provided in Reference 31 should be used to determine the temperature of the pumped fluid used in the calculation of NPSH available to the ECCS pumps."

   Then on page 123, step 3 states "the range of expected temperatures of the pumped fluid should be considered when evaluating the NPSH available to the ECCS pumps. In making a determination of the range of expected fluid temperatures, the following should be considered:

   a) the plant licensing basis may specify the maximum expected fluid temperature. If specified in the licensing basis, this value should be used unless the plant licensing basis is changed.

   b) the maximum fluid temperature may be calculated using industry accepted analytical

tools such as Contempt, GOTHIC, Contain, etc."

There does not appear to be any consistency in the guidance as to which maximum temperature should be used in the NPSH available calculation, i.e., the Reference 31 value, the tech spec value, or the value calculated by the analytical tools. The maximum value stated in the tech specs or FSAR should be used in the NPSH calculated unless the plant licensing basis is changed.

3. The staff is unwilling to consider license amendments to provide credit for containment pressure to plants who do not already have it approved. In addition, the staff is unwilling to consider increases in the amount of pressure credited for plants who were licensed with credit for containment pressure. Since the issuance of RG 1.1, the staff has been unwilling to consider such requests, and is still reticent to do so.

4. In the URG, it is stated that the head loss data collected by the BWROG is applicable to other strainer designs. The URG should explicitly discuss or describe the criteria that need to be satisfied in order to ensure that data is properly applied.

5. The staff and its contractor are currently in the process of compare values calculated with equations 6-8 (with bump-up factors) with the data collected during the BWROG's alternate strainer test program (i.e., EPRI tests). When the calculated values were compared to four of the tests, three of the measured values were higher than the calculated value (by as much as 25%). Considering the NPSH margin that some plants have a 25% difference could be significant. Are there any conditions that cannot be attributed solely to curve fitting were equation 6-8 consistently under predicts head loss that the staff should be made aware? Has the BWROG attempted to quantify the uncertainty/confidenceassociated with equation 6-8?

URG Overall

1. The URG does not appear to provide a specific methodology for analyzing a plant. Rather, it chooses to provide many different options which licensees can pick and choose at their discretion. The fact that the BWROG "does not recommend" a certain option does not stop a utility from using it. Many of the options are sufficiently ambiguous as to allow multiple interpretations. The acceptability of any particular calculation cannot be judged on its own. It must be evaluated as an entire analysis. A calculation of one aspect of an analysis may be conservative, but that does not mean that the whole analysis will be conservative. For instance, to assume 100% of the fiber in containment is generated as debris may be conservative. But if only a minute fraction of that debris is considered as being transported to the suppression pool, the entire analysis may end up non-conservative. In other words, the URG does not provide any assurance that a utility will follow a specific combination of options which will lead to a reasonable or conservative analysis (i.e., solution).

The staff is of the opinion that our resources would be better used in reviewing detailed plant specific responses because the URG allows so many variations that we will be

compelled to perform detailed reviews or audits of plant specific fixes. A licensee committing to perform its analysis in accordance with the URG has not provided the staff with sufficient information on which to determine the acceptability of their response.

2. The words bound (incl. bounding) and conservative should be clearly defined in the URG, because the definitions of these words tend to be subjective. The staff needs to have a firm and clear understanding of their usage.

GE Nuclear Energy

General Electric Company
175 Curtner Avenue, San Jose, CA 95125

OG97-044-161
January 30, 1997

NRC Project 691
NRC Bulletin 96-03

Mr. Robert B. Elliott
U.S. Nuclear Regulatory Commission
One White Flint North [8H7]
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Rockville, MD 20852-2738

Subject: ***BWR Owners' Group Response to NRC Comments and Questions Regarding NEDO-32686 Revision 0, "Utility Resolution Guidance for ECCS Suction Strainer Blockage"***

Attachments: (1) BWR Owners' Group Response to NRC Comments and Questions Regarding the Utility Resolution Guidance for ECCS Suction Strainer Blockage
(2) Facsimile Transmittal, Mr. Tom Green from Michael L. Marshall,Jr., "Transmittal of NRC Staff's Initial Comments on URG", dated December 23, 1996

The BWR Owners' Group (BWROG) ECCS Suction Strainer Committee has prepared responses to the NRC initial comments and questions regarding the BWROG Utility Resolution Guidance (URG) for ECCS suction strainer blockage (see Attachment 1).

We believe that this supplementary information along with the preliminary plant specific alternate passive strainer design information previously transmitted to you on January 13, 1997 will support your ongoing efforts to complete the URG review in a timely manner. As you are aware, BWRs with fall '97 refueling and maintenance outages will require approval of the URG calculational methodology in order to minimize risks associated with their ongoing efforts to design and fabricate alternate passive strainers.. Installation of these strainers is expected to resolve the ECCS pump suction strainer plugging issue for the affected BWR plants.

Please note that the BWROG currently plans to amend the URG when all of the comments and questions are appropriately resolved, and the NRC has issued their Safety Evaluation Report (SER). At that time we will provide further clarifications to our members in accordance with the SER and issue an approved document package.

The attached response to initial NRC comments and questions has been prepared by the BWROG ECCS Suction Strainer Committee to support the NRC review of the URG and the related technical documentation. This letter should not be interpreted as a commitment of any individual member to a specific course of action. Each member must

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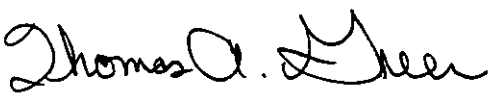
formally endorse the BWROG position in order for that position to become the member's position.

If you have questions regarding this transmittal please contact the committee chairman, R. Sgarro (PP&L) at 610-774-7552, or the undersigned.

Very truly yours,



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J.H. Wilson, NRC
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K.K. Sedney, GE

g044-161

Attachment 1

BWR Owners' Group Response to NRC Comments and Questions Regarding NEDO-32686 Revision 0, "Utility Resolution Guidance for ECCS Suction Strainer Blockage"

This document provides the BWROG response to the comments and questions of the NRC staff dated December 23, 1996 regarding the BWROG Utility Resolution Guidance (URG) document.

Suggested Solutions

The NRC staff provided three comments related to suggested solutions.

Comment 1

This comment expresses an NRC staff position that it is unwilling to consider scheduler extensions because a licensee requests a license amendment and encourages licensees to stay within their current licensing basis, if possible, in resolving this issue. Those licensees which do require a license amendment as part of the issue resolution should request them as early as possible.

BWROG Response

The BWROG agrees that licensees which anticipate that a license amendment will be necessary for the resolution option to be implemented should make their intentions known to the NRC staff as early as possible in order to facilitate the timely submittal and processing of the license amendment.

Comment 2

This comment is related to pipe break locations and is addressed in that section of the BWROG response.

Comment 3

This comment expresses an NRC staff concern that the URG counsels utilities to delay action, not even conducting 50.59 evaluations, until the NRC approves the URG.

BWROG Response

The BWROG addressed this comment during a meeting with the NRC staff held December 17,

1996. In summary, the section of the URG referred to by the staff comment encourages licensees to proceed with a *final* solution to the strainer blockage issue but cautions them that pursuit of *interim* solutions may identify an unreviewed safety question whose resolution may divert the resources of both NRC staff and the licensee, resulting in a delay in implementation of a final solution.

Pipe Break Locations

The NRC staff provided four comments related to pipe break locations.

Comment 1

The first comment is item 2 under the "Suggested Solutions" heading. This comment expresses an NRC staff concern that a utility may evaluate only a limited set of break locations (but enough to comply with 10 CFR 50.46), conduct partial replacement of insulation for those selected breaks, and then ignore other potential breaks where large volumes of fibrous insulation could be generated.

The BWROG response to this comment is incorporated in the response to Comment 2.

Comment 2

The second comment is item 1 under the "Pipe Break Locations" heading. This comment expresses an NRC staff concern that the NUREG-0800 Standard Review Plan (SRP) Section 3.6.2, and Branch Technical Position MEB 3-1 are not sufficient for meeting the requirements of 10 CFR 50.46 for the strainer clogging issue. The NRC staff believes that the pipe break locations identified in Regulatory Position 2.3.1.5 of Regulatory Guide 1.82, Revision 2 provide a more complete scope of breaks needed to meet the intent of 10 CFR 50.46.

BWROG Response

Based on the BWROG survey provided to the NRC staff on January 13, 1997, 11 of 24 BWR units responding to this survey anticipate using an MEB 3-1 approach in the selection of pipe break locations to be considered in the evaluation of debris generation. Other plants have licensing basis pipe break locations based on MEB 3-1 criteria but plan to use the guidance in the URG which provides a simplified analysis method (e.g., assume all fibrous insulation in the drywell is within the ZOI) to determine the amount of debris generated.

While the BWROG believes that SRP 3.6.2 and MEB 3-1 provide an acceptable means for identification of pipe break locations to be evaluated, the NRC staff should not infer that the evaluation approach provided in the URG is intended to "cherry pick" break locations to minimize the amount of debris generated. The URG clearly recommends that licensees consider

the break locations identified in Regulatory Position 2.3.1.5 of Regulatory Guide 1.82, Rev. 2 if these break locations have not already been evaluated. (An exception noted in the URG is pipe break locations described in Regulatory Position 2.3.1.5 (d) which is addressed in Comment 4).

It should also be noted that based on the BWROG survey previously referenced, only one plant is giving consideration to crediting pipe restraints in the evaluation of the zone of influence. Most plants intend to treat the breaks as unrestrained breaks producing double-ended jets. This will result in very large zones of influence. For example, an unrestrained break of a 28 inch recirc line (25.6 inch inside diameter) will result in a spherical zone of influence of approximately 44 ft. in diameter for unjacketed Nukon® insulation. These large zones of influence will assure that a conservative amount of debris will be input to the next step in strainer head loss evaluation. As discussed further in the response to Comment 2 under the Debris Generation section, another conservatism in the size of the zone of influence is that the URG methodology does not take into account the attenuation which would occur as the jet expands and interacts with piping, equipment and structures which fill the drywell.

The BWROG believes that SRP 3.6.2 and MEB 3-1 are sufficient for meeting the requirements of 10 CFR 50.46. The BWROG notes that SRP 3.6.2 identifies four specific areas reviewed by the NRC during the operating license stage. The fourth of these areas to be reviewed is described as:

> "The design adequacy of systems, components, and component supports to assure that the intended design functions will not be impaired to an unacceptable level of integrity or operability as a result of pipe whip *or jet impingement loadings*." (emphasis added) SRP 3.6.2, Rev. 1, July 1981.

The "Review Procedures" section of SRP 3.6.2 discusses the review criteria used by the NRC staff, including those related to jet impingement. It states, in part:

> "Analyses of jet impingement forces are reviewed. These analyses should show that jet impingement loadings on nearby safety-related structures, systems, and components will not be such as to impair or preclude essential functions."

The BWROG believes that the jet impingement loading on piping insulation and other materials in the drywell are within the scope of dynamic effects evaluated under SRP 3.6.2. Therefore, a plant with a licensing basis population of pipe break locations that are in accordance with the requirements of SRP 3.6.2 (which includes MEB 3-1 criteria) has already identified those breaks which are required to be evaluated. Imposition of selection criteria for pipe break locations different than used to identify the existing plant licensing basis pipe break locations would introduce regulatory inconsistency in the way pipe break locations are selected. Further, it is expected that a backfit analysis would be required prior to imposition of pipe break location selection criteria different than those embodied in the existing plant licensing basis. Performance of a backfit analysis would be inconsistent with the current NRC position that the strainer blockage issue is a compliance backfit.

Comment 3

The third comment is item 2 under the "Pipe Break Locations" heading. This comment expresses an NRC staff concern that the URG provides no guidance on how to evaluate pipe breaks inside the bio-shield wall or if it is necessary to do so.

BWROG Response

The reference to pipe break locations inside the bio-shield wall was made in the URG so that licensees did not inadvertently ignore the potential debris which may be generated from breaks inside the bio-shield. As can be seen from the utility responses to the BWROG survey, for most plants the insulation materials inside the bio-shield wall are not expected to be a major debris contributor. However, for those few plants which may have significant debris sources inside the bio-shield wall, a plant specific analysis is recommended to address debris generation inside the bio-shield. Because of the small number of plants affected and plant specific factors which would affect this analysis, the URG did not attempt to provide generic guidance on this issue.

Comment 4

The fourth comment is item 3 under the "Pipe Break Locations" heading. This comment expresses an NRC staff concern that the URG does not adequately address the pipe break selection criterion identified in Regulatory Position 2.3.1.5 (d) of Regulatory Guide 1.82, Rev. 2, i.e., medium and large breaks with the largest potential particulate debris to insulation ratios by weight.

BWROG Response

As discussed on URG pg. 28, lines 12 – 16, the criterion discussed in Regulatory Position 2.3.1.5 (d) of Regulatory Guide 1.82, Rev. 2 is associated with high head loss for low fiber loads. The BWROG has not observed the thin-bed effect on strainers of alternate geometry (e.g., star and stacked disc strainers.) In lieu of imposing another pipe break selection criteria which would apply to all plants, even those with strainer designs which have not been shown to be susceptible to the thin-bed effect, the URG provides alternate criteria for assuring that the thin-bed effect is appropriately addressed on those strainer designs which may be susceptible to the effect. This is discussed on URG pg. 118, lines 7 –19.

The BWROG has thoroughly tested the 60 point star strainer to evaluate the effect of thin fibrous beds in combination with large quantities of iron oxide sludge. Run number J21 (Appendix C of URG Reference 3; Tab 2, Volume I) sequentially determined the strainer head loss for fibrous loads over the range of 3 to 25 lbm. of Nukon when a constant 180 lbm. of iron oxide sludge was also present. This loading corresponds to a theoretical bed thickness of 0.086 to 0.71 inches for this 175 square foot strainer. For a flow rate of 5000 gpm the resulting head loss gradually

increased from 26 to 236 inches of water as the quantity of fiber was increased. There was no evidence of increasing head loss at lower fiber loads due to thin bed effects.

The stacked disk strainer #2 was also evaluated for potential thin bed effects. Run number P4 showed that there was no measurable head loss when the strainer was loaded with 3 lbm. of Nukon and 100 lbm. of iron oxide sludge. This loading represented a theoretical bed thickness of 0.089 inches for this 169 square foot strainer. When the quantity of Nukon was increased to 10 lbm. (Run number P8) the resulting head loss was only 33 inches of water at 5000 gpm. This represented a theoretical bed thickness of 0.30 inches. Note that for the 18 square foot truncated cone strainer tested by the BWROG very high head losses occurred when fiber loads were in the range of 0.5 to 3.0 lbm. and significant quantities of iron oxide sludge was present. These conditions represent a theoretical bed thickness of 0.28 to 0.83 inches.

As documented in Appendix I of URG Reference 3, the BWROG has concluded that star and stacked disk strainers have physical geometries that preclude the high head loss measured on flat surface strainers with minimal fiber and high corrosion product loads. This is because (1) star and stacked disk strainers have much larger strainer surface areas and lower fluid velocities for which head loss is directly proportional to velocity, and (2) these strainers do not collect fibers such that a uniform film can be formed.

Debris Generation

Comment 1

The NRC has questioned the calculation on page 36 of the URG which estimates the bulk dynamic pressure in the drywell from the downward flow of steam and air (or nitrogen if the containment is inerted).

BWROG Response

This calculation, for a typical Mark II containment, showed that the resulting dynamic pressure was two orders of magnitude below the destruction pressures of the most limiting insulation materials of interest. The table below summarizes the bases and bulk dynamic pressure calculation results for the three U.S. BWR containment types. Typical Mark I and III containments have higher calculated bulk dynamic pressures due to the smaller containment cross-sections. The Mark I calculation shown is for the grating elevation near the main steam line exit locations; the bulk dynamic pressures could be an order of magnitude higher in the upper drywell elevations (neck of containment).

These results confirm (even for upper elevations of Mark I containments) that properly installed and maintained insulation would not be susceptible to failure from the bulk dynamic pressure forces in any of the three BWR containment designs evaluated. Note 1 of URG Table 2 (page 47) cautions that "care should be exercised to assure that the critical characteristics of design for the material being evaluated (e.g., material of construction, method of attachment, methods of

construction including welds, latches, foil thickness, banding, etc., as appropriate) are representative of the materials tested". A similar caution on the use of appropriate attachment mechanisms is provided in Note 2 of URG Tables 4, 5, and 6. The BWROG believes the URG provides an appropriate level of guidance to utilities to assure that insulation is properly installed and that existing programmatic controls are adequate to assure proper maintenance.

Typical Bulk Dynamic Pressure (1)

Parameter	Mark I	Mark II	Mark III
Major Diam. (ft)	64(2)	90	65
Minor Diam. (ft)	26(2)	29	32
Total Area (ft^2)	2690(2)	5700	2510
Estimated Porosity	0.6	0.8	0.7
Estimated Net Flow Area (ft^2)	1610	4560	1760
Max. Steam +Air/N_2 Flow (lbm./sec) (3)	12,800	14,700	15,600
Time of Max. Flow (sec) (3)	1.6	1.3	1.8
Containment Press. (psia) (3)	52.6	42.5	35.0
Steam + Air Density ($lbm./ft^3$)	0.12	0.10	0.08
Bulk Dynamic Press. ($lbf./in^2$)	**0.06**	**0.01**	**0.11**

note (1) basis is 28 inch double ended guillotine break
note (2) grating near main steam line exit location
note (3) GE power uprate calculations for representative BWRs

Comment 2

This comment expresses an NRC staff concern that the URG Zone of Influence (ZOI) section does not provide information on the debris size distribution for ZOI Methods 1 and 2. Further information is also requested on the application of Method 2 to a full size containment.

BWROG Response

The Zone of Influence section of the URG does not address debris size distribution for any of the four ZOI methods discussed. Information on the debris size distribution is contained in URG Section 3.2.3.2.1, "Debris Size Distribution" (page 70). The method used for the ZOI determination does not affect the "destruction factors" provided in Table 4 of the URG (page 71) as the destruction factors provided are material dependent. Of course for any given destruction factor, more material will be available for transport to the suppression pool for larger ZOIs. URG page 86, lines 10 – 16 provide guidance on how to apply the destruction/transport factors to the amount of material located within the calculated ZOI.

As to the question regarding application of Method 2 to a full size containment, it is important to note that Method 2 is based on the largest ZOI which would result from the fully separated, double-ended rupture of any pipe for the material of interest. The actual break location is not a consideration. The resulting spherical ZOI is then sequentially overlayed within all regions of the drywell to determine the most limiting quantities of debris.

In the Method 2 approach to overlaying the calculated ZOI sphere to encompass all regions of the drywell, a portion of the sphere may fall outside of the drywell. This may also occur when using the break location dependent ZOI Method 3. Those portions of the calculated ZOI which fall outside of the drywell are neglected in the analysis. The URG approach for calculation of the ZOI does not credit the expected attenuation of the jet emanating from a break which would occur as the jet expands and interacts with the piping, equipment and structures which fill the drywell. Should a pipe rupture occur in the drywell, this attenuating interaction is expected to result in an actual ZOI which is significantly smaller than the theoretical ZOI calculated via the URG methodology. As previously noted in the response to Comment 2 on pipe break locations, licensees intend to consider pipe breaks as unrestrained breaks which will result in large ZOIs and when considering that these large theoretical ZOIs will be applied at multiple break locations, there is confidence that a conservative amount of debris will be considered in the evaluation of the strainers.

Comment 3

This comment expresses an NRC staff concern that a larger break will generate a different debris distribution (i.e., more fines) than the distribution measured during the BWROG Air Jet Impact Testing (AJIT) program. The staff believes that the size of the nozzle in a debris generation experiment may affect the percentage of debris fines that are generated.

BWROG Response

A formal scaling analysis would show that the fines generated in a test where insulation is located at a downstream distance (x) from a nozzle of diameter D_B is a function of:

$$\% \text{ fines} = \text{function}\left(\frac{x}{D_B}, \frac{D_i}{D_B}, \ldots\right)$$

where D_i is the outer diameter of the insulation, which in this case was 18 inches. The nozzle size at CEESI (D_B = 3 inches) was fixed by the limited air supply volume so that the flow was choked at the nozzle. The more general question that could be asked is whether the tests which were run with $D_i/D_B = 6$ were representative with respect to the production of fines. The answer to this question is a qualified yes.

Fines are believed to be generated by jet interaction with insulation materials over time, as well as insulation interaction with the test vessel or containment prior to being transported to the wetwell (this is the insulation residence time). For BWROG containments, the residence time is of the order of seconds. This is obtained by dividing the drywell airspace volume by the volumetric flow from the break . CEESI air jet impact tests had blowdown durations of five or more seconds.

The production of fines by the direct impact of the jet with the insulation occurs when the insulation is close to the break with the jet immersing the insulation. The initiation of the jet flow immediately breaks the cassette or insulation blanket away from the pipe and accelerates the essentially intact cassette or blanket away from the break. The interaction time of the insulation in the jet is short and very few fines are produced. When the cassette or blanket is located further from the break, a smaller fraction of the momentum forces of the jet intersect the cassette or blanket, and the insulation does not instantaneously break free from the pipe. The jet flow structurally weakens the cassette or blanket as it undergoes mechanical failure until the insulation is sufficiently weakened, and no longer remains intact on the piping. The insulation is eventually released and is accelerated away from the pipe. For this case, the interaction time of the insulation in the jet is longer, and fines are most likely produced prior to the release from the pipe as well as during acceleration. This scenario is believed to result in the maximum amount of fines. It should be further noted that from ANSI Standard 58.2, the jet will expand to an asymptotic diameter of about 6.5 break diameters in about 3 break diameters downstream. Therefore, CEESI tests conducted at 5 break diameters downstream of the nozzle have insulation cassettes or blankets which are being impacted by a major fraction of the jet momentum.

From the above evaluation, it is concluded that the percentage of fines generated will not be greater for larger pipe breaks since the interaction time in the jet will be shorter due to the higher integrated forces over the insulation cassette or blanket. The BWROG position is that the percent fines measured at CEESI is typical and possibly conservative with respect to that expected from medium to large pipe breaks of interest.

Comment 4

This comment expresses an NRC staff concern that it is unclear how the debris on the ruptured pipe is included in the estimation of fine debris. The staff also commented that the BWROG has previously conceded that insulation located on the break will be destructed into fines.

BWROG Response

The BWROG has not conceded that the insulation on the break will be destructed into fines, but has agreed to assume that the insulation in the zone of influence between the break and approximately three diameters from the break is 100% fines. This conservative assumption was adopted because tests were not conducted at CEESI where the insulation material was placed directly on the break.

The debris generated on the ruptured pipe is taken to be fines by setting $\eta_B = 0$ for $x \leq x_a$ where x_a is approximately 3 break diameters as described in URG Reference 5, page E-3 (URG Technical Support Documentation, Volume 2, Tab 2, Appendix E). Therefore, with the computation of $\bar{\eta}_B$, which is the average fraction of blanket material with low transport efficiency in the zone of influence, the fines produced in the vicinity of the break are reflected in the computed value $\bar{\eta}_B$ (see the Table on page E-3).

Comment 5

This comment expresses an NRC staff concern that debris distribution should in part be a function of distance from the break. When comparing the data on different debris sizes produced from the BWROG AJIT test, it was noted by the NRC staff that the tests where the target was closest to the nozzle did not increase the percentage of the smaller debris sizes.

BWROG Response

The BWROG interpretation as to why less fines are produced nearer to the break was given in response to Comment 3 above. To reiterate, the BWROG believes that when the insulation is installed very close to the break so that a major fraction of the momentum flux of the jet is intersected by the insulation target, the insulation is immediately released from the pipe and accelerates away from the break with relatively little production of fines. Maximum fine production would occur at a downstream distance where the jet momentum intersected by the insulation was marginally able to break the cassette or blanket from the piping. Here the insulation would have a maximum interaction time in the jet to undergo erosion and other mechanisms that produce fines.

Comment 6

This comment expresses an NRC staff concern that a more quantitative description of fibrous debris size should be included in the URG.

BWROG Response

The discussion of debris sizes in the URG is based on the debris characterization provided in the report on the BWROG sponsored Air Jet Impact Testing (URG Reference 6.) The AJIT report separately characterizes RMI debris and fibrous debris. As noted in NUREG/CR-6224, prior research had been done by others to quantitatively characterize fibrous debris sizes and it was not the intent of the BWROG to repeat this previous work. The intent of the BWROG debris characterization was to group debris into classifications appropriate for use in evaluation of drywell transport.

When collecting debris after each fibrous AJIT test, the debris was identified as being in one of the following three categories:

- fines, small fibers, and dust
- large fiber pieces
- blankets and covering material

A size approximately equal to the size of the hand was used to differentiate between small fibers and large fiber pieces. This provided the personnel collecting the debris with a ready reference size to use when categorizing the debris. After each test, the large fiber pieces, intact blankets and pieces with covering material was collected first. The remaining material (fines, small fibers, and dust) was then collected.

The URG states that pieces greater than hand-size are considered as large fiber pieces. See URG page 73, line 8.

Comment 7

This comment expresses an NRC staff concern that a statement in URG Reference 21 (page 28, 2nd paragraph, last line). The statement under question is that the amount of unqualified coating expected to fail in the early stages of a LOCA is small compared to the amount of qualified coatings that would fail from direct impingement of the jet. The staff also expressed a concern that pictures in NUREG-0897, Revision 1 show walls that are distant from the test location being stripped of wall paint which appears to be inconsistent with URG Reference 21.

BWROG Response

The BWROG believes that the statement in Reference 21 that the amount of debris generated

from unqualified coatings in the early stages of a LOCA is expected to be small compared to the amount of coatings removed by direct impingement is correct. As discussed in Section 2.8 of Reference 21 (pages 18 - 19), the failure of unqualified coating would not be expected to occur until after several hours or more of exposure to LOCA conditions which are needed to cause a pressure differential across the coating. Only after a pressure differential is formed which is then followed by an abrupt decrease in drywell pressure is there a likelihood that an unqualified coating could disbond from the surface. This build-up of a pressure differential across the coating which is then followed by an abrupt decrease in drywell pressure is not expected to occur in the early stages of a LOCA. Therefore the amount of debris expected from direct jet impingement in the early stage of a LOCA is greater than the amount of debris expected from failure of unqualified coatings (not directly impacted by the jet) early in a LOCA.

The BWROG believes that the photographic evidence from the HDR tests reported in NUREG-0897, Revision 1 support the information in URG Reference 21 as to the failure mechanism of unqualified coatings. The HDR facility was built in the early 1970s and the first blowdown test was conducted there in 1977. Although the exact composition and method of application for coatings employed in the HDR facility are not provided in NUREG-0897, it would be reasonable to conclude that given the timeframe on when the HDR was built that these coatings would fall into the "unqualified" category as currently used at US BWRs. Given that multiple blowdown tests were run at the HDR facility, the failure of unqualified coatings would be expected after exposure to LOCA conditions.

It should also be noted that without additional information beyond that provided in NUREG-0897 on the exact HDR test sequences, the location of the stripped coatings relative to the break location, and the relationship between the photographs and the test sequences; some uncertainty exists as to whether the stripped coatings shown in the photographs were in fact removed by direct impingement of a LOCA jet or whether it is the result of the failure of an unqualified coating.

Comment 8

The NRC has questioned the statement that insulation removal occurs when the fluid stagnation pressure exceeds a certain value, "which has been shown to typically range from several psi to about 50 psi for fibrous insulation materials".

BWROG Response

Table 2 of the URG (page 46) summarizes the destruction pressures for various insulation materials tested by the BWROG at CEESI. For insulation materials other than reflective metal, the destruction pressures range from 4 psi (for Min-K) to 40 psi (for K-Wool). The destruction pressures for the more common fibrous insulation (Nukon, Knaupf, and Temp-Mat) range from 10 to 17 psi.

Drywell Transport

Comment 1

This comment expresses an NRC staff question on how the transport fractions for materials other than Nukon and RMI were determined.

BWROG Response

As noted on URG page 75, lines 14 – 18, the BWROG believes that the transport test results reported in Reference 5 for fine Nukon insulation are sufficiently conservative to account for any minor variations in transport efficiency that may occur for other types of fibrous insulation. Therefore, the same transport fractions are used for all fibrous insulation materials addressed in the URG.

However, because of their non-fibrous nature, the BWROG does not believe it is appropriate to apply the transport fractions for fibrous materials to calcium silicate, Koolphen-K or Min-K insulation materials unless supported by test or further analysis. For these material types, the URG assumes a transport fraction of 1.0 for the fines and other small debris pieces for all US BWR containment designs.

Comment 2

This comment expresses an NRC staff question on how the results shown in Figure 1 in Appendix E of URG Reference 5 are adjusted for a ZOI that is smaller than 100D.

BWROG Response

Questions regarding the application of the curve relating percent large fibrous debris as a function of distance from the pipe break (URG Reference 5 in Technical Support Documentation Volume 2, Tab 2, Page E-2) were resolved during the meeting with the NRC on December 17, 1996. The percent large fibrous debris (y-axis parameter) is determined using this graphical correlation after the equivalent spherical diameter of the zone of influence (x-axis parameter) is calculated.

There is a substantial amount of data for Nukon from the BWROG sponsored air jet test program which demonstrates how the generation of material with low transport efficiency varies as a function of insulation target distance from the test nozzle. The linearized model provides a reasonable fit to the data and all other insulation materials should follow a similar trend. Furthermore, for all materials there is a distance from the break for which the material is not destructed (η_B equals 100 percent) as was demonstrated by the Nukon data. This provides an additional data point to provide a best estimate of the linearized fit. It is our opinion that running additional tests for the other insulation materials will not significantly change the estimated

values for the average fraction of blanket material with low transport efficiency that are presented in the Technical Support Documentation, Volume 2, Tab 2, Appendix E, page E-3.

NPSH Calculations

Comment 1

The NRC staff expressed a concern with the description of the possibility of operation at reduced ECCS flow rates provided in the URG on page 121, lines 14 through 19, and on page 124, lines 22 through 24. These sections discuss the possibility of reducing ECCS flow rates later in the LOCA event, at times when suppression pool temperatures are maximum. Reduction in ECCS flow at this time would result in an increase in NPSH margin.

The NRC staff's concern is that it was not clear how reduced ECCS flows would be modeled in the LOCA analysis, and the approach described in the URG did not appear conservative.

BWROG Response

The URG does not recommend any reduction in ECCS flows below values required by the LOCA analysis. Rather, the intent of the discussion on page 121 lines 14 through 19 and on page 124 lines 22 through 24 is to ensure that any reduction in ECCS flow which is credited in the NPSH calculation is consistent with the flow assumptions in the current licensing basis LOCA analysis.

Two possibilities for ECCS flow reduction without reducing flow below the values credited in the LOCA analysis have been identified by the BWROG.

First, the design basis value for ECCS flow in the LOCA analysis is typically lower than the actual pump capability. In some cases, the pump capability exceeds the LOCA requirement by a substantial margin. In these cases, actual ECCS flows could be reduced while still maintaining flow rates equal to or above those assumed in the licensing basis LOCA analysis. This may be of particular value for plants with a ring header ECCS suction line configuration.

Secondly, once reactor pressure vessel level is recovered following completion of the reflood stage (typically in the first few minutes of the event), the LOCA transient is over from a fuel integrity standpoint. ECCS flow rate assumptions are a key input to this early phase of the transient, as they have a direct impact on the time to reflood, the predicted peak fuel clad temperatures and fuel failure predictions. Following recovery of reactor pressure vessel level, current EOPs allow the operators to reduce ECCS flow to that required to maintain RPV level in a normal range. Since the maximum debris loading on the strainers and maximum suppression pool temperatures are not achieved until significantly after the reflood is complete, it is acceptable to calculate NPSH margins at reduced ECCS flow rates required to provide RPV makeup and adequate suppression pool cooling.

The intent of the URG guidance is to ensure that, if this approach is used, (1) operating procedures and operator training are adequate to ensure actions to reduce flow are taken when required to protect ECCS pump NPSH margins and (2) that the ECCS flow rates remain consistent with the assumptions in the licensing basis LOCA analysis.

Comment 2

The NRC staff is concerned that the guidance provided in URG Section 3.2.6.3 on pages 122 and 123 regarding selection of suppression pool temperatures for NPSH calculations is inconsistent, and does not require use of the maximum value stated in the Tech Specs or FSAR.

BWROG Response

The intent of paragraph 3 (a) on page 123 of the URG is to require use of the current licensing basis maximum suppression pool temperatures in calculation of NPSH margins, where these values are specifically identified in the current licensing basis. The intent of paragraphs 3 (b) on page 123 and paragraph 3 (c) on page 124 is to provide guidance on calculation of maximum suppression pool temperatures where these values are not specifically identified in the current licensing basis, or when a licensing basis change is being considered.

In addition, the BWROG recognized that the change in the design basis for the ECCS suction strainer from an assumed 50% strainer blockage to calculation of actual head losses with debris beds fully covering the strainer makes it necessary to consider operation at low suppression pool temperatures as well as high suppression pool temperatures to ensure a conservative design. Reference 31 of the URG discusses the competing effects of viscosity and vapor pressure as a function of temperature. Basically, head losses at the strainer increase with decreasing temperature due to increased viscosity, while vapor pressure related head losses decrease with decreasing temperature. Due to these competing effects, it is necessary to evaluate a range of suppression pool temperatures from a low design basis value to a high design basis value to determine which case results in minimum NPSH margin.

The intent of paragraph 1 (c) on page 123 is to provide guidance indicating the need to consider both high and low suppression pool temperatures in the ECCS suction strainer NPSH calculations.

Comment 3

The NRC staff expressed a position that it is unwilling to consider license amendments to provide credit for containment pressure to plants who do not already have it approved. The staff is also unwilling to consider increases in the amount of pressure credited for plants which were licensed with credit for containment pressure.

BWROG Response

As stated on URG page 120, lines 14 – 15, the URG recommends that plants with a current licensing basis which does not allow credit for containment pressure should not pursue a change to the licensing basis to allow such credit. Further, as noted on page 120, lines 8 – 12, the BWROG recommends that plants whose licensing basis allows credit for containment pressure should consider, if practicable, use of a strainer that results in acceptable ECCS pump NPSH without reliance on containment pressure.

Comment 4

The NRC staff expressed a concern that the URG should explicitly discuss or describe the criteria that need to be satisfied in order to ensure that BWROG head loss data is properly applied to other strainer designs.

BWROG Response

Strictly speaking, the BWROG data for truncated cone strainers, stacked disk strainers, and star strainers should only be applied to designs that are geometrically similar to strainers which have been tested. Geometrically similar strainers are those which have all dimensions scaled up or down by a constant factor. This criteria cannot be met exactly for stacked disk strainers since the distance between disks is maintained to allow fiber to enter the space between disks. Geometrical scaling of 60 point star strainers will result in a 60 point star strainer with identical angles at the peaks and valleys. This geometrical scaling does not apply to hole size of the perforated plate used to build strainers, since this hole size is chosen to restrict debris from entering the ECCS suction lines (the perforated plate has an insignificant affect on the total strainer head loss).

Comment 5

The NRC staff expressed a concern that some of the calculated bump-up factors determined from Equation 6-8 of Reference 2 (see Appendix A) may not be conservative with respect to actual head loss data obtained at EPRI.

BWROG Response

The bump up factors calculated with equation 6-8 were compared with data obtained in the BWROG alternate strainer test program. The bump-up factor calculation was developed to provide conservative results. The calculations shown in Table 6-1b in the Alternate Strainer Report (Reference 2, Technical Support Documentation, Volume 1, Tab 2, page 55) indicate that the calculations are conservative for all the test cases.

The results from these calculations are shown below:

No Recipe Run	No Recipe Head Loss (inches of H_2O)	Recipe Run	% Recipe (%)	K_{bu}	Measured Head Loss (inches of H_2O)	Predicted Head loss (inches of H_2O)
J4	74	J6	25	3.19	234	236
J8	130	J11	25	1.60	150	208
J8	130	J11	50	2.21	215	287
J27	203	J28R	100	1.26	238	256
J22	74	J23	100	2.25	160	167

These calculations show that the predicted head loss is always greater than the measured value of head loss. The calculations were performed following the procedure outlined in the Alternate Strainer Report which requires that when the M_c/M_f ratio is greater than 4, this ratio is set equal to 4 to compute the bump-up factor.

The uncertainty associated with the measurements has been documented in the Alternate Strainer Test Report (Technical Support Documentation, Volume 1, Tab 2, Appendix H). However, the effect of the uncertainty in the measurements and the data repeatability has not been used to quantify the uncertainty or confidence associated with equation 6-8 which predicts head loss.

URG Overall

Comment 1

The NRC staff expressed an opinion that because of the many different options available to a licensee provided in the URG that their resources may be better utilized reviewing detailed plant specific responses than in review of the URG.

BWROG Response

The BWROG acknowledges that the URG provides flexibility for licensees to evaluate and resolve the strainer blockage issue. This flexibility was necessarily included in the URG to accommodate the variations among plant designs and licensing basis that exist among the BWRs and to avoid a prescriptive approach to resolution that would introduce unjustified costs or operational constraints. While the URG does offer flexibility in resolution of the issue, the BWROG is confident that a licensee which follows the guidance in the URG will implement a resolution to the strainer blockage issue which will assure that the NPSH available to the ECCS pumps is conservatively adequate to meet their design basis requirements.

As agreed during the December 17, 1996 meeting with the NRC staff, in order to provide

additional information to the NRC on which options of the URG licensees planned to use; the BWROG conducted a survey to identify utility intentions on how they plan to address each of the key alternate design methodologies documented in the URG. The results of the BWROG survey were provided to the staff on January 13, 1997. It is expected that the survey results will assist the NRC staff in their evaluation of the URG.

The BWROG believes that the responsibilities of the NRC and the interests of licensees will best be served by the generic approval of the URG. As noted in the BWROG survey, there are many areas where licensees are relying on NRC acceptance on the methodologies provided in the URG (e.g., zone of influence, debris generation, transport, etc.). Should the NRC decide to pursue plant specific reviews in lieu of a generic approval of the URG, there will be a large increase in the workload for both the NRC staff and the individual licensees to obtain NRC approval on a plant specific basis. Pursuit of these issues on a plant specific basis will further challenge the already difficult resolution schedule.

Comment 2

The NRC staff expressed a comment that it needs to have a firm and clear understanding of the words bound (including bounding) and conservative as used in the URG.

BWROG Response

The terms "bound" or "bounding" are commonly used to describe conditions where the value used in the analysis clearly equals or exceeds any physically possible value for the parameter of interest. The term "conservative" is commonly used to indicate instances where the value used in the analysis provides some amount of margin above the best estimate value.

The commonly accepted usage of the terms "bound" and "conservative" was not strictly adhered to in the URG text. Use of the phrases "bound" and "bounding" in the URG should generally be interpreted as "conservative" except in the following instances:

1. ZOI Method 1 is clearly a bounding method for calculating the amount of material which may be subject to destruction;
2. a transport fraction of 1.0 applied to various debris species is bounding;
3. the assumption that 100% of the fibrous material inside 3 pipe diameters from the break is destructed into fines and small fibers (i.e., transportable) is bounding.

Except as noted above, as used in the URG the terms conservative and bounding in effect mean the same thing, i.e., conservative.

GE Nuclear Energy

BWR Owners' Group
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OG97-610-161
September 19, 1997

NRC Project 691
NRC Bulletin 96-03

Mr. Robert B. Elliott
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11555 Rockville Pike
Rockville, MD 20852-2738

SUBJECT: ***BWR Owners' Group Response to NRC Comments Regarding the Effect of RMI and Fiber Combination on Strainer Head Loss***

References:
(1) CDI Report No. 95-09, " Testing of Alternate Strainers With Insulation Fiber and Other Debris", Revision 4, November 1996
(2) Alden Research Laboratory Test Report, "Head Loss of Reflective Metal Insulation Debris With and Without Fibrous Insulation Debris and Sludge for BWR Suction Strainers", May 1996

The purpose of this transmittal is to respond to the NRC's comments received on August 19, 1997 regarding the effect of RMI and fiber combinations on strainer head loss. The NRC referenced URG Section 3.1.2 page 14 which states, "The head losses which resulted from the tests with combined RMI, fiber and particulate debris were bounded by those seen in similar tests for the equivalent loading of fiber and particulate without RMI debris." We believe this statement is correct and conservative. The BWROG has carefully evaluated the tests referenced by the NRC and has provided additional clarifications. Furthermore, gravity head loss testing conducted by Continuum Dynamics, Inc. (Ref. 1) and testing conducted by Alden Research Laboratory (Ref. 2) indicate that the head loss for fiber and particulates decreased when combined with RMI debris.

Consider the test points compared in the August 19, 1997 facsimile transmission from the NRC which are reproduced in Table 1 below. These data points are used to suggest that the addition of RMI to fiber and particulate debris is not bounded by the head loss of fiber and particulates alone. However, the comparisons made between runs 15 and 33 and J6 and J7 are not valid. For tests 15 and 33 the debris beds were made at different velocities and under these conditions the bed compression can significantly affect the head loss. A better comparison would be between runs 13 and 33, see Table 2. Run 33 uses 60 pounds more sludge than run 13 and 88 square feet of RMI; but the addition of sludge and RMI decreased head loss by 29%. For runs J6 and J7, the comparison with pump 2 running is difficult to support because the flow rate through the strainer is unknown when pump 2 is operating because of the location of the venturi in the piping layout. It is not known how the flow splits between the two pumps. However, a valid comparison can be made when pump 2 is not running as shown in Table 2. Finally, reference is made to tests J23 and J24. Although pump 2 is used for test J24, it is only used for a short time interval and the results can probably be compared. The tests have essentially identical head loss 160 inches of water compared to 164 inches of water. The difference between the results is well within experimental error. Therefore, we suggest the data supports the statement in the URG in Section 3.1.2 on page 14.

Some gravity head loss testing was conducted with fiber, sludge and miscellaneous debris as reported in URG Technical Support Document Volume 1 Tab 2 Appendix F. Figure 1 plots head loss for Tempmat with sludge, paint chips, rust, sand, cement dust and zinc filler with and without RMI (runs 266 and 269). A similar comparison is made for Nukon base wool (runs 226 and 268) with a different loading of miscellaneous debris and RMI. Both comparisons demonstrate that head loss is reduced when RMI is added to the debris loading.

Table 1: Invalid comparisons of head loss with and without RMI

Test #	Strainer	Flow made bed	Flow	Nukon	Sludge	Recipe	RMI	Head Loss
		GPM	GPM	lbm	lbm	%	sq. ft.	in H_2O
15	20 pt. Star	2500	2500	3	240	0	0	50
33	20 pt star	5000	2500	3	240	0	88	115
J6	Trun. cone	5000	5000	0.5	180	25	0	23 5
J7	Trun. cone	5000	5000	0.5	180	25	60	310 with pump 2 running

Table 2 Valid comparisons of head loss with and without RMI

Test #	Strainer	Flow made bed	Flow	Nukon	Sludge	Recipe	RMI	Head Loss
		GPM	GPM	lbm	lbm	%	sq. ft.	in H_2O
13	20 pt. Star	5000	5000	3	180	0	0	215
33	20 pt star	5000	5000	3	240	0	88	153
J6	Trun. cone	5000	5000	0.5	180	25	0	234
J7	Trun. cone	5000	5000	0.5	180	25	60	210 without pump 2
J23	60 pt star	5000	5000	5	180	100	0	160
J24	60 pt star	5000	5000	5	180	100	510	164

Finally, consider the results of the Alden Research Laboratory tests documented in test report, "Head Loss of Reflective Metallic Insulation Debris With and Without Fibrous Insulation and Sludge for BWR Suction Strainers", dated May 1996. This report found that with Nukon and RMI debris alone (no particulates) at high approach velocities, the addition of RMI resulted in slightly higher head losses (Reference 2, Figure 7). However, for approach velocities below 0.75 ft/sec there appeared to be no significant difference in head loss when RMI debris was added. Replacement ECCS strainers typically have approach velocities well below 0.5 ft/sec. A more important comparison is with sludge, since all BWR have some level of sludge in their wetwells.

When sludge is combined with fibrous and RMI debris the Alden Research Laboratory results confirm the BWROG position with respect to combined debris head loss. Figures 10 through 15 of Reference 2 compare head loss with and without RMI over a

range of approach velocities. For all velocities of interest, the head loss with RMI is not greater than the head loss without RMI and is usually substantially lower. Test results showed that in general head loss "decreased when RMI debris is present in the mix of fibrous insulation with sludge." Alden plotted the head loss with RMI mixed with fiber insulation and sludge at the various tested velocities against the corresponding values of head loss for fibrous insulation and sludge without RMI (Reference 2, Figure 16). Points above the 45 degree line represent head losses higher with RMI, while points below the line represent lower head loss with RMI. Nearly all the points lie below the line (the biggest exceptions occur at approach velocities of 1.5 ft/sec).

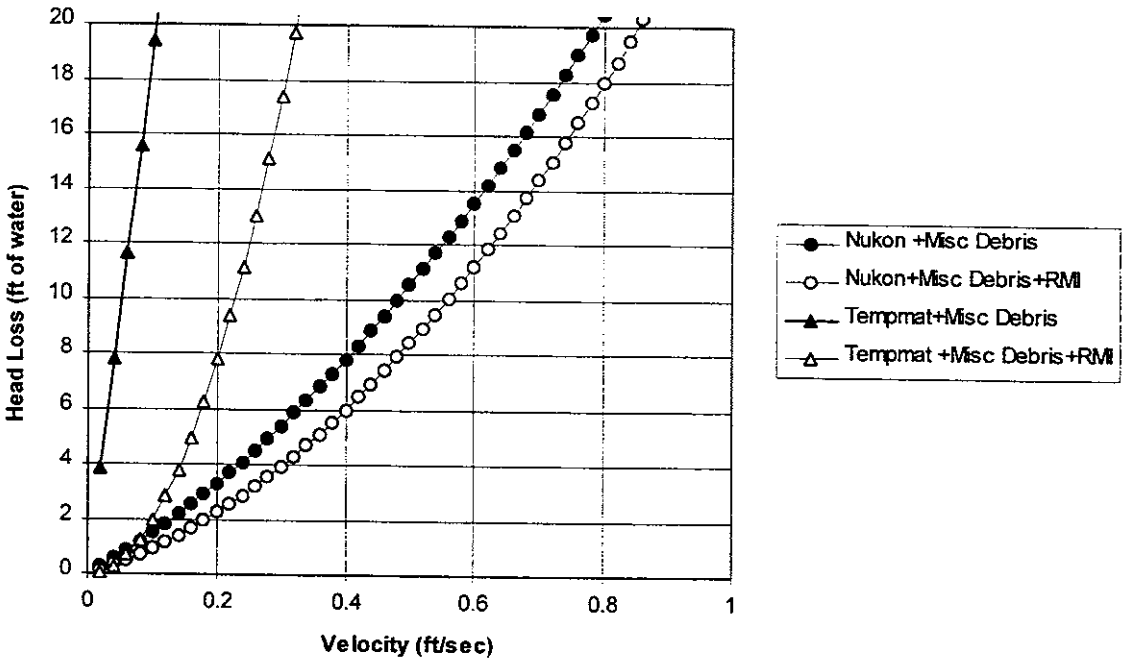


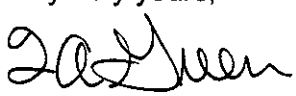
Figure 1: Plot of head loss versus velocity for fiber and miscellaneous debris and fiber, miscellaneous debris and RMI from gravity head loss testing

The BWROG reserves the option to use plant specific test data for sizing strainers that utilizes combinations of RMI, fibrous debris and particulates. The BWROG URG position is to treat the head loss from fiber and particulates separately from RMI and to size a strainer based on which case has the higher head loss.

Based on the above information, we request that the URG position with respect to combined debris head loss be approved.

If you have additional questions regarding this information please contact Rocky Sgarro (PP&L) at (610) 774-7552 or the undersigned.

Very truly yours,



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NRC Project 691
NRC Bulletin 96-03

BWROG-98004
March 13, 1998

US Nuclear Regulatory Commission
Washington, DC 20555-0001

Attention: Document Control Desk

SUBJECT: ***BWR Owners' Group Comments Regarding NRC Draft Safety Evaluation Report of the BWR Owners' Group Utility Resolution Guidance for ECCS Strainer Blockage (NEDO-32686) dated December 31, 1997***

References:
(1) NEDO-32686, "Utility Resolution Guidance for ECCS Suction Strainer Blockage" dated November, 1996
(2) Letter from Carl H. Berlinger (NRC) to Rocky Sgarro (PP&L), "Draft Safety Evaluation Report of the Boiling Water Reactor Owners' Group Utility Resolution Guidance for ECCS Suction Strainer Blockage", dated December 31, 1997

The BWR Owners' Group (BWROG) has reviewed the draft Safety Evaluation Report (SER) of the BWROG Utility Resolution Guidance (URG) for ECCS Suction Strainer Blockage (Reference 2). We appreciate the staff providing this opportunity to provide comments on this important document. On February 6, 1998 the BWROG ECCS Suction Strainer Committee met with the NRC staff to provide preliminary comments on the draft SER. This letter supplements the information provided during the February 6th meeting and also provides additional information on issues that were not discussed with the staff because of time limitations. Please note that it is not the intent of the BWROG to revise the URG, however we do plan to document the acceptable ECCS strainer blockage resolution methods and distribute it to our members. The complete documentation package will consist of the following: the original URG; all BWROG responses to NRC requests for additional information on the URG; this letter; and the final NRC SER.

The major concerns noted in the body of this letter were discussed with the staff during the meeting of February 6th. The staff acknowledged their understanding of these concerns and expressed a willingness to work with the BWROG to reach a mutually acceptable resolution. The BWROG wishes to note our appreciation to the staff for their consideration in addressing these critical issues.

During the evolution of the ECCS issue, several factors have resulted in substantial uncertainty in the final acceptance criteria which will be used by the NRC to determine the acceptability of licensee actions in response to Bulletin 96-03. These factors include the identification of the need to evaluate the significance of coatings inside containment as a potential debris source term, and the issues raised by Generic Letter 97-04 regarding calculation of available NPSH margin. Also, NRC's need to address these and other emergent issues resulted in a significant delay in issuance of an SER for the URG, which was initially anticipated in the January-February 1997 timeframe.

Licensees have acted in good faith by assuming the regulatory and financial risks associated with installing replacement strainers without an NRC-approved methodology for evaluating their acceptability, and this uncertainty has increased because of emerging issues with coatings and NPSH calculational methods. Licensees are designing and installing replacement strainers to the schedule required by Bulletin 96-03 (i.e., by the end of the first refueling outage after January 1, 1997) without assurance that the plant modifications being made are sufficient to satisfy NRC concerns on critical issues. While all of this uncertainty cannot be eliminated in the near term, we believe that obtaining a final SER on the URG is important. The comments in this letter support BWROG member efforts to ensure that their ECCS strainer designs will have a sufficient level of conservatism and will retain margin where possible to address the remaining open issues. The issuance of this SER will significantly reduce the current level of uncertainty with the final acceptability of the plant modifications either already completed or underway.

Bulletin 96-03 Closure

A significant concern involves the schedule for completion of the activities required by Bulletin 96-03. The Bulletin requires submission of a report confirming completion of the requested actions within 30 days of installation of the replacement strainers. Although strainers are being installed, BWROG licensees will typically be unable to ensure compliance with all the provisions of Bulletin 96-03 due to the regulatory uncertainties described above.

The issues identified in the draft SER and the possible actions which may be required once the staff completes their review of 1) the coatings issue (draft Generic Letter 97-XX), and 2) the NPSH information provided in response to Generic Letter 97-04, will likely impact the closure of licensee responses to Bulletin 96-03. These issues, based on our discussions on February 6, are not currently projected by the NRC to be fully resolved prior to the issuance of the SER on the URG. The BWROG requests that the staff consider issuing a supplement to Bulletin 96-03 that provides blanket schedule relief to the licensees in reaching final technical closure on Bulletin 96-03 until an NRC-accepted methodology is available that fully and completely addresses all the issues affecting the calculation of ECCS pump NPSH. The BWROG is not requesting blanket deferral for the installation of replacement strainers but only for final closure

of the Bulletin 96-03 technical response. Once the final NRC-accepted methodology is available, licensees should be given adequate time to review their strainer designs, debris loading calculations, and the need for any further actions (e.g., license changes for containment overpressure credit) before closure of Bulletin 96-03 is required.

The BWROG has activities in progress to address the effect of unqualified coatings on strainer performance. The BWROG intends to work closely with the staff on the coatings issue as well as with any issues that may arise from Generic Letter 97-04. Our objective is to expedite resolution of these open issues so that closure of Bulletin 96-03 can be achieved in the near future.

Compounded Conservatism

A second major concern expressed by BWROG member utilities is that the SER requests licensees to compound the conservatism in several individual areas; this results in an overall level of conservatism that is excessive. Licensees should be permitted to use less conservative methods than prescribed by the SER, provided that the overall level of conservatism of the licensee's analyses is sufficient. The BWROG recognizes the difficulty for NRC staff review and approval due to the multiple paths allowed by the URG methodology which vary in the levels of conservatism. However, the BWROG believes that plant-specific submittals provided by licensees demonstrate that utilities are appropriately combining the individual portions of the URG methodology to arrive at an overall application that is sufficiently conservative.

The staff has noted in the draft SER the very conservative nature of the zone of influence (ZOI) proposed by the BWROG. In developing the URG, the BWROG elected to recommend a very conservative approach on the ZOI in recognition of the engineering judgment in some areas of the analysis and to preclude differences of opinion or questions on how the available data should be used in analyzing the issue. In fact, the BWROG elected to neglect the loss of jet momentum due to steam jet interactions with piping, equipment and containment structures. We believe that the radius of the calculated ZOI is therefore conservative by at least a factor of two (2) for insulation materials with lower destruction pressures (such as Nukon fiberglass wool). This results in a volumetric ZOI which is conservative by a factor of at least eight (8). Other conservatisms that the staff has acknowledged are in the use of bump up factors, the use of a jet perpendicular to the insulation target when developing destruction pressures, and in the amount of debris considered to be transportable.

Requiring use of the more conservative approach in each area as suggested by the draft SER can result in unnecessary overall conservatism that could potentially challenge the acceptability of the new strainer designs. Most BWR utilities have installed or plan to install the largest strainers allowed by interferences or structural analysis; excessive conservatism could require a passive strainer of a size that could only be installed following extensive re-analysis of the containment loads and other structural members, or through increased reliance on containment overpressure when calculating NPSH. The BWROG also notes that undue conservatism may require additional modifications (e.g., insulation replacement and/or installation of jacketing and banding) that would not provide a measurable increase in safety margins. The exposure

incurred during installation and subsequent inspections would not be in keeping with ALARA objectives if the modification is driven by excessive conservatism in the analysis.

The BWROG recommends that the SER communicate an expectation that licensees will apply individual portions of the URG with a primary focus on the overall conservatism of their plant-specific application of the URG in determining strainer head loss and the resulting ECCS pump NPSH margin. The BWROG agrees that each licensee should evaluate its use of the URG to ensure that the plant-specific application of the guidance provides an overall conservative approach ensuring the new strainers comply with the requirements of 10CFR50.46. The BWROG recognizes that, if varying from the requirements in the SER, licensees would be required to seek staff review and approval of the plant-specific strainer head loss evaluation in order for the staff to reach a conclusion that the overall methodology is sufficiently conservative. The BWROG urges the staff to include a discussion recognizing the overall conservatism of the URG approach in order to minimize the burden on both the staff and licensees in performing plant-specific reviews.

On-Site Reviews and Inspections

A third area of concern relates to inspection activities. During the February 6th public meeting, the staff indicated that on-site reviews would be conducted by NRR headquarters staff for an initial set of plants. The need for and mechanism for accomplishing on-site reviews and/or inspections for other plants is undecided pending the outcome of the initial on-site reviews.

The BWROG believes that because of the technical complexity and the demonstrated high knowledge level of the NRR headquarters staff involved with this issue, it is appropriate for the headquarters staff to conduct the initial on-site reviews. The BWROG is interested in how this broad and complex knowledge base will be translated into future inspection guidance. Accordingly, the BWROG requests the opportunity to review and comment on proposed NRC inspection plans and modules that would be used to guide inspection activities subsequent to the on-site reviews.

Significant Technical Issues

The BWROG participating utilities have evaluated the draft NRC SER with respect to impact on completed and in-process strainer designs. Attachment A summarizes the BWROG recommendations on each of the issues of interest. As stated previously, the BWROG believes that formal NRC staff approval of an acceptable methodology which is sufficiently conservative, but which leaves margin where possible for licensees to respond to remaining open issues, is a high priority. The BWROG comments focus on areas of most importance in achieving this goal.

This letter has been endorsed by a substantial number of the members of the BWR Owners' Group; however, it should not be interpreted as a commitment of any individual member to the specific course of action. Each member must formally endorse the appropriate BWROG position in order for that position to become the member's position.

If you have any questions regarding the enclosed documentation, please contact Rocky Sgarro (PP&L), BWROG ECCS Suction Strainer Committee Chairman, at (610) 774-7552 or Thomas A. Green, the GE Project Manager at (408) 925-1308.

Very truly yours,

Thomas J Rausch

TJ Rausch, Chairman
BWR Owners' Group

Attachments

cc: C Berlinger, NRC
RB Elliott, NRC
R Lobel, NRC
L Malloy, NRC
M Marshall, NRC
A Serkiz, NRC
D Skay, NRC
D Fetters, Chairman BWROG Executive Committee
BWROG Executive Oversight Committee
WG Warren, Vice Chairman BWROG
RC Evans, NEI
BWROG Primary Representatives
BWROG ECCS Suction Strainer Committee
DB Townsend, GE
JF Quirk, GE

BWROG Response to Draft SER on URG

No.	Draft SER References	Issue Description	BWROG Recommendations
		General Issues	
1*	Overall	Compounded conservatism's The approach adopted by the staff in reviewing the URG results in comments on each area where, in several cases, the staff identifies a more conservative application than the method provided in the URG. Application of the more conservative application suggested by the staff in each and every area can result in an overall conservatism that is so great for some plant that it could require a passive strainer of a size that it could only be installed by re-opening the containment loads analysis, or through reliance on containment overpressure (not currently credited) when calculating NPSH. In the draft SER the staff does not provide a perspective on how the overall conservatism of the URG methodology will be considered when evaluating the acceptability of any individual portion of the analysis.	The BWROG recommends that the SER communicate an expectation that licensees will apply individual portions of the URG with a primary focus on the overall conservatism of their plant-specific application of the URG in determining strainer head loss and the resulting ECCS pump NPSH margin. The BWROG agrees that each licensee should evaluate its use of the URG to ensure that the plant-specific application of the guidance provides an overall conservative approach ensuring the new strainers comply with the requirements of 10CFR50.46. The BWROG urges the staff to include a discussion recognizing the overall conservatism of the URG approach in order to minimize the burden on both the staff and licensees in performing plant-specific reviews.
2*	Overall	Open issues require deferral in closure of Bulletin 96-03 responses The issues identified in the draft SER and the possible actions which may be required once the staff completes their review of 1) the coatings issue (draft Generic Letter 97-XX), and 2) the NPSH information provided in response to Generic Letter 97-04, will likely impact the closure of licensee responses to Bulletin 96-03. These issues, based on our discussions on February 6, are not currently projected by the NRC to be fully resolved prior to the issuance of the SER on the URG.	The BWROG requests that the staff consider issuing a supplement to Bulletin 96-03 that provides blanket schedule relief to the licensees in reaching final technical closure on Bulletin 96-03 until an NRC-accepted methodology is available that fully and completely addresses all the issues affecting the calculation of ECCS pump NPSH. The BWROG is not requesting blanket deferral for the installation of replacement strainers but only for final closure of the Bulletin 96-03 technical response. Once the final NRC accepted methodology is available, licensees should be given adequate time to review their strainer designs, debris loading calculations, and the need for any further actions (e.g., license changes for containment overpressure credit) before closure of Bulletin 96-03 is required.
3*	Overall	On Site Reviews and Inspection During the 2-6-98 public meeting to discuss the draft SER the staff indicated that on-site reviews would be conducted by NRR headquarters staff for a small number of plants. The need for or mechanism for accomplishing on-site reviews and/or inspections for other plants is undecided pending the outcome of the initial on-site reviews.	The BWROG believes that because of the technical complexity and the demonstrated high knowledge level of the NRR headquarters staff involved with this issue, it is appropriate for the headquarters staff to conduct the initial on-site reviews. The BWROG is interested in how this broad and complex knowledge base will be translated into future inspection guidance. Accordingly, the BWROG requests the opportunity to review and comment on proposed NRC inspection plans and modules that would be used to guide inspection activities subsequent to the on-site reviews.

*Items marked with an asterisk were discussed with the NRC staff during a public meeting on 2-6-98.

BWROG Response to Draft SER on URG

No.	Draft SER References	Issue Description	BWROG Recommendations
4.	Pg. 2, 2nd para Pg. 8, 1st para	Actions required for portions of URG not "accepted" by NRC. "Licensees desiring to use the portions of the URG not accepted by the staff should address the concerns cited herein in plant-specific submittals." "Since the staff lacked sufficient detail and supporting justification on many of the 'resolution options,' these were generally considered unacceptable without additional supporting justification or technical details being provided by a licensee or the BWROG. If individual licensees desire to make use of any portions (analytical or resolution options) of the URG that are not accepted by the staff, they should resolve the staff's concerns cited herein in a plant-specific submittal."	The BWROG requests that the staff reconsider this position based on the responses provided herein to their specific comments on individual resolution options. We have attempted to clarify where plant-specific responses are appropriate. If further information is required, the staff is requested to clarify the nature of such information.
		Resolution Option Issues	
5.	Pg. 11, 1st para of "Staff Eval"	Minimal fibrous insulation. BWROG should clarify what is meant by "minimal" amount of fibrous insulation.	See URG pg 117, ln 29..(1/8 inch coverage is "minimal")
6.	Pg. 11, last para. and continues on pg. 12	URG flowchart doesn't match with text in regards to bounding assumption on debris.	The BWROG agrees that the flowchart could be clearer. There really are two methods intended, either of which is acceptable. One method is to use a zone of influence that encompasses 100% of the material of interest in the drywell and 100% transport to the suppression pool. The second method is to take 100% of the material of interest in the drywell and then use the transport factors provided in the URG to determine the amount of insulation that reaches the suppression pool.

·Items marked with an asterisk were discussed with the NRC staff during a public meeting on 2-6-98.

BWROG Response to Draft SER on URG

No.	Draft SER References	Issue Description	BWROG Recommendations
7.*	Pg. 12, 2nd para.	RMI head loss should be added to head loss from fiber+particulates. NRC position is that the URG statement that head loss from RMI+fiber+particulates is bounded by head loss from fiber+particulates is incorrect. NRC wants RMI head loss added to fiber+particulate head loss.	From discussions during the 2-6-98 public meeting it appears that the staff concerns are focused on the URG statement that fiber+particulates "bounds" the head loss from fiber+particulates+RMI and that the staff believes there are potentially cases where the URG statement may not be valid. The BWROG concurs that for cases with extremely small fiber loadings, the RMI+fiber+particulates head loss may exceed that for fiber plus particulates without RMI. The intent of the URG statement was that for cases where the fiber plus particulate head losses exceed or are comparable to the head losses for RMI alone, the addition of RMI to the fiber plus particulate bed always results in a decrease in strainer head loss. This position is supported by the BWROG test data (see OG97-010-161). The BWROG believes that this issue can be most readily addressed on a plant-specific basis by having the licensee assure the strainer vendor reviews the debris combinations of interest to the particular plant and confirm that the head loss from fiber+particulates+RMI does not exceed that of fiber+particulates. If this confirmation cannot be provided, appropriate corrections based on plant-specific conditions should be made to account for the increase in the head loss attributed to the RMI.
8.	Pg. 13, 1st para., last sentence	Hydrodynamic loads. "The staff cautions that licensees making changes to hydrodynamic load calculation coefficients and/or methodologies should not do so without testing to demonstrate the validity of the revised calculations."	The BWROG believes that this is a plant-specific issue and is outside the scope addressed in the URG. The URG notes the need to consider hydrodynamic loads but does not attempt to address appropriate methods for performing hydrodynamic load calculations as those issues are not related to strainer performance per se. The BWROG recommends that issues related to hydrodynamic loads be resolved on a vendor and plant-specific basis.
9.	Pg. 13, 3rd para.	Application of BWROG test data to other strainer designs. "The staff finds that there is insufficient information as to how to apply the BWROG test results to other strainers. .... For this reason, the staff recommends that licensees use vendor specific data based on the licensee's analyzed conditions as the basis for determining head loss across the strainer."	The BWROG is not aware of any licensee that intends to install a strainer of a design based solely on the BWROG test data. The BWROG concurs that licensees should use vendor specific data consistent with the licensee's analyzed conditions as the basis for determining head loss across the strainer.

*Items marked with an asterisk were discussed with the NRC staff during a public meeting on 2-6-98.

BWROG Response to Draft SER on URG

No.	Draft SER References	Issue Description	BWROG Recommendations
10.*	Pg. 13, 4th para.	Use of banding/jacketing. "Due to the lack of information as to how a plant is to apply this option, the staff is unable to reach any conclusion regarding this option. In addition, the characterization of the effectiveness of insulation jacketing on this page is inconsistent with the test report (AJIT).....Without further detailed information on how to apply this option and the associated benefits achieved, and the technical basis supporting the use of this measure, the staff is unable to make a determination as to the acceptability of this option."	The BWROG notes that information on the use of jacketing and banding is provided in URG Volume II Tab 3, page 181- 183, paragraph 5.1.1. The BWROG recommends that those licensees which intend to credit banding/jacketing in order to minimize debris generation should have available appropriate documentation on how the URG data was applied which support the technical basis for such credit.
11.	Pg. 14, 2nd para.	Pool cleaning frequency. "...the staff believes that regular inspections of the suppression pool and ECCS suction strainers, and cleanings when necessary, should be conducted every refueling outage until licensees have demonstrated over time the ability to control foreign materials."	The BWROG believes that licensees have taken significant steps to improve suppression pool cleanliness in response to Bulletins 93-02 and 95-02. The BWROG recommends that licensees ensure that assumptions made for debris source terms in sizing the strainers are appropriate given the plant-specific actions taken to remove and control foreign materials. One key element is the planned frequency of pool inspection and cleaning. However, the BWROG believes that requiring all licensees to perform inspections and cleanings every refueling outage adds an unnecessary burden to plants which have taken significant actions to control foreign materials, or which have used very conservative assumptions in strainer design.
12.	Pg. 14, 3rd para. and top of pg. 15	Containment overpressure "The staff concurs that additional containment overpressure (other than the amount already approved by the staff for the existing licensing basis) should not be used as part of the resolution of this issue. The staff is evaluating its position on use of containment overpressure in calculating NPSH margin as part of its review of (GL 97-04)....."	The BWROG recommends that, if practicable, plants not credit containment overpressure in the resolution of this issue. However, the URG notes that in some cases various plant-specific factors may make it necessary to credit containment overpressure. The BWROG recommends that licensees intending to make a change to their licensing basis relative to crediting containment overpressure should perform the appropriate analyses to demonstrate the minimum amount of containment overpressure available. These analyses should be separately submitted for staff review and approval. The BWROG notes that the more conservative the requirements are in the areas of zone of influence, debris generation, transport, and head loss correlation the more likely that some licensees will need to credit containment overpressure in order to meet the requirements of Bulletin 96-03. Excessive conservatism should be avoided.

*Items marked with an asterisk were discussed with the NRC staff during a public meeting on 2-6-98.

No.	Draft SER References	Issue Description	BWROG Recommendations
13.	Pg. 15, 2nd para.	Reanalyze suction penetration loads The URG suggests use of more sophisticated techniques or reduction in conservatism of current design basis calcs without reopening the licensing basis for containment loads. "The staff's concerns regarding Section 3.1.3.1 are stated above and apply to this section of the URG also." (URG section 3.1.3.4.6, pg 21)..	This is similar to the hydrodynamic loads issue. See response to Item No.8.
14.	Pg. 15, 3rd para.	Re-evaluate for worst case when changing insulation. "...however, when using this option for a selected break, the licensee should go back and reassess other breaks to ensure that the licensee has not changed the break which is the most limiting in terms of NPSH margin."	The BWROG concurs.
15.	Pg. 15, last para. and continues on pg. 16	Defense-in-depth. "The staff strongly encourages the enhancement of alternate water sources (including maintenance of crossover valves), operator training, and emergency operating procedures to ensure that operators can mitigate any situation involving loss of ECCS flow due to strainer clogging. ....the staff concurred with the ACRS comment and agreed to 'place more emphasis on the need to improve, where appropriate, the procedures to better address core cooling from alternate sources of water.' "	The BWROG understanding of this language is that defense in-depth is an "encouragement" but not a requirement. The BWROG recommends that the staff use language in the SER that clearly differentiates actual requirements from that of encouragements and prudent actions and suggested evaluation approaches. Doing so would avoid confusion with actual requirements.
		Pipe Break Locations	
16.	Pg. 16 thru 2nd para. on pg. 18	Use of MEB 3-1 for selection of break locations to be evaluated.	We note that for ease of analysis, BWROG licensees have typically chosen not to use the MEB 3.1 approach and instead used an approach that considers those breaks that would result in the maximum debris generation.

*Items marked with an asterisk were discussed with the NRC staff during a public meeting on 2-6-98.

BWROG Response to Draft SER on URG

No.	Draft SER References	Issue Description	BWROG Recommendations
17.*	Pg. 18 last para. thru top of pg. 20 Pg. 21, 2nd para.	Thin bed effect – Medium LOCAs. "...the staff believes that licensees considering a solution option using an alternate strainer design should experimentally verify (or ensure using existing vendor or BWROG data) that the thin-bed effects is not an issue for the strainer design being considered using debris quantities which are consistent with a MLOCA for their plant. Otherwise, the licensee should consider the MLOCA when performing their plant analysis. If verified experimentally, the licensee would not need to analyze medium LOCAs with largest potential particulate debris to insulation ratio by weight. "Licensees may screen out MLOCAs in performing their plant-specific analysis if they intend to install a strainer similar to the stacked disk number 2, star strainer, or another geometrically similar strainer with deep crevices sufficient to hold debris loadings consistent with a MLOCA for their plant."	The BWROG recommends that this issue can be most readily addressed on a plant-specific basis by having the licensee assure that the strainer vendor reviews the debris combinations of interest to the particular plant and confirm that the head loss from the maximum debris loading bounds that of lesser debris loads. The debris combination resulting in the highest strainer head loss for the expected flow rate should be used in the NPSH calculation for the ECCS pumps. This can be accomplished by parametric variation of the debris loads when performing head loss calculations. This approach is recommended because it avoids the burden of explicitly establishing the expected ZOI, debris generation and transport resulting from MLOCAs while still assuring the most limiting head loss case is considered. The BWROG believes that the stacked disk strainer designs typically being installed as replacements have sufficiently deep crevices that MLOCAs can be screened out of consideration.
18.*	Pg. 20, 1st para.	Large LOCAs with highest particulate to fibrous debris by weight "Therefore, the staff concludes that licensees should still evaluate large LOCAs with the highest particulate to fibrous debris ratios by weight to ensure that those breaks do not become more limiting in terms of head loss than the breaks that produce the highest volume of fibrous debris."	The BWROG recommends that this issue can also be addressed by following the recommendation in the previous item.
19.	Pg. 21, 4th para.	Alternative evaluation methods. "Each alternative evaluation method presented must provide reasonable assurance that the most severe ECCS suction strainer debris loadings (from drywell insulation sources) be suitably evaluated;"	The BWROG concurs provided such alternative evaluation methods are consistent with the plant licensing basis.
20.	Pg. 21, 5th para.	Bounding analyses. "Bounding analyses, if used by licensees in lieu of specific pipe break location analyses, need to address all debris species (from insulation sources) which have not been addressed by the specific pipe break location evaluations."	The BWROG concurs.
21.	Pg. 21, 6th para.	Breaks inside bio-shield. "The URG guidance on pipe breaks inside the bio-shield wall is incomplete. ....the staff believes that additional guidance on the analytical considerations to be evaluated by the licensee would be beneficial and consistent with the BWROG's stated goal of providing a consistent industry response to NRCB 96-03."	The BWROG believes that the plant unique aspects of the amount and type of insulation inside the bio-shield will govern the most appropriate means of addressing this debris source. For many plants the amount of debris available inside the bio-shield is negligible relative to other debris sources and can be discounted. The BWROG recommends that this issue is best addressed on a plant-specific basis.

*Items marked with an asterisk were discussed with the NRC staff during a public meeting on 2-6-98.

No.	Draft SER References	Issue Description	BWROG Recommendations
		Zone of Influence	
22.	Pg. 23, 2nd para.	Bulk dynamic pressure. "The BWROG calculations underestimate bulk dynamic pressures in Mark I containments by a factor of 10 at some locations. However, the staff's analysis concludes that the bulk dynamic pressures would likely be insufficient to damage insulation materials such as those presently used in operational BWRs, if the insulations are properly installed and well-maintained. ....Licensees should ensure that the analysis is reflective of the actual plant conditions. In addition, the URG calculations for bulk dynamic pressure in a Mark I containment should be updated to be consistent with the BWROG's response to staff RAIs in Reference 13."	As noted by the staff, the BWROG previously addressed this issue in response to NRC RAI. A revision of the URG is not anticipated. Further, the BWROG notes that even if the bulk dynamic pressure was sufficient to remove insulation, no impact on the strainer performance would be expected given that loose insulation would come off as relatively intact blankets which, in accordance with the NRC Drywell Debris Transport Study, are not transportable.

BWROG Response to Draft SER on URG

No.	Draft SER References	Issue Description	BWROG Recommendations
23.*	Pg 23, 3rd para. Pg. 23, 4th para. and top of pg. 24. Pg 25, 5th para. Pg. 26, 3rd para.	Jet Centerline Pressure (JCL) vs. Target Area Averaged Pressure (TAAP). "The staff believes that a target area averaged pressure or jet impingement load are more technically correct bases for assessing potential damage. If this approach is not taken, the BWROG should provide a better rationale for selecting the local jet centerline pressure at the L/D location where incipient damage was first observed as the fundamental property that uniquely controls insulation damage." "The BWROG should develop a logical rationale which would also resolve the staff's concern (described in Appendix B) relative to applying the BWROG air jet impact testing results to full size BWR drywells." The NRC concludes that the JCL approach would result in a smaller ZOI for insulations with a higher P_{dest} (i.e., DARMET, with Camloc strikes and latches, Transco RMI, Jacketed NUKON with Sure-Hold Bands, Diamond Power Mirror with Sure-Hold Bands, and CalSil with Aluminum jacketing) than would a TAAP based analysis. The effect of JCL vs TAAP would be minimal on other insulation types (those with a lower P_{dest}). "These two methods [ZOI Methods 2 & 3] are then sufficiently conservative to compensate for the weaknesses noted above, and therefore are considered acceptable by the staff for use on insulation with low P_{dest} values. For insulations noted above with high P_{dest} values, the staff recommends that the ZOI be developed based on the "target area averaged pressures" instead of JCL pressures."	Suggesting that target area averaged pressure (TAAP) may be a more technically correct basis for assessing potential damage to insulation presupposes one understands the failure mechanisms of various insulation types subjected to impingement by a LOCA jet. It is not obvious that an impacting jet, which has a smaller diameter than the target diameter is not more destructive than a jet which is very wide compared to the target diameter. This is because the smaller jet may not remain attached about the target, and may redirect the momentum of the incoming flow at right angles to the flow direction. The larger jet on the other hand presumably remains attached, and the resulting drag forces could be less than that resulting from the smaller diameter jet. Unfortunately, the situation is technically complex, and in light of the application methodology, the jet centerline stagnation pressure was chosen as the metric to quantify the insulation destruction pressure. If one considers the fact that in a drywell where all piping is randomly oriented, the average target would be oriented 45° to the jet centerline, use of jet centerline stagnation pressure, as the measure insulation destruction pressure is very conservative. The BWROG believes that, without a commensurate increase in safety benefit, the added complexity of the TAAP model is not justified and that imposing it as a requirement would cause unnecessary reanalysis. Further, as noted previously, the BWROG believes that the overall conservatism in the various phases of the analysis is adequate to address any concerns that may arise regarding the acceptability of a particular area. The BWROG recommends that the staff approve the JCL model for use on all insulation types tested by the BWROG.
24.	Pg. 25 last para. and top of pg. 26	Single vs double-ended flow from a steam line break. "The staff recommends that utilities not take credit for a single jet in the case of a main steam line break inside containment."	The BWROG recommends that licensees be given the option to demonstrate on a plant-specific basis that the ZOI for a steam line break is less than that caused by assuming double-ended flow from the break. Alternatively, licensees may conservatively assume double-ended flow.
25.*	Pg. 26, 2nd para.	URG Insulation Destruction Data Limited for Some Insulations "As a result, the staff believes that utilities having materials where the data are limited should conduct additional testing for those materials unless they use a bounding approach to those materials."	The BWROG recommendation is, given the overall conservatism of the analysis previously discussed, that the staff should not impose requirements for additional destruction testing of materials nor should they impose a bounding approach on those materials where there is limited data.

*Items marked with an asterisk were discussed with the NRC staff during a public meeting on 2-6-98.

No.	Draft SER References	Issue Description	BWROG Recommendations
26.	Pg. 26, last para. and top of pg. 27	ZOI Method 4 Not Acceptable "As a result, Method 4 is not considered acceptable by the staff without further detailed justification on a plant-specific basis."	BWROG concurs
27.*	Pg. 47, 6th bullet	Damage to CalSil Should be Treated as Erosion "Damage to calcium silicate should be treated as erosion as demonstrated by Swedish experiments. Table 2 should be revised to alter the failure criterion."	During the meeting on 2-6-98 the staff raised concerns about the limited number of BWROG tests of calcium silicate insulation, possible variations in results among different types of calcium silicate insulation and the effect of aging on the P_{dest} of the insulation. Due to these issues, the BWROG recommends that licensees with calcium silicate insulation resolve this on a plant-specific basis.
		Other Drywell Debris	
28.	Pg. 29, 1st para.	Periodic Inspections are Necessary "As a result, the staff considers the following statement on page 51 of the URG to be unacceptable, 'Note that where use of an adequately conservative value is assumed for a particular debris species (e.g., dirt/dust), periodic inspections are not necessary.' It is the staff's opinion that periodic inspections are **always** necessary regardless of any baseline assumptions used in the ECCS analysis. The interval between such inspections should only be adjusted based on actual licensee performance and the amount of conservatism in the base assumption."	The BWROG notes that the intent of this URG statement is that inspections to quantify the amount of dirt/dust are not required. It was not intended to imply that general cleanliness inspections were not appropriate.
29.	Pg. 29, 2nd para.	Assure URG Guidance is Applicable to Your Plant "The staff notes that licensees should make every effort to ensure that the guidance in Section of 3.2.2, or any other section of the URG, is applicable to their plant before implementing that guidance on their plant."	The BWROG recommends that as part of the overall evaluation of the issues raised by Bulletin 96-03 each licensee should qualitatively consider whether the generic guidance contained in the URG is appropriate for their plant. It should not be necessary for licensees to conduct detailed quantitative evaluations to justify NRC-accepted values in the URG (e.g., dirt/dust, rust flakes, sludge distribution, etc.) Licensees may elect to use different values than those provided in the URG and, where less conservative than the approved URG values, should document an adequate basis for the values used.

*Items marked with an asterisk were discussed with the NRC staff during a public meeting on 2-6-98.

BWROG Response to Draft SER on URG

No.	Draft SER References	Issue Description	BWROG Recommendations
30.	Pg. 30, 2nd para. Pg. 32, 1st para.	150 lbm. Dirt/Dust Value Not Adequately Supported "The staff believes it would be prudent for utilities to verify this number through sampling. It would be relatively straightforward for the BWROG or an individual licensee to take samples of dirt and dust from the drywell and suppression pool areas, determine typical weight-per-unit-area on collecting surfaces, and calculate a bounding values for all applicable surfaces. An allowance would have to be added for concrete dust generated by LOCA forces. .... In addition, consideration should be given to containment size, and the potential for additional dirt and dust accumulation over the operating life of the plant. While the staff does not believe that use of the URG 150 lbm assumption is inappropriate, the staff does believe that it would be prudent for individual licensees to conduct a more thorough evaluation." "Considerable time was devoted to the development of the NUREG/CR-6224 (Ref 31) study to develop conservative estimates of dirt/dust and rust. Where provided, the values suggested in the URG are about the same or larger than NUREG/CR-6224 values. As a result, the staff concludes that use of these values is acceptable; however, the staff notes that the NUREG/CR-6224 study was conducted on a reference Mark I containment. For this reason and the additional reasons cited above, the staff believes it would be prudent for individual licensees to evaluate the recommendations of this section for applicability to their plant.	The BWROG understanding of this language is that the staff considers 150 lbm value to be acceptable. Further, the BWROG believes that this issue is adequately addressed given the recommendation in Item 1 for each licensee to consider the overall conservatism of their evaluation and, as described in Item 29, the appropriateness of the URG guidance to their plant. The BWROG believes that there is negligible safety benefit to be achieved by requiring (or encouraging) that each licensee explicitly verify this value and that the radiation exposure received in accomplishment would not be justified.
31.	Pg. 30, 3rd para.	50 lbm. Rust Flake Value Not Adequately Supported "This presents the same concern to the staff for this suggestion as for the dirt/dust value noted above. Again, the staff believes that a sound technical basis could be developed by sampling applicable drywell and suppression chamber areas combined with walkdowns to establish typical quantities of rust per unit area. ...As with the dirt and dust discussion noted above, the staff does not believe that use of the 50 lbm assumption is inappropriate."	See the BWROG response to comment 30. The BWROG understanding of this language is that the staff considers the 50 lbm. value to be acceptable and that verification is not a requirement.

*Items marked with an asterisk were discussed with the NRC staff during a public meeting on 2-6-98.

No.	Draft SER References	Issue Description	BWROG Recommendations
32.		Coatings Impacted by the LOCA Jet Still an Open Issue	The BWROG notes that because the staff still has this issue under review, many licensees may not be able to reach a conclusion on whether or not the replacement strainers will satisfy the requirements of Bulletin 96-03. The impact on the schedule for closure of the Bulletin 96-03 response is discussed in further detail in Item No. 2.
	Pg. 31, 1st para.	"The staff has not identified any current concerns relative to the conclusions in Reference 51 [Bechtel Report]. However, the staff points out that the issue of coatings and their potential impact on the ECCS is an issue currently under staff review, and is the subject of a generic letter expected to be issued in early 1998. As a result, the conclusions of Reference 51 are still under staff review."	
	Pg. 32, 2nd para.	"Consistent with the staff's guidance above, it would also be prudent for licensees to evaluate the conclusions of the Bechtel coatings report to ensure applicability of those conclusions to their plant."	See BWROG response to Item No. 29.
33.		NRC Disagrees that Unqualified Coatings are a Latent Debris Source	See the BWROG response to Item No. 32.
	Pg. 31, 2nd para.	"The staff is particularly concerned because there is no basis for this statement, and in the staff's opinion, it is entirely inaccurate. In fact, there is no evidence that indeterminate or unqualified coatings would be latent debris at all. ....then there is no reason to assume that the turbulent environment of the reactor vessel blowdown could not cause the coating to detach and transport to the suppression pool."	The BWROG has undertaken a testing program for unqualified coatings. The testing and associated analyses will be used to address the concerns raised by the staff. This is a separate effort that will not be addressed by the URG.
	Pg. 31, 3rd para.	"In light of recent qualified coating events and the lack of substantive technical basis for the BWROG guidance regarding unqualified and indeterminate coatings, the staff does not have enough information to evaluate the adequacy of the BWROG guidance."	
	Pg 32., 3rd para.	"Most importantly, as noted above, the staff concludes that licensees should be cautioned to carefully evaluate the potential impact of unqualified and indeterminate coatings on ECCS suction strainer head loss. If in doubt, assuming the coatings reach the strainer surface would clearly be the conservative measure. This would provide the licensee with less risk relative to the coatings issue, and could lead to additional margin in strainer design if URG statements which minimize the potential impact of unqualified protective coatings are supported by the results of the staff's coating review."	
		Drywell Debris Transport	
34.		Complete Insulation Destruction within 3 L/D	100% destruction to 3 L/D was assumed for all debris types.
	Pg. 33, 5th para. (Item 1)	"In addition, the URG estimates assume that for NUKON, all insulation contained within 3L/D of the break is destroyed into fines. It is not clear, however, that this assumption was made for all debris types."	

*Items marked with an asterisk were discussed with the NRC staff during a public meeting on 2-6-98.

BWROG Response to Draft SER on URG

No.	Draft SER References	Issue Description	BWROG Recommendations
35.*	Pg. 35, 1st para.	Opening in Lowest Level Gratings "Large debris generated above the lowest grating should not be discounted if the lowest floor grating is not continuous or has substantial openings in it through which larger debris could transport. In this case, an appropriate fraction of large debris from above the grating should be considered as transportable."	To resolve this issue, the BWROG recommends that the staff consider the overall conservatism in the BWROG approach as being sufficiently conservative to address this concern. The BWROG notes that there are multiple levels of gratings and other obstructions which would also be effective at preventing the transport of debris but they are not credited in the analysis. If the above approach is not adopted, the staff should clarify what constitutes "substantial openings" and "appropriate fraction of large debris" as these terms could lead to inconsistent regulatory interpretation.
36.*	Pg. 35, 2nd para.	Mark II Transport Values Not Acceptable "Therefore, the staff finds the transport fractions for Mark II containments listed on pages 75 and 80 of the URG to be unacceptable. Fractions are also given on the same pages for fine fibrous debris transport and RMI debris transport in Mark I's and III's. The values given for Mark I's and III's assume that 100% of the fine debris will transport to the suppression pool. ....The staff believes that these same fractions should also be used for Mark II's."	The basis for the staff's current position not to accept the transport values for Mark IIs is the results of testing conducted by the NRC. These tests are documented in NUREG CR/6369 which has not yet been published. The staff completed these test in the first half of 1997 and made a presentation of the results in July 1997. The BWROG has previously requested a draft of the NUREG so as to be able to review the details of the test setup, parameters and procedures. The staff has stated that they cannot release the NUREG until final publication.. The BWROG requests the opportunity to defer their response to this issue until the NUREG is made available. Upon receipt, we will evaluate the impact of the test differences between the BWROG scaled tests and the NRC tests on the outcome of the results.

*Items marked with an asterisk were discussed with the NRC staff during a public meeting on 2-6-98.

No.	Draft SER References	Issue Description	BWROG Recommendations
37.*	Pg. 35, 3rd para.	100% Transport of Large Debris Below the Lowest Grating. "The staff concludes that insufficient technical justification has been provided for assuming a transport fraction less than 100% for large debris generated below the lowest drywell grating."	This issue was discussed with the staff and resolved at the February 6th meeting. In summary, the BWROG approach is to calculate a transport factor as a percentage of the total debris while the staff approach is to use a transport factor for transportable debris. The BWROG notes that in the NRC Drywell Debris Transport Study, the NRC interpretation of the AJIT test report is that 40% of the NUKON insulation within a ZOI is in the form of "canvassed debris" which is not transportable. Hence the NRC position is that the maximum amount of debris which can be transported to the suppression pool from the lower portion of the drywell is 60% of the initial insulation within the ZOI, a lower number than the corresponding 78% of the URG. This provides further evidence that the recommended values in the URG support the BWROG position that the overall methodology is sufficiently conservative.
38.*	Pg. 35, 4th para.	Erosion from Unthrottled ECCS Flow "If it does continue for more than three hours, than the licensee should determine an appropriate fraction to assume. Erosion of NUKON was shown to be linear in the NRC tests, so scaling of erosion of NUKON can be performed easily. Similar testing could be conducted for other insulation types, if necessary, to determine an appropriate fraction to assume for erosion."	The staff concern discusses the erosion rate but does not consider the conservative position taken in the URG on the amount of insulation material that would be exposed to erosion. Following the break, the fibrous debris generated will be distributed over the containment and only a small fraction will come to rest within striking distance of spill from the break. A portion of that which does reside in the spill area will be pushed aside by the flowing water as it splashes onto the drywell floor. Therefore, only a small fraction of the large fiber debris is subjected to wash down erosion. Despite this, the URG assumes that 25% of fibrous "large debris" (i.e., not fines) is exposed to the eroding affects of the spill from the break. The BWROG believes that any concerns regarding the effect of erosion over periods greater than 3 hours are more than offset by the conservative assumption on the amount of insulation exposed to the break leakage flow. The BWROG also notes that adopting the staff position could result in additional operator burdens and would require a change to emergency operating procedures which would be inconsistent with their symptom-based design. The BWROG recommends that erosion values consistent with those in the URG (e.g., 6.25% for Nukon fiber, 25% for Min-K, etc.) be accepted and that a time dependent factor not be introduced.

*Items marked with an asterisk were discussed with the NRC staff during a public meeting on 2-6-98.

BWROG Response to Draft SER on URG

No.	Draft SER References	Issue Description	BWROG Recommendations
39.*	Pg. 38, 1st para.	New Destruction Values Needed for Some Insulations "However, the staff identified that N_b values were obtained for several insulations based on a very limited set of experimental data. Examples are Temp-Mat, K-wool and some of the RMI. ....Therefore, the staff suggests that licensees with these insulations determine N_b values as follows: 1. Assume that all insulation contained in 3D spherical region becomes destroyed into fines, and 2. Assume that rest of the insulation would be destroyed such that local N_b is equal to the lowest N_b value measured in the experiments."	The URG methodology assumes 100% fines (fiber) within 3 pipe diameters. Where test data was limited for some materials, the BWROG used curve shapes that were consistent with materials for which several data points existed. The volume averaged destruction factor is not significantly affected by the curve shape. Based on the overall conservatism in the ZOI methodology, the BWROG recommends that the guidance in the URG be accepted and that the licensees not be required to adopt the approach suggested by the staff in the draft SER.
		NPSH and Head Loss Model	
40.	Pg. 42, Item 1	BWROG Head Loss Model is Unreliable and Incomplete Use of cookbook procedure may lead to erroneous head loss predictions. The staff does not believe their previous comment on this topic has been resolved.	All BWR licensees intend to use the head loss model provided by the selected strainer vendor which is specific to the replacement strainer. Consequently, the issue is moot and further response is not provided. The BWROG does note that licensees should be sensitive to the issues raised by the staff regarding head loss correlations and should assure that, where applicable, these issues are adequately addressed by the strainer vendor.
41*	Pg. 42, Item 2	Variation in Fiber Density NUKON fiber density as-manufactured (2.4 lbm/ft3) is greater than as-destroyed (~1.3 lbm/ft3) and the BWROG model does not address which could lead to inconsistent results.	See response to Item 40. The BWROG also notes that mass, not density, is typically used in head loss correlations.
42.	Pg. 42, Item 3	Limited Applicability of Model Applying the BWROG head loss prediction model to plant conditions that differ markedly from tested conditions could lead to erroneous head loss predictions. These limitations should be clearly stated.	See response to Item 40.

*Items marked with an asterisk were discussed with the NRC staff during a public meeting on 2-6-98.

No.	Draft SER References	Issue Description	BWROG Recommendations
43.	Pg. 43, Item 4	Head Loss Model Not Applicable to Thick Beds The test data and correlation were based on low debris loadings on the strainer surface. The staff's opinion is that the equation and the procedures are not applicable to thick combination fibrous/particulate debris beds. "As a result, the staff recommends that licensees utilize vendor specific test data demonstrating the strainer head loss for various debris loadings up to and including the licensee's limiting debris load."	See response to Item 40.
44.	Pg. 43, Item 5	Thin-bed Effect "The experimental data is neither complete nor was it supported by sufficient quantitative analytical reasoning to support the URG statement that the thin-bed effect is not a concern for alternate strainers. .....it is reasonable to state that medium breaks will not result in large head losses that are not bounded by large breaks, but a statement that no 'thin-bed effect' was observed is incorrect."	See response to Item 40.
45.	Pg. 43, Item 6	Use Licensing Basis for Operator Actions "In calculating NPSH, licensees should ensure that their calculations are consistent with their licensing basis. For instance, typically, no operator action is credited for the first 10 minutes during a postulated LOCA. Therefore, NPSH should be evaluated at runout flow until the plant licensing basis allows otherwise."	The BWROG concurs.
46.	Pg. 43, Item 7	Temperature Correction is Unacceptable "Reference 31 in the URG [CDI Memo 96-13 Effect of Temperature on NPSH Including Strainer Head Loss] is considered as an unacceptable methodology by the staff for determining minimum NPSH. The staff finds this methodology unacceptable because it incorrectly assumes that head loss across the strainer will be governed by laminar flow."	From the discussions during the meeting on 2-6-98 it was learned that the staff position is that the temperature correction methodology is not applicable to RMI debris beds. The BWROG concurs that it is not applicable to RMI beds but that the URG methodology is applicable to fiber beds.
47.*	Pg. 41, Item 5	Particulate mass not accurately accounted for in the debris/head loss correlation.	See response to Item 40.

*Items marked with an asterisk were discussed with the NRC staff during a public meeting on 2-6-98.

No.	Draft SER References	Issue Description	BWROG Recommendations
		Other Comments	
48.	Pg ES-3, last sentence	Submit analyses for pipe separation/single ended blowdown "Licensees desiring to take credit for limited separation of the broken ends due to pipe restraints or single ended blowdown should conduct supporting analyses and submit them for further review before their use."	The BWROG recommends that the staff revise this position and not require that licensees submit supporting analyses for pipe separation or single ended blowdown for staff review prior to their use. Instead, licensee should assure these analyses are available for review during inspection.

BWR OWNERS' GROUP

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NRC Project 691
Document Control 96-266
NRC Bulletin 96-03

BWROG-96125
November 20, 1996

US Nuclear Regulatory Commission
Washington, DC 20555-0001

Attention: Document Control Desk

SUBJECT: ***Transmittal of BWR Owners' Group Utility Resolution Guidance for ECCS Suction Strainer Blockage***

Attachments: (1) NEDO-32686, "Utility Resolution Guidance for ECCS Suction Strainer Blockage" dated November, 1996
(2) Technical Support Documentation for Utility Resolution Guidance (3 Volumes)

The subject Utility Resolution Guidance (URG) for ECCS Suction Strainer Blockage and the associated Technical Support Documentation are attached for your final review and approval. This documentation has been developed to provide guidance to operators of BWRs for responding to Bulletin 96-03. The URG supplements, and in some cases provides alternatives to, guidance contained in Regulatory Guide 1.82 Revision 2.

As noted in plant specific submittals to the NRC in response to Bulletin 96-03, many operators of BWRs are planning to use the URG methodology to establish design criteria for strainer debris loadings. Timely NRC approval of key URG positions on a generic basis is requested to support schedules for design and implementation of plant specific resolutions to the issues raised in Bulletin 96-03.

The URG is supplemented by three volumes of supporting technical documentation. The documents in these volumes contain the results of BWROG analyses and testing which support the evaluation methodology described in the URG. In some instances, these support documents contain the calculational methodology to be used in evaluation of strainer performance. The URG directs the user to the appropriate section in the technical support documents, when needed, to complete the evaluation.

Revision bars in the document margins have been employed to highlight additions and text editing changes from the draft URG and draft Technical Support Documents which were transmitted to the NRC on October 7, 1996. Note that URG Section 3.2.3 "Drywell Debris Transport" and the associated Technical Support Document (URG Reference 5) were not included in the earlier transmittal. This information was, however, discussed with the NRC in a public meeting on October 16, 1996. Except for the addition of URG Reference 5, Reference 34 (NRC Bulletin 95-02), and Reference 35 (NRC Information Notice 96-59); the only changes to the Technical Support Document package are in Appendix A and B of the Alternate Strainer Test Report (URG Reference 3) and the inclusion of an omitted page (Reference 3, page 115). These latter revisions are not significant.

The BWR Owners' Group desires to promptly answer questions and provide clarifications that may arise during the NRC staff review of the URG documentation package in order that utilities may receive the safety evaluation report at the earliest possible date. This will allow participating utilities to resolve NRC Bulletin 96-03 at the earliest opportunity.

This letter and the attached documentation have been endorsed by a substantial number of the members of the BWR Owners' Group; however, it should not be interpreted as a commitment of any individual member to the specific course of action. Each member must formally endorse the appropriate BWROG position in order for that position to become the member's position.

If you have any questions regarding the enclosed documentation, please contact Rocky Sgarro (PP&L), BWROG ECCS Suction Strainer Committee Chairman, at (610) 774-7552 or Thomas A. Green, the GE Project Manager at (408) 925-1308.

Very truly yours,

KP Donovan, Chairman
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GE Nuclear Energy

NEDO-32686, Rev. 0

Class 1

November 1996

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Utility Resolution Guidance

for

ECCS Suction Strainer Blockage

prepared by

Boiling Water Reactor Owners' Group

Disclaimer of Responsibility

****IMPORTANT NOTICE REGARDING CONTENTS OF THIS REPORT****

PLEASE READ CAREFULLY

The information contained in this document is furnished for the purpose of providing the members of the BWR OWNERS' GROUP with bases and methods for resolution of the ECCS suction strainer blockage issue. The only undertakings of General Electric Company (and the General Electric subcontractors) with respect to information in this document are contained in the contract between each Boiling Water Reactor Owner and General Electric (i.e., the Standing Purchase Orders for participating utilities in effect at the time this report is issued) and nothing contained in this document shall be construed as changing the contracts. The use of this information by anyone other than that for which it is intended, is not authorized: and with respect to any unauthorized use, General Electric Company makes no representation or warranty, and assumes no liability as to the completeness, accuracy, or usefulness of the information contained in this document.

Acknowledgments

ECCS SUCTION STRAINER COMMITTEE

The following individuals were either members of the Boiling Water Reactor Owners' Group (BWROG) ECCS Suction Strainer Committee (ESSC) or primary subcontractors supporting the ESSC and as such provided overall guidance and support for resolution of this issue. Their efforts included identification of the overall phenomenology of strainer blockage, providing technical input to the analysis and testing conducted in support of this effort, providing perspective on design and licensing constraints for the various resolution options considered, and review of this document and the supporting technical reports.

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1

UTILITY RESOLUTION GUIDANCE WORKING GROUP

The individuals listed below were members of the BWROG Utility Resolution Guidance (URG) Working Group, a subgroup of the ESSC. Drawing on the support and assistance from many others, the URG Working Group had primary responsibility for the preparation of this document. The group's efforts included an integrated review of technical data from numerous sources, identification of BWROG activities needed to support URG objectives, consideration of BWR design and licensing inputs related to the issue, development of recommended resolution options, and resolution of NRC questions and comments. This work required original thinking to develop a comprehensive understanding of the phenomenology and months of effort to distill the complex and interrelated technical data into a simplified evaluation methodology that is consistent with the physical reality of a LOCA event, conforms with regulatory requirements, and provides utilities which implement the guidance with the necessary flexibility to account for the plant unique factors which must be considered.

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After preparation by the URG Working Group, this document was reviewed and approved by the BWROG.

The BWROG acknowledges contributions made by Alan Bilanin, Andrew Kaufman and J Munchausen (Continuum Dynamics), John Lynch (Entergy Operations) and Fred Moody (GE) for their valuable support in the investigation of key technical issues. The BWROG also acknowledges the efforts by Leonard Loflin (Electric Power Research Institute, Plant Support Engineering) in coordinating EPRI resources to support the testing conducted by the BWROG at the EPRI facility in Charlotte, North Carolina. The work of John Gisclon (EPRI) is noted for his assistance to the BWROG in preparation of portions of the OECD International Task Group report, "Knowledge Base for Emergency Core Cooling System Recirculation Reliability."

Finally, the BWROG also wishes to acknowledge the valuable contributions made by various individuals from utility companies, subcontractors supporting the BWROG, insulation vendors, the Nuclear Regulatory Commission staff, organizations supporting NRC research, and the international nuclear community.

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1. Introduction

The postulated rupture of a pipe located inside the drywell/containment and carrying high-energy fluid is one of the key assumptions used in development of the licensing, design and operational requirements for nuclear reactors. Although the realistic probability of a double-ended guillotine break of a large pipe in a BWR is extremely low (on the order of 1E-9 to 1E-12 per year of reactor operation)[1], it is an event which reactors must be designed to withstand, without jeopardizing the health and safety of the public. This design basis accident (DBA) is referred to as a loss-of-coolant accident (LOCA).

Should such an event ever occur, the high-energy fluid released from the ruptured pipe could lead to damage of adjacent equipment and materials. A portion of the LOCA-generated debris resulting from this damage could then be transported from the drywell where the rupture occurred, to the suppression pool where it could then be drawn to emergency core cooling system (ECCS) pump suction strainers. If debris accumulation on the strainers is sufficiently severe , it could jeopardize the ability of the ECCS pumps to draw suction thus compromising the primary design function of the ECCS. Determination of the quantity and characteristics of debris generated from a given pipe rupture, the amount of debris transported to the ECCS pump strainers, and the effect of such debris on the ECCS, is necessary to assure that the reactor design is capable of withstanding the DBA-LOCA.

In the last few years there have been events at operating reactors (but not pipe ruptures) which indicate that existing plant designs may be more susceptible to the reduction of ECCS flow from ECCS suction strainer blockage than previously believed. The events at Barsebäck, Perry and Limerick[2] have resulted in the need to re-evaluate this issue and, where necessary, enhance the plant design and operating practices to ensure that a high level of safety is maintained.

[1] See Reference 32

[2] See the Background section of NRC Bulletin 96-03 (Reference 1) for a discussion of these events.

The BWROG has developed this URG document and supporting technical reports to provide guidance to operators of BWRs for responding to NRC Bulletin 96-03 (Reference 1). Upon review and approval by the NRC, this URG document also provides acceptable alternatives to the applicable guidance contained in Regulatory Guide 1.82, Rev. 2, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," May 1996 (Reference 2).

It should be noted that the determination of pipe break locations, zone of influence, destruction factors, and other calculational bases described herein are solely for ECCS strainer design purposes and are not intended to replace the plant licensing or design basis for other purposes.

2. Overview

This document (also referred to herein as the URG) provides guidance to BWR licensees to evaluate the susceptibility of ECCS pump suction strainers to blockage resulting from the effects of a postulated LOCA. It also provides alternative resolution options for consideration should plant evaluations reveal a susceptibility to strainer blockage.

The complexity of the plant-specific evaluation should not be underestimated. The evaluation of whether existing strainers are acceptable will require significant technical effort and time to complete. The selection of a technically sound and economically effective resolution which preserves operational flexibility, and resolves the strainer issue within the design constraints imposed by other regulatory requirements, will be especially challenging. Note that one of the considerations in developing this URG was to avoid re-opening containment analysis issues which the BWROG believes would have resulted in significant delays in resolution of the ECCS strainer blockage issue.

It should be recognized at the outset that a multi-discipline approach will be required to conduct the plant specific evaluation as the issue affects many aspects of plant operation and design. Changes to the current licensing basis of the plant will be required. Plant design basis documentation must be updated. A key management challenge is the balance between operational flexibility and design margin in developing design assumptions for the final resolution.

As a general rule, the required size of an alternate passive ECCS pump suction strainer will increase in direct proportion to the number of conservative assumptions used in the analysis. Additional effort to develop more precise values for the inputs to the analysis will likely result in a smaller strainer being acceptable. The decision as to whether to commit additional resources to develop more precise values or instead accept a larger strainer will be affected by the resolution option preferred by the utility and other design constraints such as available NPSH margin and hydrodynamic loads on ECCS suction piping. Arriving at a technically sound decision in this

regard is complicated by consideration of other factors such as the performance characteristics of various strainer designs, changes to piping insulation (e.g., installation or modification of jacketing and/or banding), housekeeping controls, pool cleaning frequency and changes to the plant licensing basis. All of these factors can affect strainer size.

The URG should be used only as a guide to resolving the ECCS strainer blockage issue on a plant specific basis. It is not a "cookbook," but a roadmap. There are numerous plant-specific considerations that dictate unique evaluations and resolutions by each plant. This document is intended to allow flexibility and preserve management prerogative in developing plant-specific resolutions. It should also be noted that licensees may elect to employ alternate calculational methodologies from those provided in the URG. In these cases, the BWROG recommends that licensees obtain NRC review and approval of methodologies which are at variance with those provided herein prior to reliance upon their results in the sizing of passive strainers used to assure compliance with the requirements of 10 CFR 50.46.

The complex interrelationship of the various design considerations suggest that ideally a core team maintain cognizance of the resolution development. While drawing on the input of various technical and management entities, the dedicated core team could maintain the focus necessary to develop a detailed understanding of the many factors affecting the resolution of the issue. This team can then balance the pros and cons for each of the many individual decisions in order to arrive at an integrated resolution that is in the best overall interest of the utility.

Section 3.1 provides additional definition of the technical challenges. Section 3.2 provides guidance on sizing a passive strainer and is the major focus of this document. Other sections provide information on other potential resolution options and other design considerations such as defense-in-depth.

The URG is supplemented by three volumes of the key technical support documentation. The documents in these volumes contain the results of extensive BWROG analysis and testing which support the evaluation methodology described in the URG. In some instances, the technical

support documents contains the calculational methodology to be used in evaluation of strainer performance. The URG directs the user to the appropriate section in the technical support documents, when needed, to complete the evaluation.

3. Guidance for Demonstrating Compliance with 10 CFR 50.46

3.1 Evaluation of Resolution Options

3.1.1 Overview

This section provides guidance intended to assist utility management and staff personnel in selection of the most efficient approach to evaluating and resolving concerns with the performance of passive ECCS suction strainers. Key factors affecting the complexity and cost of the evaluation of performance, and the implementation of potential resolutions, are identified and recommended approaches are provided. This section provides an overview of alternative approaches to evaluation of resolution options. Detailed guidance for demonstrating that the option selected satisfies the requirements of 10 CFR 50.46 is provided in Sections 3.2 through 3.4.

This document primarily addresses the issues related to debris blockage of ECCS suction strainers since it is that issue that the Barsebäck, Perry and Limerick events[3] have shown to be of concern. There are other important issues related to the design of suction strainers (e.g., air ingestion, size of opening in the strainers, missile protection, etc.) that are not discussed herein. Even though these issues are included in Regulatory Guide 1.82, Rev. 2, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," May 1996 (Reference 2), the current licensing and design bases related to these other issues is considered to be adequate and these other issues need not be re-addressed for purposes of resolving the ECCS strainer blockage issue.

The events at Barsebäck, Perry and Limerick, and utility actions in response to those events, have also provided valuable information which can be applied to better assure that ECCS pumps will have adequate NPSH available post-LOCA. The event at Barsebäck demonstrated that a

significant portion of debris can be transported from the drywell to the suppression pool as a result of washdown when downcomers are flush to the drywell floor. The event at Perry highlighted how particulate material, when combined with a thin bed of fiber, can result in significant head loss across a strainer. The event at Limerick reinforced the lesson from the event at Perry. Licensee actions in response to these events have shown the importance of containment and suppression pool cleanliness in reducing the challenge to ECCS strainers from operational debris sources. The lessons learned from these events have been carefully considered in developing this document. The importance of reducing operational debris is further emphasized in Section 3.2.2.

Effective resolution of this issue requires applying efforts to problem definition, analysis, plant modification, and operational controls in the most efficient manner. While the basic phenomenology of the event is essentially the same at all plants (i.e., a LOCA is postulated, generating insulation debris, some fraction of the insulation and other drywell debris is transported to the wetwell, and eventually to the ECCS strainers), the optimum level of effort to apply to each phase of the evaluation is dependent on plant-specific factors.

Figure 1 provides a flow chart outlining the key phases of the analysis as a function of the more important plant-specific factors. This is intended as an aid to be used in identifying an overall resolution approach. Figure 2, Figure 3 and Figure 4 provide a process diagram for the various portions of the evaluation of ECCS pump NPSH. The process diagram shows references to major sections of the URG which provide the details necessary to complete that portion of the evaluation.

Important plant-specific factors are the type, amount, and location of insulation present in the drywell. Another important factor are the design features (e.g., plant layout) which affect the NPSH available to the ECCS pump assuming no head losses across the strainer. Recommended approaches to select the optimum resolution option for plants with various types and amounts of insulation material in the drywell are discussed in Sections 3.1.2 through 3.1.3.

[3] See the Background section of NRC Bulletin 96-03 (Reference 1) for a discussion of these events.

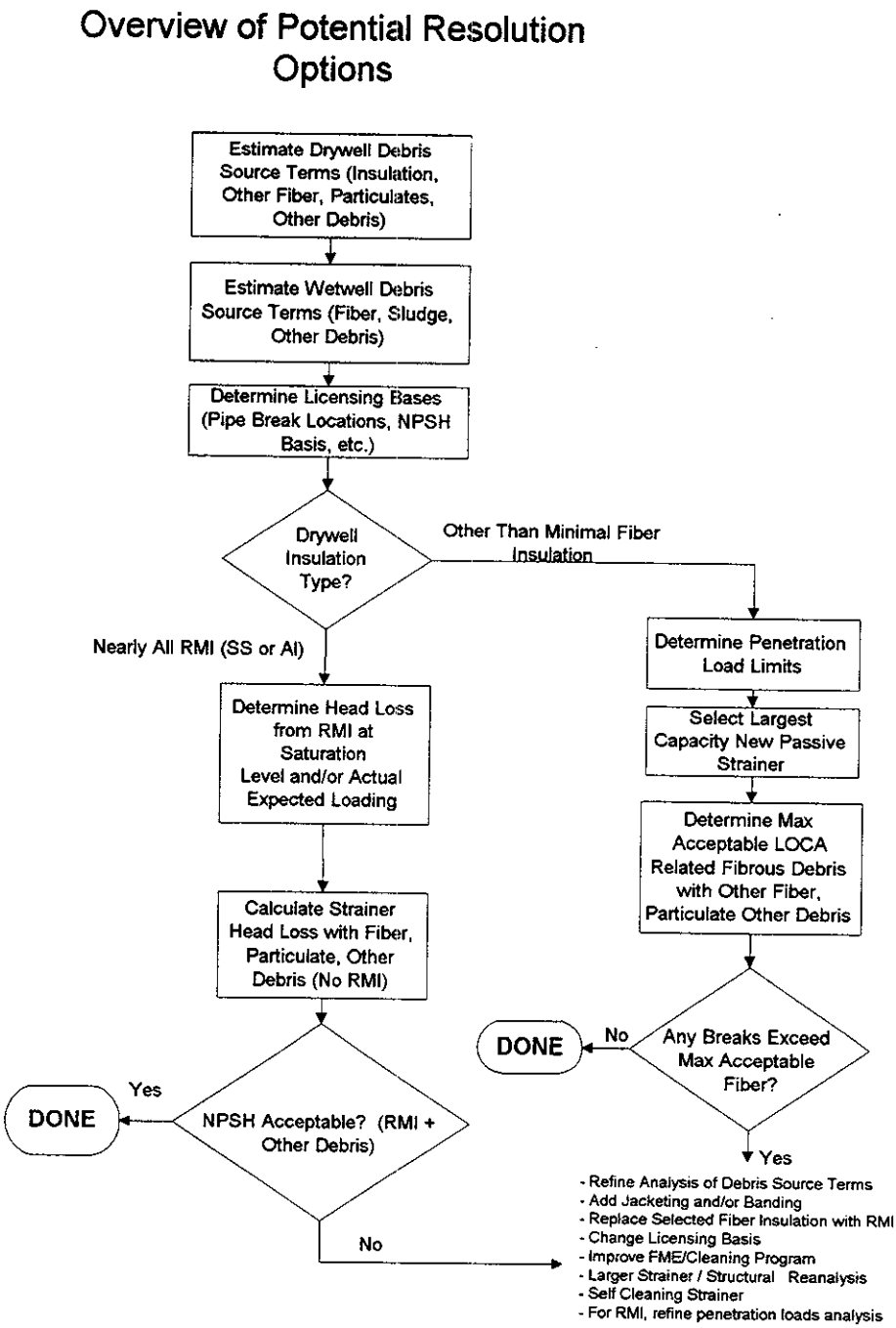
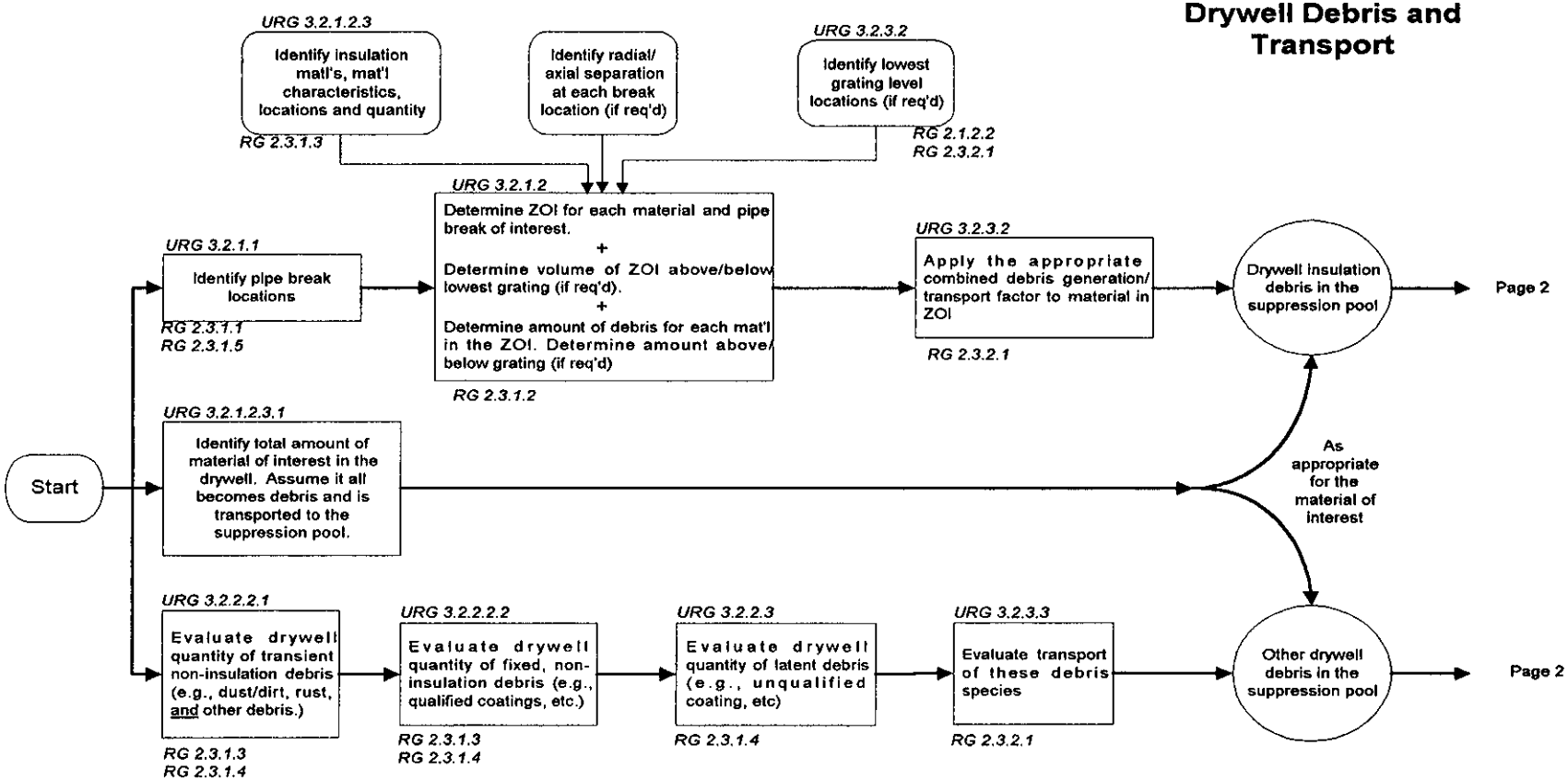


Figure 1 - Overview of Potential Resolution Options

1

ECCS Pump NPSH Evaluation Process Diagram

Drywell Debris and Transport



This Figure shows the major steps in the evaluation of ECCS pump NPSH as described in the URG. It is not a replacement for the guidance in the URG. Reference is made to applicable sections of the URG, and Reg. Guide 1.82, Rev. 2 as an aid to the user.

Licensees may use alternate methodologies from those provided in the URG for any portion of the evaluation of NPSH. The BWROG recommends that NRC review and approve methodologies which are at variance with those in the URG prior to reliance upon their results in the sizing of passive strainers used to assure compliance with the requirements of 10CFR50.46.

Figure 2 - Evaluation Process Diagram - Drywell Debris and Transport

ECCS Pump NPSH Evaluation Process Diagram

Suppression Pool Debris and Transport

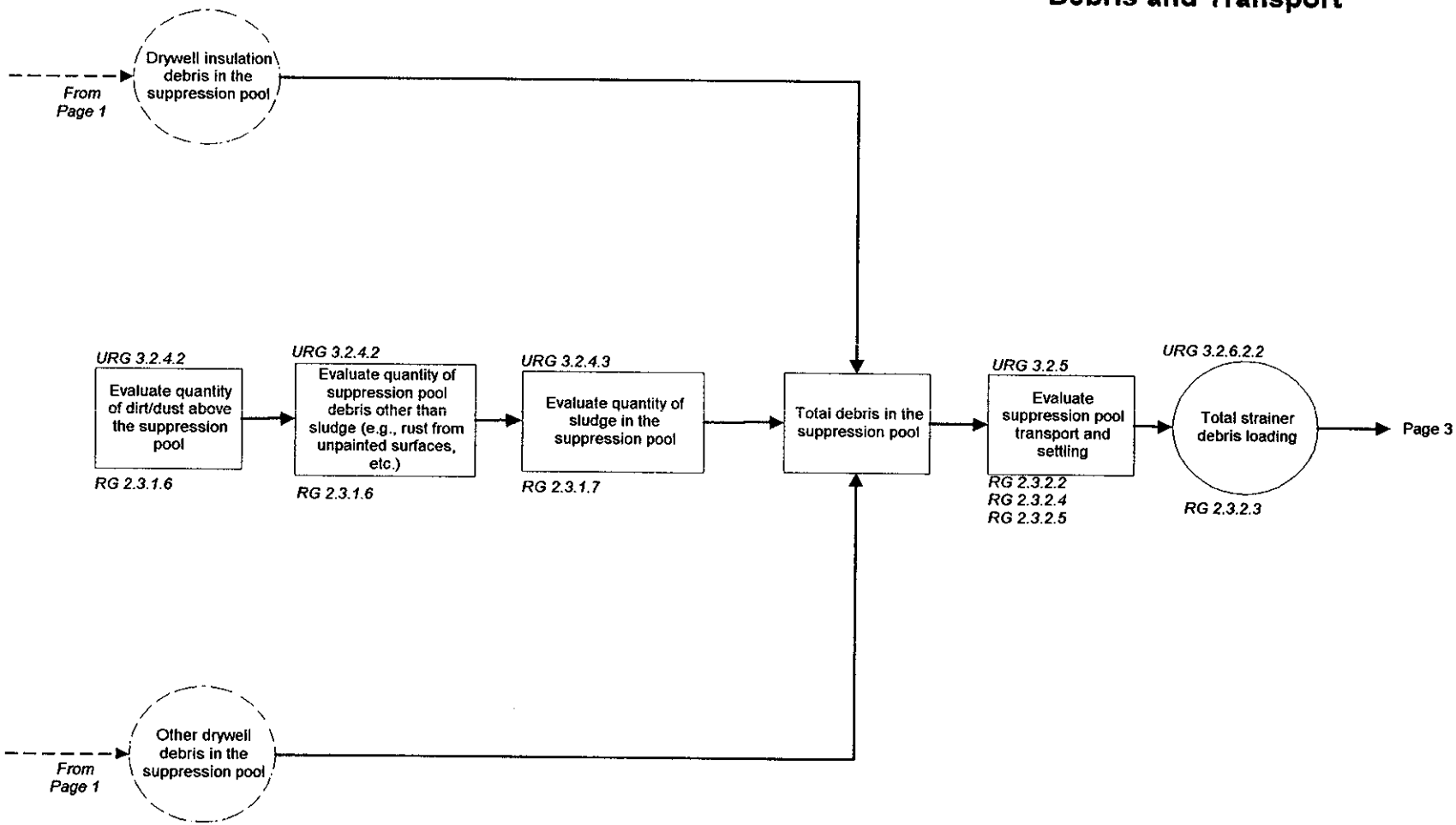
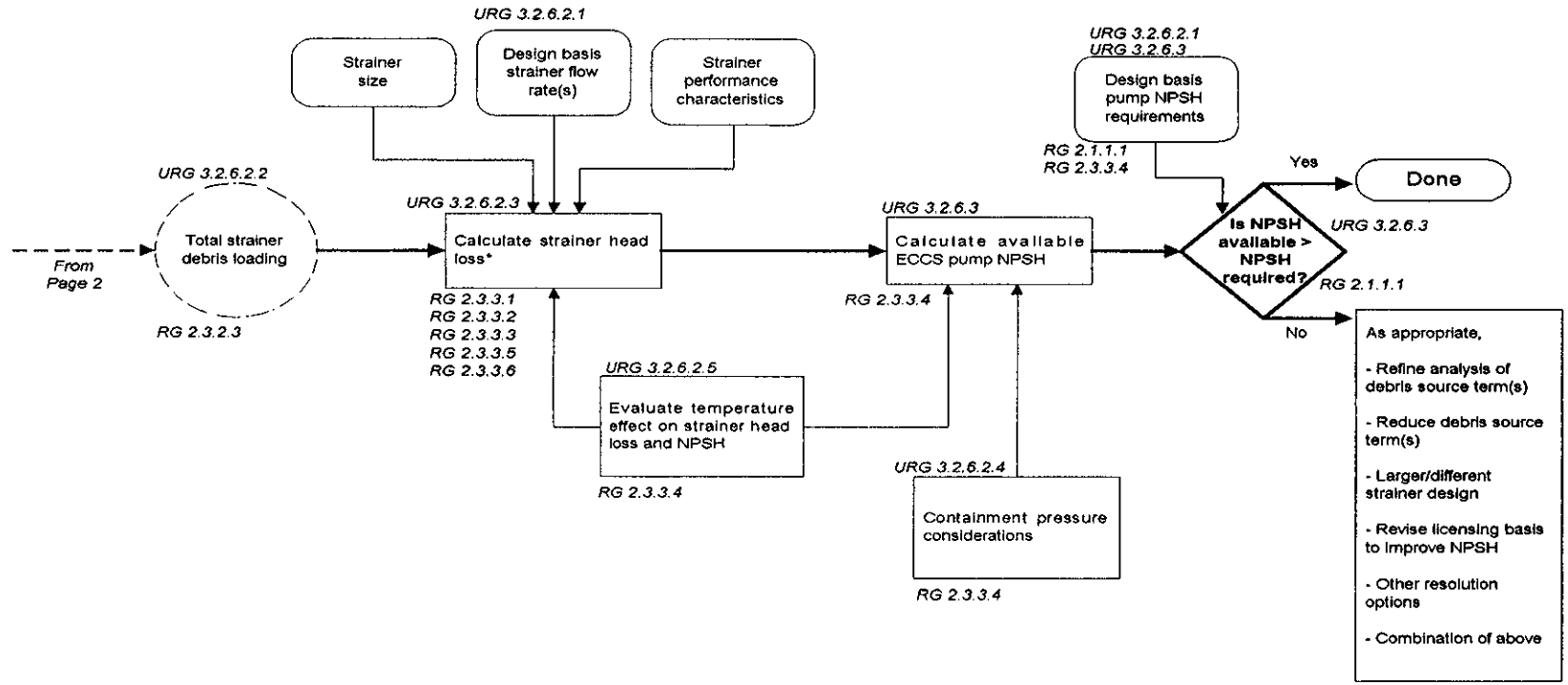


Figure 3 - Evaluation Process Diagram - Suppression Pool Debris and Transport

ECCS Pump NPSH Evaluation Process Diagram

NPSH Evaluation



* Assure that the URG head loss correlations for the debris of interest are applicable to the strainer design evaluated. If not, those head loss correlations which are applicable to the strainer being evaluated should be used, and their basis appropriately justified.

Figure 4 - Evaluation Process Diagram - NPSH Evaluation

3.1.1.1 Estimation of Debris Source Terms

Each plant must perform an evaluation of the types and quantities of debris sources present. Two major categories of debris sources will be addressed: 1) fixed debris sources, which are those sources which must be impacted by the LOCA jet or blowdown forces in order to become debris capable of transport to the ECCS strainers; and 2) transient debris, which generally result from normal plant operations, and are present in a transportable form prior to the postulated LOCA. Examples of fixed debris sources include piping insulation materials in the drywell and paint on drywell surfaces. Examples of transient debris sources include dust, dirt, and any miscellaneous loose fibrous materials present within either the drywell or the suppression pool.

Sections 3.2.1, 3.2.2, and 3.2.4.2 identify potential debris sources which must be considered during evaluation of ECCS suction strainer performance. Also, these sections provide guidance on the level of analysis required to quantify each of these potential sources which is dependent upon the precision required to support assumptions made in the evaluation of ECCS pump NPSH margin. Precise quantification of the debris source terms can become a significant part of the burden of the overall evaluation. Use of conservative values is recommended as part of an initial simplified scoping evaluation to identify the most likely resolution options for each plant. Detailed evaluation of each source term is recommended only to the degree necessary to support the final design of the selected resolution option.

3.1.1.2 Identification of Key Licensing Basis Assumptions

Each plant should identify the current licensing bases for the ECCS strainers, including the assumptions supporting calculation of ECCS pump NPSH margin.

In particular, the current licensing basis relative to crediting containment pressure in the calculation of NPSH margin should be clearly defined. Older Mark I containment plants typically

are not committed to the requirements of Regulatory Guide 1.1 (Reference 27), which do not allow credit for containment pressure in calculation of available ECCS pump NPSH. Depending on the plant-specific licensing basis, some plants may be allowed to credit containment pressure in calculating available NPSH. For some of these plants, current design basis calculations may reveal that containment pressure need not be credited in order to demonstrate adequate ECCS pump NPSH, given the assumptions made regarding strainer loadings. This does not necessarily mean that containment pressure cannot be credited in the revised analysis performed as part of the resolution of the current concern with ECCS suction strainer performance. Design basis calculations may include assumptions which are conservative relative to the actual licensing basis commitment.

The BWROG recommends that plants whose licensing basis allows credit for containment pressure should consider, if practicable, use of a strainer that results in acceptable ECCS pump NPSH without reliance on containment pressure. This approach provides additional conservatism in the ECCS pump NPSH margin. It is also recognized that this additional conservatism may not be practicable for some plants because of the various plant-specific factors such as suppression pool layout, pump locations, containment load issues, etc. Therefore, consideration of containment pressure in the determination of available ECCS pump NPSH is acceptable when it is allowed by the plant licensing basis.

Similarly, licensing basis assumptions regarding suppression pool temperature used as input to NPSH margin calculations should also be identified, and a licensing change of this parameter may also be considered. A reduction in the suppression pool temperature used for NPSH calculations, if justifiable, can result in a significant increase in the NPSH available to the ECCS pumps.

Another potential licensing issue is the selection of pipe break locations to be analyzed. There is a potential for conflict between the pipe break locations identified in the plant licensing basis and those to be used for analysis of the ECCS strainer blockage issue. This issue is discussed further in Section 3.2.1.1.

3.1.2 Plants with Reflective Metal Insulation

Strainer head loss testing was performed by the BWROG to determine the head loss for RMI debris, both stainless steel and aluminum, as a function of the bed thickness and strainer approach velocity. The testing included tests with increasing amounts of RMI debris without any fiber or particulate material; tests of RMI debris with particulates alone; and tests of RMI debris with fiber insulation and particulates. The head losses which resulted from the tests with combined RMI, fiber and particulate debris were bounded by those seen in similar tests for the equivalent loading of fiber and particulate without RMI debris.

For most plants the head loss from fibrous debris, in combination with suppression pool sludge, is expected to dominate the strainer head loss. However, depending on the strainer approach velocity and expected RMI debris loading, the head loss caused by RMI debris may be significant and therefore should be evaluated.

3.1.2.1 Demonstration of the Adequacy of Existing ECCS Strainers

Even plants with all or nearly all RMI will be challenged to demonstrate that the performance of existing ECCS suction strainers is acceptable. Licensees attempting to justify continued use of existing strainers should be aware that while the total amount of fibrous debris that can be accommodated by the existing strainers is a function of strainer size and the amount of particulates present, testing performed by the BWROG and the experience at Perry and Limerick indicate that small amounts of fiber in the suppression pool (as low as ½ - 1 pound per strainer), in combination with suppression pool sludge, may be sufficient to result in unacceptably high head losses.

Plants choosing to demonstrate the adequacy of existing truncated cone strainers will need to perform a thorough identification and quantification of potential sources of debris, as described in Sections 3.2.1, 3.2.2 and 3.2.4. Implementation of very aggressive foreign material exclusion (FME) and housekeeping program controls, consistent with maintenance of the low values of

debris in both the drywell and the wetwell, may be necessary to assure ECCS operability for plants relying upon existing strainers. There are various other strainer designs currently installed at plants which were not tested by the BWROG. The BWROG recommends that licensees with these other type strainers should not assume better performance than truncated cone strainers unless supported by appropriate testing or analysis.

The potential operational impacts of the controls required to maintain debris source terms at or below the values assumed in the evaluation of ECCS suction strainer performance should be considered. Reliance upon rigorous foreign material exclusion and housekeeping programs in order to ensure very low levels of debris could reduce the efficiency of normal and/or outage operations, and could potentially increase outage length and cost. Consideration should be given to the cost-effectiveness of reliance upon rigorous FME programs when selecting the quantities of transient debris to be included in the evaluation of strainer performance.

Consideration should also be given to the potential impact of a failure to fully comply with FME or housekeeping requirements which then results in an amount of debris in the drywell and/or the suppression pool exceeding the assumptions in the evaluation of ECCS suction strainer performance. Such an occurrence would result in a challenge to ECCS operability.

3.1.2.2 Resolution Options

Several options exist should the existing strainers not provide adequate capability for the largest potential quantity of LOCA related RMI debris in combination with other debris source terms. Selection of the most cost effective option will be based on plant specific conditions.

The resolution options for plants with predominantly RMI are generally the same as for plants with significant amounts of fibrous insulation and are discussed in Section 3.1.3.4.

3.1.3 Plants with Significant Amounts of Fibrous Insulation

Testing performed by the BWROG indicates that conical or cylindrical perforated plate strainers typical of those originally installed at many US BWRs develop high head losses with small loadings of fiber (on the order of one pound is typically sufficient to cover each strainer with about 1/8 inch of fiber) and particulate debris. In response to this "thin bed" phenomenon, the BWROG funded development and testing of passive strainers of alternate design which perform significantly better under combined fiber and particulate debris loadings.

Licensees planning to continue using quantities of fibrous insulation in the drywell which would result in fibrous debris loadings greater than approximately ½ - 1 pound per strainer (or plants which cannot assure less than this quantity of fiber from operational debris) should consider replacing their existing strainers with either passive strainers of alternate design or with a strainer design which maintains acceptable head losses by actively removing accumulated debris. Sections 3.2.1 through 3.2.4 recommend an approach to evaluation of options for replacement of existing strainers with passive strainers of alternate design. Section 3.4 provides guidance on the use of active self-cleaning strainers.

For installation of an alternate strainer that by itself, or in combination with other actions (e.g., insulation removal/replacement, jacketing/banding, etc.), results in an acceptable final resolution to the ECCS strainer blockage issue, selection of the size and type of alternate strainers is dependent on numerous plant-specific factors. Where penetration load limits and margins are well known, installation of the highest capacity alternate design strainer possible within the existing load limits (i.e., without reopening the licensing basis for containment loads) is recommended. It is anticipated that NRC reviews of containment load changes could significantly protract installation of a final resolution.

Until there is confidence that the NRC will accept the methodology used to calculate strainer debris loadings/head losses for the specific strainer design being considered, the BWROG recommends that licensees carefully assess whether installation of an alternate strainer as an

interim action is appropriate. This is because the optimum resolution option(s) for the utility may change depending upon the analytical methodology and requirements ultimately approved by the NRC, and proceeding with installation of an alternate strainer on an interim basis may divert utility resources from more important activities and delay final resolution of the ECCS strainer blockage issue. Licensees should also be aware that performance of the plant specific evaluation required by 10 CFR 50.59 prior to installation of a new strainer as an interim measure may result in identification of an unreviewed safety question (USQ). The USQ may be applicable either to a strainer of alternate geometry or to a larger strainer of the same design as the existing strainer. Should a licensee determine that a USQ exists, the resolution of the USQ with the NRC may further divert both utility and NRC resources and impact implementation of a final resolution to the ECCS strainer blockage issue.

3.1.3.1 Evaluation of Containment Penetrations Load Margins

Each plant planning to continue use of significant quantities of fibrous insulation should identify existing containment penetration load margins for each ECCS suction line penetration and load margins on the suppression pool structure. An evaluation should be performed to determine the optimum alternate strainer geometry, size and weight which could be supported by each penetration within the bounds of the current analysis. Pool structure loads should also be considered. This evaluation should also identify any excess conservatism used in the existing structural analysis which could be reduced through the use of alternate analysis methods.

When initially scoping the resolution options, licensees may review the existing penetration load calculations to identify the margin between the loads calculated and the loads allowed. If additional margin is desired it may be possible to recalculate the penetration loads using updated plant-specific values and analysis techniques which were not available during the original loads analysis. This recalculation of penetration loads may provide additional margin.

A plant modification to add supports to a strainer is also an option which can avoid excessive containment penetration loads.

Care should be taken to assure that any changes in analytical methods are consistent with licensing basis commitments made for analysis of penetration loads and margins or dialogue with the NRC begun early in the process regarding anticipated changes. Plant specific licensing changes and FSAR changes may be required.

3.1.3.2 Physical Constraints

Each plant should conduct a review of physical constraints which would limit installation of larger strainers due to interference during the installation process. Limits on the size and configuration of possible alternate strainers due to physical constraints at each penetration and in the installation path should be identified.

3.1.3.3 Selection of Passive ECCS Suction Strainer Type and Size

Unless existing strainers can be shown to meet the requirements of 10CFR 50.46, the BWROG recommends that each plant select the largest capacity alternate design strainer which also meets plant-specific limits for penetration loads and physical constraints. An evaluation of ECCS pump NPSH margin should then be performed consistent with the guidance provided in Section 3.2.6. Figure 2 through Figure 4 outline the process recommended by the BWROG in performing this evaluation. A scoping approach to this evaluation is to set values for all debris source terms (including RMI debris), other than the LOCA-related fibrous insulation debris source term, and solve for the amount of fibrous insulation debris which can be accommodated by the alternate strainer while maintaining acceptable NPSH margin. If the amount of fibrous insulation debris which the strainer can accommodate exceeds the maximum value generated by any assumed LOCA break location, then the evaluation is complete and replacement of the strainer alone will resolve the issue. If not, one or a combination of the resolution options discussed in Section 3.1.3.4 should be considered.

3.1.3.4 Resolution Options

Several options exist should the largest capacity alternate strainer which can be installed within the current set of design limitations not provide adequate capability for the largest potential source of LOCA-related fibrous/RMI debris. Selection of a resolution option which meets the requirements of 10 CFR 50.46, preserves the desired operational flexibility, and is also the most cost-effective option, will be based on plant-specific conditions.

3.1.3.4.1 Further Refinement of Fixed Debris Source Terms

Licensees have a choice of the approach used to establish the amount of debris resulting from LOCA forces acting on fixed debris sources. Both simplified and increasingly detailed analysis methods are available for establishing the quantity of fibrous, RMI, or particulate debris. There is necessarily a tradeoff between these approaches. The simplified analysis is generally easier to perform but results in a more conservative amount of debris than the more detailed analysis. The detailed analysis approach may be more burdensome and costly for a licensee to perform but could result in an amount of fixed debris less than the value produced through the simplified analysis. Specific details on use of either the simplified or detailed analysis approach are included in the applicable sections for various debris species.

If the simplified, conservative estimates of one or more debris source terms were used as part of the initial analysis, the cost/benefit of more accurately determining these source terms should be considered. Reductions in the debris source term may be justified through use of more detailed analysis or inspections.

3.1.3.4.2 Replacement of Existing Strainers with Passive Strainers of Alternate Design

For most plants, demonstration that existing truncated cone ECCS suction strainers will provide adequate performance may not be possible. This is due to the limitations associated with the size

and design of typical truncated cone (or stacked disk) strainers, coupled with the bounding assumptions and simplifications necessary to analyze the issue in a practical manner. In these cases, replacement of existing truncated cone strainers with strainers of alternate design is recommended. Alternate passive strainer designs evaluated by the BWROG include stacked disc, 60 point star, and 20 point star strainers. When properly applied, the results of the extensive testing conducted by the BWROG may be applied to strainers other than those tested by the BWROG.

3.1.3.4.3 Installation of Jacketing to Reduce the Insulation Debris Source Term

Testing performed by the BWROG (Reference 6) confirms that the fibrous insulation which is protected with metal jacketing is able to survive without producing debris at distances much closer to a pipe break than the same fibrous insulation without the jacketing. Even within a few pipe diameters of the break, installation of metal jacketing and an appropriate attachment mechanism to hold the jacketing in place, will significantly reduce the amount of fibrous debris which can be transported to the suppression pool and contribute to strainer blockage.

Testing by the BWROG shows that the manner in which the jacketing is attached is critical. Test results indicate that some of the jacketed fibrous insulation currently installed in plants may require modification of the attachment mechanism and/or addition of banding in order to assure the protection offered by the jacketing is achieved.

Additional details on the use of jacketing is provided in Section 3.2.1.

3.1.3.4.4 Reduction in Transient Debris Source Terms

FME and housekeeping programs are typically the principal means employed by licensees to control transient debris. If the results of the evaluation indicate that the selected alternate design strainers are close to providing adequate ECCS pump NPSH margin, a reduction in the transient

fiber or particulate sources may be adequate to demonstrate acceptable performance. Implementation of further FME and housekeeping controls or pool cleaning frequency enhancements may provide the needed small increase in NPSH margin. The operational and ALARA impacts of such enhanced controls should be carefully considered.

3.1.3.4.5 CHANGE EXISTING LICENSING BASIS

Demonstration of adequate NPSH margin with the selected alternate strainers may not be possible using current licensing basis assumptions. Licensees may choose to pursue a change to the existing licensing basis if a justifiable change would result in adequate NPSH margin with the selected alternate strainers. One example of a potentially justifiable change would be a revised calculation of post-LOCA suppression pool temperatures using more accurate decay heat curves in lieu of the conservative decay heat curves used during original licensing of many plants.

Requests to change the licensing basis to now allow for credit of containment pressure in determination of ECCS pump NPSH is not recommended. (See Section 3.2.6.2.4)

3.1.3.4.6 REANALYSIS OF ECCS SUCTION LINE PENETRATION LOADS

It may be possible to further increase the size of the alternate strainer by reanalyzing ECCS suction penetration loads and suppression pool structural loads using more sophisticated techniques or through reduction of conservatism in current design basis calculations, but without reopening the licensing basis for containment loads. The reanalysis of loads may or may not include actual structural changes planned to support a strainer of increased size or weight.

The costs and potential benefits of performing such an analysis should be evaluated on a plant specific basis. The impact of such reanalysis on licensing commitments made during the original analysis of containment loads should be carefully evaluated. The BWROG does not recommend reopening the licensing basis for containment loads.

3.1.3.4.7 PARTIAL REPLACEMENT OF FIBROUS INSULATION WITH RMI

Plants may opt to replace fibrous insulation with RMI on some portion of drywell piping within the zone of influence such that the remaining debris loading is within the capability of the selected alternate strainer.

3.1.3.4.8 USE OF STRAINER BACKFLUSH SYSTEM

The BWROG recommends against use of strainer backflush systems as a primary means of resolving the ECCS suction strainer issue. The reasons for this recommendation are: 1) the time frame within which backflush would be required will typically be significantly less than 30 minutes, raising operator burden; 2) for many plants, repeated backflushes would be necessary within 30 to 60 minutes, which may not be feasible given limitations on ECCS pump motor starts, and 3) the NRC staff has indicated that use of backflush by itself would probably not be considered adequate[4]. Use of backflush for defense-in-depth purposes rather than the primary success path may be a viable option for those plants with the existing capability to align systems to backflush strainers.

Section 3.3 provides additional detail on the basis for the BWROG recommendation, as well as guidance for any plant choosing to use a strainer backflush system, either as part of its demonstration of compliance with 10CFR50.46 or as a defense-in-depth measure.

3.1.3.4.9 INSTALLATION OF SELF-CLEANING STRAINERS

Self-cleaning strainers can, in principle, be used to resolve concerns with ECCS suction strainer performance. However, significant design, qualification, and surveillance issues would need to be

[4] See NRC letter to R. Sgarro (PP&L), dated 7-25-96, "Comments on Draft Utility Resolution Guidance Sections 3.1.4, 3.2.1.1, 3.2.2.2, and 3.2.3.4" Enclosure 1, Comment 6 of Section 3.1.4 "Backflush" (Reference 15)

addressed prior to installation of self-cleaning strainers. Guidance on specific issues related to use of self-cleaning strainers as part of demonstration of compliance with 10CFR50.46 is provided in Section 3.4.

3.1.4 Other Potential Solutions

The BWROG investigated the debris handling capacity of several existing and alternate strainer designs. Solutions investigated by the BWROG are discussed in this URG document and in supporting test reports. However, there are strainer designs and other potential solutions which were not within the scope of the generic BWROG activities and these designs have not been thoroughly evaluated. Individual licensees may elect to use a strainer design or solution other than those investigated by the BWROG in resolution of the ECCS strainer blockage issues but should be aware that, depending on the option selected, additional testing may be required to demonstrate the viability of the solution. A number of the solutions listed below have been installed in operating plants in Europe. Others have not been installed in any plant, and have had varying amounts of performance testing conducted to date. Some of the alternate solutions follow:

- An improved optimized stacked-disk type strainer design with a much larger debris capacity.
- Strainers with very large capacity which can handle any credible volume of debris. One design uses a cylindrical strainer several feet in length which is supported from the floor of the suppression pool to avoid excess penetration loads. Another design uses a panel of corrugated perforated plate of large area which is attached to the walls of the suppression pool. A third design consists of a large diameter cylinder that spans multiple bays of a Mark I containment and is connected to a number of torus suction nozzles.
- Bi-stable self-cleaning strainers, which change state at a certain design value of strainer head loss, cutting off flow to one portion of the strainer area. This is intended to allow

the debris bed to fall off of the portion of the strainer for which flow has been stopped, while maintaining adequate ECCS flow through the other portion of the strainer.

- Passive self-cleaning strainers with protruding "wings". These strainers are designed to allow the debris bed to fall away from the strainer when flow is stopped (or significantly reduced) without the need for a backflush system.
- Strainers with an accumulator to allow backflush of the strainer without interruption of flow to the ECCS pump.
- Powered self-cleaning strainers which may be installed outside the suppression pool in ECCS piping systems. Commercial versions of these strainers are available in the U.S. from several vendors.

Other alternate passive strainer designs are currently being developed by various vendors. The inclusion or non-inclusion of information on any of these other potential solutions does not constitute endorsement or non-endorsement of any of these solutions by the BWROG.

3.2 Methodology for Sizing Passive ECCS Suction Strainers

3.2.1 Drywell Insulation Debris Sources

Determination of the various source terms of debris which may contribute to strainer head loss is a critical input to the sizing of passive strainers. The quantity and characteristics of debris from piping insulation as well as other debris sources must be considered.

This section discusses determination of the amount of LOCA-generated debris from piping insulation. Section 3.2.1.1 discusses selection of pipe breaks to be evaluated. Once the pipe break locations are selected, the zone of influence (ZOI) of the LOCA jet and the amount of pipe insulation debris resulting from the LOCA jet are determined. Section 3.2.1.2 provides guidance on determination of the zone of influence and associated destruction factors for piping insulation typical of that installed in BWRs.

The quantity of debris from piping insulation is not the only drywell debris source. Other potential debris sources are also located in the drywell and may produce debris as a result of LOCA forces. These other debris sources are discussed later in Section 3.2.2.

3.2.1.1 Pipe Break Locations

3.2.1.1.1 INTRODUCTION

The location at which a pipe break occurs can potentially affect the sizing of passive ECCS suction strainers. A postulated pipe rupture of a given size whose zone of influence encompasses a volume with a relatively large amount of potential debris sources will produce more debris than the same sized break in a location where lesser amounts of debris sources are contained within the volume of the zone of influence.

10 CFR 50.46 discusses the basis for pipe break locations to be considered in the evaluation of ECCS cooling performance. Section (a)(1)(i) of 10 CFR 50.46 includes the following statement:

> "ECCS cooling performance must be calculated in accordance with an acceptable evaluation model and must be calculated for a number of postulated loss-of-coolant accidents of difference sizes, locations, and other properties sufficient to provide assurance that the most severe postulated loss-of-coolant accidents are calculated."

As can be seen from the above statement, it is not necessary to evaluate all possible pipe break locations but rather a sufficient number of breaks of different sizes and locations to reasonably assure acceptable ECCS performance under the most severe conditions.

Methods for determining an adequate population of break locations to be evaluated in assuring ECCS performance have evolved over time. Section 3.6.2 of the Standard Review Plan (Reference 28) "Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping" states:

> "Acceptable criteria to define postulated pipe rupture locations and configurations inside containment are specified in Branch Technical Position (BTP) MEB 3-1."

In the background section of MEB 3-1 the NRC provides perspective on the selection of break locations:

> "Our observations of actual piping failures have indicated that they generally occur at high stress and fatigue locations, such as at the terminal ends of a piping system at its connection to the nozzles of a component. The rules of this position are intended to utilize the available piping design information by postulating pipe ruptures at locations having relatively higher potential for failure, such that an adequate and practical level of protection may be achieved."

As can be seen from the above discussion of MEB 3-1, the NRC concluded that an 'adequate and practical level of protection' may be achieved by evaluation of the breaks which are most likely to occur. This is consistent with the prior NRC position on selection of break locations for evaluation of ECCS suction strainer blockage. NUREG 0897, Revision 1 "Containment Emergency Sump Performance," (Reference 26), Section 3.3.1 (2) states:

> "SRP Section 3.6.2, 'Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping,' should be used to identify potential break locations."

However, many older plants are not licensed to the current requirements of the Standard Review Plan. Not surprisingly, there are variations in the pipe break locations identified in plant specific licensing requirements.

In addressing the spectrum of licensing requirements for postulated pipe break locations, the NRC provided the following criteria on which pipe break locations should be considered. Section 2.3.1.5 of Regulatory Guide 1.82, Revision 2 (Reference 2) states:

> "As a minimum, the following postulated break locations should be considered.

- Breaks on the main steam, feedwater, and recirculation lines with the largest amount of potential debris within the expected zone of influence,
- Large breaks with two or more different types of debris within the expected zone of influence,
- Breaks in areas with the most direct path between the drywell and wetwell, and
- Medium and large breaks with the largest potential particulate debris to insulation ratio by weight."

The first three of these criteria are focused on identification of pipe breaks which would produce the largest amount of debris which can be readily transported to the suppression pool.

The fourth criterion addresses concerns about the "thin-bed" effect where a thin film of fiber on the strainers traps an amount of sludge or other particulate debris and results in a higher head loss than would a thicker bed of fiber with the same sludge. Appendix I of Reference 3 discusses the thin bed effect and which strainer designs are susceptible. Section 3.2.6.2.3 addresses this concern separately from the selection of break locations to be evaluated.

3.2.1.1.2 BWROG GUIDANCE

1. The following options are recommended methods for selecting pipe break locations:

   a) Plants which have identified licensing basis pipe break locations through performance of a pipe stress and fatigue analysis consistent with Branch Technical Position MEB 3-1 of Section 3.6.2 of NUREG-0800 (Reference 28), or through use of equivalent analytical methods approved by the NRC on a plant-specific basis, should consider the effects from pipe break locations identified using the pipe stress analysis methodology. However, not all break locations identified through the pipe stress analysis methodology are required to be evaluated. Licensees should evaluate a sufficient number of these licensing basis pipe break locations to provide reasonable assurance that the expected zone of influence from a break includes the largest amount of

potential debris. As a minimum, the following postulated break locations should be considered:

- Breaks on the main steam, feedwater, and recirculation lines with the largest amount of potential debris within the expected zone of influence,
- Large breaks with two or more different types of debris within the expected zone of influence, and
- Breaks in areas with the most direct path between the drywell and wetwell.

Because of the large number of pipe break locations typically included in the licensing basis for a plant with an MEB 3-1 type analysis, it is expected that the licensing basis pipe break locations will include the minimum break locations specified above. Should the minimum break locations specified not be included in the licensing basis break locations, the licensee should analyze the additional breaks necessary to meet the minimum requirements. However, the licensee should be clear in submittals to the NRC whether or not it intends to change its licensing basis pipe break locations. (See BWROG Guidance, Item 4 in this section for additional detail.)

b) Plants which have not identified licensing basis pipe break locations using an approved stress analysis methodology may choose to, but are not required to, perform such an analysis to identify pipe breaks locations using the MEB 3-1 methodology, or an equivalent analytical method approved for use on a plant-specific basis by the NRC. However, not all break locations identified through the pipe stress analysis methodology are required to be evaluated. Licensees should evaluate a sufficient number of these pipe break locations to provide reasonable assurance that the expected zone of influence from a break includes the largest amount of potential debris. As a minimum, the following postulated break locations should be considered:

- Breaks on the main steam, feedwater, and recirculation lines with the largest amount of potential debris within the expected zone of influence,
- Large breaks with two or more different types of debris within the expected zone of influence, and
- Breaks in areas with the most direct path between the drywell and wetwell.

Because of the large number of pipe break locations typically identified as a result of an MEB 3-1 type analysis it is expected that the identified pipe break locations will include the minimum break locations specified above. Should the minimum break locations specified not be included in the identified break locations the licensee should analyze the additional breaks necessary to meet the minimum requirements. However, the licensee should be clear in submittals to the NRC whether or not it intends to change its licensing basis pipe break locations. (See BWROG Guidance, Item 4 below for additional detail.)

c) Plants which have not identified licensing basis pipe break locations using an approved stress analysis methodology should evaluate a sufficient number of pipe break locations to provide reasonable assurance that the expected zone of influence from a break includes the largest amount of potential debris. As a minimum, the following postulated break locations should be considered:

- Breaks on the main steam, feedwater, and recirculation lines with the largest amount of potential debris within the expected zone of influence,
- Large breaks with two or more different types of debris within the expected zone of influence, and
- Breaks in areas with the most direct path between the drywell and wetwell.

2. An evaluation may be done by identifying the location of potential debris sources installed in the drywell and identifying potential pipe break locations for which the break jet zone of influence could include the debris sources. The shape of the zone of influence for various break types (e.g., restrained vs. unrestrained) should be selected using guidance provided in section 3.2.1.2. This evaluation may be performed manually using plant drawings, specifications, and other design information, augmented as necessary by plant walkdowns. Alternatively, a software model and database can be used to identify pipe break locations with the greatest potential for generation of debris, providing the model used incorporates or conservatively bounds the zone of influence identified in Section 3.2.1.2. The software should be appropriately qualified for use in a safety-related application.

3. In lieu of performing an analysis based on break location to determine the amount of debris generated, licensees may use a bounding amount of the quantity of a specific debris species available. For example, a plant with only a few percent of fibrous insulation installed in the drywell may choose to assume all the transportable debris which could be generated from all of the fibrous insulation in the drywell is transported to the suppression pool. Similarly, a licensee may choose to assume a bounding amount of fixed particulate debris (see Section 3.2.2.2.2.1 for details) in lieu of performing a pipe break location based analysis for this debris species. Licensees should have a documented basis for selecting the bounding values.

4. Because the selection of pipe break locations has impacts on other design inputs (e.g., pipe whip restraints, environmental qualification, etc.) licensees should carefully review their existing design and licensing bases and ensure that actions taken in resolution of the ECCS strainer blockage issue do not result in conflicts with existing design and licensing requirements. In order to avoid potential confusion regarding the licensing basis break locations, licensees should be especially careful in submittals made to the NRC in response to the ECCS strainer blockage issue to clearly differentiate between the break locations used for the analysis of ECCS strainer blockage and the pipe break locations which are in the plant licensing basis.

5. The applicability of evaluating the debris source term resulting from pipe breaks inside the bio-shield walls should be addressed on a plant specific basis. Consideration should be given to licensing basis pipe break locations and the barriers to transport of debris when making this determination.

3.2.1.2 Zone of Influence

3.2.1.2.1 INTRODUCTION

Following identification of postulated LOCA break locations, the next step is determining the zone within which the resultant break jet would have sufficient energy to generate transportable debris. The zone within which debris may be generated is dependent on the size of the break, the break geometry, and the types of potential targets in the vicinity of the break.

Simplified bounding approaches to the analysis are provided for plants which, due either to limited amounts of potential targets of concern or use of high capacity strainers, can accept a larger amount of conservatism in the analysis. In these cases, it may be cost-effective to avoid use of more detailed approaches.

3.2.1.2.2 DISCUSSION

Two major research efforts were undertaken by the BWROG to develop a methodology for defining the zone of influence within which transportable debris might be generated for various materials of interest. The first effort was performance of computational fluid dynamics (CFD) analyses for a series of break geometries typical of those postulated in BWR drywells. The results of this effort are described in detail in Reference 4. These analyses provided information on the shape and size of steam jets expanding into free space as a function of break geometry. These analyses allow definition of the jet volume contained within various dynamic pressure surfaces.

The BWROG also conducted extensive testing of various materials of interest in evaluation of ECCS suction strainer performance to determine the dynamic pressures at which the materials will fail and generate debris in sizes evaluated to be transportable. These tests were conducted at the Colorado Engineering Experiment Station Inc. (CEESI), and are described in detail in Reference

6. The results of these tests are summarized in Table 2 - Values of Pdest for Selected Materials of Interest. Reference 4 establishes the acceptability of using air jets to simulate destructive effects of saturated steam and saturated water jets. The analysis in Reference 4 demonstrates that the air jets used in the testing at CEESI resulted in conservative pressures being applied to the target materials as compared to those which would have resulted from a similar jet using saturated steam or saturated water at conditions typical of BWR operation.

The results of these two efforts indicate that, for many materials of interest, the lengths of jets expanding in free space out to distances at which transportable debris may be generated may extend beyond the free path length in the drywell. As an example, a fully offset 22" recirculation line break would result in generation of transportable debris from steel jacketed NUKON® attached to the piping in a typical manner out to a distance of over 100 feet. This distance is greater than the free paths in the drywell; therefore the jet would be fully intercepted by major drywell structures.

The actual jet geometry which would result from any given pipe break in the drywell, and thus the specific zone within which any postulated break jet would have sufficient pressure to cause damage to materials of interest, is a complex function of break size, break geometry, and the distribution, shape and size of the drywell equipment, piping, and structures which would be impacted.

The BWROG guidance provides a simplified, conservative methodology which defines the zone of influence by determining the volume contained within any dynamic pressure surface of interest for a jet expanding in free space, and mapping a spherical (or, for single ended jets, hemispherical) zone of influence of equal volume into the drywell space surrounding the break.

The approach recommended by the BWROG to define zones of influence is conservative, as it assumes that the jet in the drywell will have destructive force within a volume equal to that within a given dynamic pressure surface for a free space expansion. In reality, the jets which would result from postulated pipe breaks would impact on structures, equipment, and piping in the

drywell, resulting in dissipation of the jet momentum and disruption of the jet from a focused flow into a bulk flow toward the vents. This dissipation of jet momentum to a level at which dynamic pressures are no longer sufficient to result in generation of transportable debris is expected to occur in volumes smaller than those calculated for jets in free space.

The BWROG has evaluated whether the dynamic pressures generated by the bulk flow velocities during blowdown are sufficient to result in generation of additional transportable debris. It has been determined that additional transportable debris would not be generated as a result of bulk flow velocities in the drywell during reactor vessel blowdown for the materials evaluated. The basis for this conclusion follows.

A review of available literature provides the necessary information to estimate the bulk flow velocities. Once the bulk flow velocity is known, the corresponding dynamic pressure produced by that flow may be calculated. Information presented by K. Williams (Flow Simulation Services, Inc.) to the NRC sponsored BWR Transport Phenomena Identification and Ranking Table (PIRT) Panel on May 15, 1996, showed that the maximum expected drywell velocities following a main steam line break occurs in the main vents for a Mark I containment and that the velocity vector has a value of approximately 160 meters/second (525 feet/second). The BWROG has independently confirmed that similar velocities occur in the main vents during the first 2 seconds of a large pipe break event. Note however, due to the larger open flow areas, that the bulk velocities in the drywell region which typically contains the highest amount of insulation material would be significantly lower than the velocities in the main vents which are the most restricted part of the flow path leading to the suppression pool.

A bounding estimate of the bulk dynamic pressure in a drywell is straightforward to make assuming choked saturated steam flow from two 28 inch main steam lines. The bulk dynamic pressure q will be less than:

$$q = \tfrac{1}{2} \rho u^2 = \tfrac{1}{2} \frac{\dot{M}^2}{\rho A^2}$$

where:

ρ = density of steam in the drywell at maximum drywell pressure

$\dot{M}$ = steam mass flow rate from two main steam lines

A = cross-sectional area of the drywell

For a Mark II containment:

ρ = 0.106 lbm/ft^3 (saturated steam at 45 psia)

$\dot{M} \cong$ 20,000 lbm/second

A $\cong$ 5000 ft^2

Substituting, the bulk dynamic pressure q will be less than 0.02 psi which is two orders of magnitude below the destruction pressure of the most limiting insulation material of interest. Therefore, it is concluded that the maximum bulk flow is not sufficient to cause additional destruction of the insulation materials tested by the BWROG.

3.2.1.2.3 BWROG GUIDANCE

Four methods are provided for determining the zones of influence within which target materials may be destroyed into transportable form. The method selected by the licensee may be different

for various materials of interest. These methods are provided in the following sub-sections, in order of complexity.

3.2.1.2.3.1 Method 1 - Assume the Entire Drywell is the Zone of Influence

1. Identify the type and amounts of each material of interest within the drywell. The amount of fibrous type insulation should be calculated in pounds (lbm) of insulation base material and fabric covering. Metal jacketing is excluded. The amount of reflective metal insulation should be calculated as the area of the inner insulating foils in ft^2.

2. As a bounding approach, licensees may assume that the entire drywell inventory of materials of interest are destroyed and available for transport when determining ECCS strainer NPSH. No break specific analysis or calculation of specific zones of influence is required in this case. This approach may be acceptable for plants with strainer capacities adequate to accommodate large quantities of debris or where the total amount of the material of interest will result in a small increase in strainer head loss.

3. Materials of interest physically located above the lowest elevation grating in the drywell have lower transport factors than materials located below the lowest level grating, as discussed in Section 3.2.3.2.2.1. The quantity of each non-RMI material of interest located above the lowest elevation of floor grating and the quantity located below the lowest elevation of grating should be separately determined for input to the transport evaluation. Because the location of grating is not used in evaluation of RMI debris transport, it is not necessary to make this distinction for RMI materials.

3.2.1.2.3.2 Method 2 - Target Based Analysis using Limiting Size Zones of Influence

As a less conservative bounding method, licensees may perform an analysis as follows:

1. Identify the type, locations, and amounts of each material of interest within the drywell. The amount of fibrous type insulation should be calculated in pounds (lbm) of insulation base material and fabric covering. Metal jacketing is excluded. The amount of reflective metal insulation should be calculated as the area of the inner insulating foils in ft^2.

2. Determine the dynamic pressure (P_{dest}) at which destruction is assumed to occur for the largest pipe on which each material of interest is installed in the drywell using the data provided in Table 2. Note that adjustments to the values of P_{dest} provided in Table 2 must be made based on the target radius for some materials of interest, in accordance with Note 3 to that table.

3. Determine the volume of the largest zone of influence which would result from a fully separated double ended rupture of any high energy pipe in the drywell using the following equation:

$$V_{ZOI}(i) = AD^3$$

Where:

$V_{ZOI}(i)$ is the volume (ft^3)of the zone of influence for material (i);

A is a constant which is a function of P_{dest} and break geometry, and is provided in Table 1. In this case, A should be determined for the value of P_{dest} from (2) above, assuming a double ended break with a radial offset of >3D/2; and

D is the inside diameter (ft) of the pipe where the break is postulated.

It may be necessary to calculate V_{ZOI} for several cases to determine the maximum value. Both large high energy lines containing saturated steam and lines containing saturated water should be considered. Use the values of A in Table 1 and the correction factors for saturated water breaks in Note 5 of Table 1 to calculate the appropriate V_{ZOI} for both break media.

4. Determine the most limiting quantities of debris included in any drywell volume enclosed by a sphere equal in volume to the maximum value of V_{ZOI} calculated in (3) above. As a minimum, this analysis should include:
   - Identification of the volumes which contain the maximum total quantities of each material of interest regardless of the location of the material in the drywell; and
   - Identification of the volumes which contain the maximum total quantity of each non-RMI material of interest below the lowest elevation grating in the drywell. Because it is not used in evaluation of RMI debris transport, it is not necessary to identify the volume for RMI materials below the lowest grating level.

5. Non-RMI materials of interest physically located above the lowest elevation grating in the drywell have lower transport factors than materials located below the lowest level grating, as discussed in Section 3.2.3.2.2.1. The quantity of each non-RMI material of interest located above the lowest elevation of floor grating and the quantity located below the lowest elevation of grating should be separately determined for input to the transport evaluation. Because it is not used in evaluation of RMI debris transport, it is not necessary to make this distinction for RMI materials.

6. It may be necessary to perform iterative calculations of drywell to wetwell transport and ECCS suction strainer head loss using the methods in Sections 3.2.3 and 3.2.6.2.3 for cases where significant quantities of several materials of interest exist in the drywell.

3.2.1.2.3.3 Method 3 - Break Specific Analysis using Break-Dependent Zones of Influence

1. Identify the type, locations, and amounts of each material of interest within the drywell. The amount of fibrous type insulation should be calculated in pounds (lbm) of insulation base material and fabric covering. Metal jacketing is excluded. The amount of reflective metal insulation should be calculated as the area of the inner insulating foils in ft^2.

2. Determine the dynamic pressure (P_{dest}) at which destruction is assumed to occur for the largest pipe on which each material of interest is installed in the drywell using the data provided in Table 2. Note that, for some materials of interest, adjustments must be made to the values of P_{dest} provided based on the target radius, in accordance with Note 3 to Table 2.

3. For each break to be evaluated, perform the following analysis:
   a) Determine whether the break results in a single jet (such as for a steam line break) or a double jet (such as for a recirculation line break).
   b) Determine whether the break is restrained or unrestrained, and whether the pipe contains saturated steam or saturated water.
   c) For each restrained break, determine the radial offset and axial separation. If the radial offset and axial separation are not known, the break may be assumed to be unrestrained.
   d) For all unrestrained breaks, the radial offset should be assumed to be greater than 3D/2.
   e) For each break analyzed, calculate the volume of the zone of influence for each material of interest using the following equation:

$$V_{ZOI}(i) = A\,D^3$$

Where:

$V_{ZOI}(i)$ is the volume (ft^3) of the zone of influence for material (i);

A is a constant which is a function of P_{dest}, break medium (steam vs. water) and break geometry, as defined in Table 1. For saturated water breaks, multiply the value of A in Table 1 by the appropriate correction factor provided in Note 5 of Table 1; and

D is the inside diameter (ft) of the pipe where the break is postulated.

f) For each material of interest, calculate the radius of a sphere which encloses the same volume as calculated for V_{ZOI} in (e) above.

g) For breaks which result in double jets, assume a spherical zone of influence centered on the break with a radius equal to that calculated in (f) above.

h) For breaks which result in single jets, assume a hemispherical zone of influence centered on the break with a radius equal to that calculated in (f) above.

i) Determine the amount of each non-RMI material of interest located within each material specific zone of influence which is located above the lowest elevation floor grating in the drywell. Because it is not used in evaluation of RMI debris transport, it is not necessary to make this distinction for RMI materials.

j) Determine the amount of each non-RMI material of interest located within each material specific zone of influence which is located below the lowest elevation floor grating in the drywell. Because it is not used in evaluation of RMI debris transport, it is not necessary to make this distinction for RMI materials.

After completing the above evaluation for each break being analyzed, each combination of debris determined should be used as input to the transport section of the analysis as discussed in Section 3.2.3.

For materials whose P_{dest} is a function of target radius, the amount of debris calculated using Method 3 may be reduced by eliminating some conservatism in the method used to establish the

size of the zone of influence. In Method 3, the sizes of the zones of influence for such materials are determined using the P_{dest} for the largest target size for each such material in the drywell. The method assumes the same P_{dest} for all material of any one type, and does not credit the fact that the same material installed on smaller diameter pipes can have significantly higher values of P_{dest}, as described in Note 3 of Table 2.

As a further refinement, the analysis may include zones of influence for each material of interest which are based on the size of the targets located in the vicinity of each break, and credit the increased strength of the smaller radius materials. For example, if the initial evaluation used a P_{dest} of 8 psi for insulation on a 24" pipe somewhere in the drywell, and it was determined that this material was in fact only installed on 6" pipes within the ZOI calculated using the 8 psi value, then the effective size of the ZOI for this material near this break could be reduced using the equation provided in Note 3 of Table 2. Assuming an insulation thickness of 4" for both the 24" and 6" applications, a new P_{dest} of 18.3 psi would be calculated and could be used to generate a new V_{ZOI} for this material at this break location. Use of this more detailed approach may be justified for break locations where a significant reduction in the debris source term may result.

3.2.1.2.3.4 Method 4 - Explicit Use of CFD Model Results

The results of the CFD analyses documented in Reference 4 are also available for use of BWROG members in the form of data files. Two types of files are available. The first provides data which describes the actual total pressure surfaces at selected pressures for each break geometry analyzed. This data set could be used by licensees to explicitly map the actual pressure surfaces for breaks of known geometry, and perform an explicit determination of the specific targets within the surface of interest. Due to the complexities of the surfaces, such an approach would most likely require development and use of a computerized modeling method. This effort was not undertaken as part of the generic BWROG work.

The second data set that can be provided is in the form of a set of ASCII files which define the total pressure calculated at each grid point in the CFD model for each break geometry analyzed. This data could also be input to a computerized analysis method to determine explicitly which targets are exposed to pressures sufficient to result in generation of transportable debris. Again, development of such computerized methods was not included in the generic BWROG work scope.

Further description of the data available is provided in Reference 4 and the actual data files may be obtained by BWROG members upon request.

Should the licensee elect to use Method 4, results of the evaluation should be prepared in the same manner as described for Method 3, with amounts of each non-RMI material of interest within each zone of influence divided into quantities above and quantities below the lowest elevation floor grating in the drywell.

Table 1 - Values of "A" for Various Break Geometry's for Double-Ended Saturated Steam Breaks

Radial Offset = 0 Inch

p (psid)	Axial Separation				
	1 inch	D/4	D/2	D	3D/2
2	13.3	133.4	389.4	251.8	180.5
4	11.3	112.6	328.6	212.5	152.3
6	9.7	96.7	282.2	182.5	130.8
10	7.4	74.2	216.5	140.0	100.3
17	5.1	51	148.9	96.3	69.0
40	2.2	41	120.7	56.3	38.8
160	0.1	18.6	73.0	28.8	11.1
190	0.1	14.1	68.0	24.1	8.6

Radial Offset = D/4

p (psid)	Axial Separation				
	1 inch	D/4	D/2	D	3D/2
2	5.0	126.1	294.2	423.4	842.4
4	4.2	106.4	248.3	357.3	710.9
6	3.6	91.3	213.2	306.8	610.4
10	2.8	70.1	163.6	235.4	468.3
17	1.9	48.2	112.5	161.9	322.1
40	0.9	34.8	83.3	117.2	154.8
160	0.1	19.5	54.4	66.4	36.7
190	0.1	17.7	50.6	61.2	31.6

Radial Offset = D/2

p (psid)	Axial Separation				
	1 inch	D/4	D/2	D	3D/2
2	79.8	303.9	440.4	437.8	619.6
4	67.3	256.5	371.7	369.5	522.9
6	57.8	220.2	319.1	317.2	449.0
10	44.3	168.9	244.8	243.4	344.4
17	30.5	116.2	168.4	167.4	236.9
40	14.8	75.3	99.0	122.8	155.6
160	6.6	44.6	60.8	73.8	74.2
190	5.8	41.7	56.2	67.2	64.9

Table 1 (continued)

Radial Offset = D

p (psid)	Axial Separation				
	1 inch	D/4	D/2	D	3D/2
2	548.2	482.5	890.5	526.2	534.6
4	462.6	407.2	751.5	444.1	451.1
6	397.2	349.6	645.3	381.3	387.4
10	304.7	268.3	495.1	292.5	297.2
17	209.6	184.5	340.5	201.2	204.4
40	125.7	99.5	137.7	95.8	106.4
160	76.5	61.4	62.2	44.7	53.1
190	71.5	57.4	58.2	40.3	47.9

Radial Offset = 3D/2

p (psid)	Axial Separation				
	1 inch	D/4	D/2	D	3D/2
2	554.7	461.3	1013.2	741.4	608.0
4	468.1	389.3	855.0	625.7	513.2
6	402.0	334.3	734.2	537.3	440.6
10	308.4	256.5	563.3	412.2	338.0
17	212.1	176.4	387.4	283.5	232.5
40	127.8	143.9	190.2	206.8	96.9
160	75.6	91.8	90.2	110.5	38.2
190	69.7	84.9	81.5	99.9	33.9

Radial Offset > 3D/2

p (psid)	All Axial Separations
2	8469
4	7148
6	6137
10	4708
17	3238
40	2082
160	1097
190	965

Table 1 Notes:

1. Data is from Table 1 of Reference 4. *p(psid)* in Table 1 above is equivalent to P_{dest} in Table 2.
2. For breaks with a radial separation between the values provided, use the table with the higher values of "A" for the geometry of interest.
3. For breaks with an axial separation between the values provided, use the greater value of "A" for the two nearest data points.

4. Linear interpolation may be used for pressures between the values provided. Extrapolation beyond the values for *p (psid)* provided above is not appropriate. However, if higher or lower values are needed for analysis, the CFD model developed for the BWROG may be queried to obtain the requisite data.
5. All values provided are for saturated steam jets. Determine the value of "A" for the geometry of interest for steam, including completion of any interpolation. To convert to appropriate volumes for saturated water jets, multiply the value of "A" determined for a steam jet by the following correction factors. (See the Appendix to Reference 30 for additional discussion of the correction factors):

P_{dest}	*Correction Factor*
>60	0.4
50-60	0.5
40-50	0.7
30-40	0.8
20-30	0.9
0-20	1.0

Table 2 - Values of P_{dest} for Selected Materials of Interest

Material [1]	P_{dest} *(psi)* [4]
Darchem DARMET®	190[3]
Transco RMI	190[3]
Jacketed NUKON® with modified "Sure-Hold" Bands, Camloc® Strikers and Latches	190[3]
Diamond Power MIRROR® with modified "Sure-Hold" Bands, Camloc® Strikers and Latches	190[3]
Calcium Silicate with Aluminum Jacketing	160[3]
K-wool	40[2]
Temp-Mat™ with Stainless Steel Wire Retainer	17[2]
Knaupf®	10[2]
Jacketed NUKON® with standard bands	10[2]
Unjacketed NUKON®	10[2]
Koolphen-K®	6[3]
Diamond Power MIRROR® with standard banding	4[3]
Min-K	4[2]

Notes for Table 2:

1. Values are based on the test results reported in Reference 6. The materials tested are representative of the piping insulation typically found in BWRs. Additional descriptive information of the specific materials tested is provided in Reference 6 and the supporting design record files. Care should be exercised to assure that the critical characteristics of design for the material being evaluated (e.g., material of construction, method of attachment, methods of construction including welds, latches, foil thickness, banding, etc., as appropriate) are representative of the materials tested. Differences in material critical characteristics should be evaluated through analysis or test. Determination of the P_{dest} for materials not shown in Table 2 will require either analysis or test as appropriate, or application of the Method 1 described in Section 3.2.1.2.3.1. Vendor improvements in insulation design and construction, supported by analysis or test as appropriate, may result in higher P_{dest}.

2. The value of P_{dest} provided here should be used for all applications of this material, regardless of the size of the target on which the material is installed.

3. The values of P_{dest} provided here are for material of the type indicated installed on a pipe of 12 inch nominal diameter. For this material, P_{dest} varies as a function of the radius of the target, according to the following relationship: $P_{dest}(i) = P_{dest\ 12"\ pipe}[r_{i\ 12"\ pipe} / r_i]$

   Where:

   $P_{dest}(i)$ is the destruction pressure for material of outer radius r_i;

   $r_{i\ 12"\ pipe}$ is the outer radius for material installed on a 12" pipe; and

   r_i is the outer radius for material installed on the pipe size of interest.

4. The behavior of P_{dest} as a function of target radius is based on consideration of the differences in the failure mechanisms for each material. Non-porous materials (RMI, calcium silicate) fail through structural failure of retaining mechanisms caused by lift forces produced by high velocity fluid flow past the surface of the material. These forces are proportional to the target radius, and the methodology for varying P_{dest} as a function of target radius is provided.

   Unjacketed porous materials allow air/steam flow through the material. At the front of the material, the pressure is the stagnation pressure. At close to 90 degrees from the front end, the pressure is at a minimum. The pressure difference between these two points, at high Reynolds number, is between 3 and 4 times the dynamic pressure. This large pressure difference induces flow to enter the blanket at the stagnation point and

exit at the sides. When the flow exits through the sides, it is at a lower pressure and so the fluid expands. At even modest stagnation pressure, the exit velocity may approach a Mach number of 1. This high velocity flow cuts the insulation cloth covering at the point of exit of the flow, resulting in rapid release of debris.

Examination of the failed porous materials from the CEESI testing (Reference 6) supports this evaluation of the failure mechanism, with initial failure of the cloth covering occurring at 90 degrees from the jet impact centerline. The ability of the expanded jet to induce failure at the exit point from the porous material is dependent on the exit velocity. Targets of radius larger than that tested at CEESI would provide a longer flow path through the porous material between the point of entry and exit. This would result in lower velocities at exit than for target materials larger than those tested. Larger size targets would therefore be expected to be stronger than smaller targets for materials with this failure mechanism. Use of values in Table 2 for porous materials is therefore conservative.

Note that the porous material flow failure mechanism applies to all porous materials once the outer protective jacketing is removed by the lift forces. For this reason, P_{dest} for NUKON® with standard jacketing is given as 10 psi even though the CEESI testing showed failure of the jacketing at lower pressures.

3.2.2 Other Drywell Debris Sources

3.2.2.1 Introduction

Section 2.2.1.3 of Regulatory Guide 1.82, Revision 2, (Reference 2) states that all insulation, painted surfaces, and fibrous, cloth, plastic or particulate materials within the zone of influence should be considered when evaluating potential debris sources following a pipe break. Section 3.2.1 of this URG document addressed debris sources from piping insulation in the drywell. This section of the URG provides guidance on sources of drywell debris other than pipe insulation. (See Section 3.2.4.2 for a discussion of suppression pool debris sources).

Other drywell debris can be divided into three types:

- Transient debris. Transient debris is non-permanent plant material brought into the drywell, typically during an outage (e.g., tools, rags, sheeting, plastic bags, temporary filters, dirt/dust, etc.). Transient debris is principally controlled through FME and housekeeping programs.
- Fixed debris. Fixed debris is material that is part of the permanent plant that becomes a debris source only after exposure to the effects of a LOCA (e.g., paint that is stripped off as a result of impingement forces from a LOCA jet, concrete debris resulting from LOCA jet forces, etc.).
- Latent debris. Latent debris is debris that would not be present until later in the LOCA event progression after prolonged exposure to a LOCA environment. For example, unqualified coatings (not directly impacted by the LOCA jet) have the potential to detach from the surface where applied, but only after prolonged exposure to the LOCA environment and after containment pressure is reduced later in the event.

Each of these three types of other drywell debris are examined further in the subsections that follow.

Regardless of the number of potential debris sources in the drywell, it is only debris that is transported to the suppression pool and reaches the suction strainers that can challenge the ECCS capability. Section 3.2.3 of this document provides guidance on determination of the amount of debris that is expected to be transported from the drywell to the wetwell as a result of a postulated LOCA.

Foreign material exclusion (FME) and housekeeping programs, including periodic inspections and cleanings, are used to minimize the amount of transient debris that is present in the drywell. Licensees should recognize that the rigor of FME programs should be adequate to ensure that the transient debris source term used as a design input value in the strainer sizing calculations is not exceeded. Consequently, licensees should consider the trade-off between operational flexibility and strainer size when establishing the values of drywell debris considered to be available for transport to the suppression pool. Less strict FME controls may offer increased operational flexibility, but with the need for a larger strainer because of the increased source term for transient debris.

The rigor of FME and housekeeping controls are determined by the licensee. However, they should be effective at controlling the transient debris quantities such that when combined with the quantity of LOCA-generated debris and suppression pool debris, the sum is less than the design input values assumed in sizing the passive strainer (or passive portion of a self-cleaning strainer). This is the performance goal for the FME/housekeeping program.

The BWROG recognizes that a generic approach for a standard BWR FME/housekeeping program is not appropriate. Instead, a performance goal is for the FME/housekeeping program is established and the licensee is provided flexibility in how to meet that performance goal. This approach provides the licensee the opportunity to continuously improve their FME/housekeeping program over time rather than being constrained by a standard program that is not readily adaptable to plant-specific conditions and evolving work practices.

Because the FME/housekeeping program is relied upon to control debris sources such that the strainer will perform acceptably, licensees should have inspection techniques and procedures that reasonably assure the FME program is meeting the performance goal. For example, if a licensee sizes a strainer to perform acceptably with a design input that no more than X lbs. of transient dirt/dust from the drywell are transported to the suppression pool, the inspection techniques and procedures used to verify the effectiveness of the FME program should be capable of estimating whether more than X lbs of dirt/dust are in the drywell. Note that where use of an adequately conservative value is assumed for a particular debris species (e.g., dirt/dust), periodic inspection are not necessary.

Licensees should recognize that if the quantity of debris cannot be shown to be controlled at values less than assumed in the strainer sizing calculations the operability of the ECCS systems may be challenged.

3.2.2.2 Non-Insulation Drywell Debris Sources

This section of the URG addresses non-insulation debris sources in the drywell. Debris from thermal insulation is addressed separately in Section 3.2.1.

Each licensee should establish a baseline value of non-insulation debris (transient and fixed) that is assumed to be present in the drywell at the start of a postulated LOCA. Some or all of this debris, depending on the drywell-to-wetwell transport factor, can be expected to reach the suppression pool and contribute to strainer head loss.

3.2.2.2.1 TRANSIENT NON-INSULATION DEBRIS

Licensees should consider the following when establishing a baseline value of transient non-insulation debris and make enhancements where appropriate:

- review FME and housekeeping program controls

- review self-assessments, audits, surveillances, personnel training, etc. on the effectiveness of FME and housekeeping controls
- review results of previous cleanings of the drywell/suppression pool
- review related plant specific and industry operating events and information (e.g., INPO SOERs NRC Bulletins, Notices, Generic Letters, etc.). In particular, the information contained in References 1, 18, 19, 20, 34 and 35, and licensee actions/commitments in response to these NRC Information Notices and Bulletins, should be carefully considered when establishing a plant specific baseline value of transient non-insulation debris.
- walkdown of the drywell to identify potential transient non-insulation debris sources
- review other plant programs or practices which contribute to the introduction, control, or removal of transient debris
- consider adding NPSH margin through use of a larger strainer to avoid the potential operational constraints (e.g., if following drywell closeout at the completion of an outage it is discovered that a few rags had not been accounted for the NPSH margin could be considered to avoid making the rag recovery a critical path restart issue)

The specific approach for determining the overall baseline value of transient debris is left to the discretion of the licensees. However, the BWROG has provided recommendations for addressing the debris source term from a sub-category of transient debris, dirt and dust.

Dirt/Dust

A sub-category of transient debris is the dirt/dust which is present in the drywell and available for transport to the suppression pool. The BWROG recommends one of the following options for considering this debris source term in the evaluation of strainer head loss.

The first option is to assume a value of dirt/dust in the strainer head loss evaluation which adequately addresses this debris source term. The BWROG has made a judgement of what such a value should be after considering the following:

- the typical surface areas available where dirt/dust may collect
- that much of the dirt/dust which is present adheres to the surface and is not readily washed off. A significant fraction of the dirt/dust which is directly exposed to the flow from a pipe break would be expected to be washed to the suppression pool. However, only a small fraction of the dirt/dust which is not directly exposed to the LOCA jet or directly impacted by break leakage flow would be expected to be transported as a result of water splashed on it from break leakage flow, or containment spray if used.
- that FME/housekeeping programs are generally effective at removing dirt/dust in areas that are normally accessible and these areas also the areas that are more exposed to the sources of dirt/dust (e.g., high traffic areas where dirt is brought in on the bottom of shoes)

To further simplify the strainer head loss evaluation, inclusion of the source term from dirt/dust above the water level of the suppression pool (see Section 3.2.4.2) is also considered in the value recommended by the BWROG.

A final component to be considered is the debris source term from concrete resulting from the erosion of concrete which may occur if directly impacted by the LOCA jet during the blowdown portion of the event. As a result of exposure to the LOCA jet, the debris from concrete is expected to be a fine particulate and have similar head loss characteristics as dust/dirt.

It is the judgement of the BWROG that use of a value of 150 lbm of dirt/dust in the strainer head loss evaluation will conservatively address the debris from dirt/dust in the drywell, dirt/dust in the suppression chamber above the level of the suppression pool which could be washed into the pool as a result of LOCA induced pool swell, and the debris which would result should the LOCA jet impact a concrete wall. This debris source term should be added to that of the suppression pool sludge (see Section 3.2.4.3) when evaluating strainer head loss. It is judged that the FME/housekeeping controls typical of those employed at BWRs are adequate to assure that the

conservative value assumed will not be exceeded and therefore no measurements or inspections beyond those already specified by the FME/housekeeping programs are required.

Alternatively , licensees may use a value lower than the conservative value recommended by the BWROG. Should licensees choose to use such an approach, they should document the basis for the value and assure that the inspection criteria in their FME/housekeeping programs are adequate to assure the value assumed would not be exceeded.

Other Transient Debris

There are several potential sources of transient debris. All potential sources of this debris should be considered. Experience has shown that transient debris is sometimes found in areas which are difficult to inspect (e.g., inside downcomers) and licensees should be especially vigilant in identifying and removing transient debris from these areas. In particular, the information contained in References 1, 18, 19, 20, 34 and 35, and licensee actions/commitments in response to these NRC Information Notices and Bulletins, should be carefully considered when establishing a plant specific baseline value of transient non-insulation debris.

As part of an effective FME/housekeeping program each licensee should assure that the baseline values of transient non-insulation debris used as design inputs to the strainer head loss calculations remain valid. Consideration may be given to the margin between the ECCS pump NPSH required and the NPSH available when establishing the frequency of inspections/audits to assure the baseline values are not exceeded. A larger NPSH margin should require less frequent inspection/audit than a smaller margin. The BWROG believes a specific formula for determining the frequency of inspections/audits for a given NPSH margin is not appropriate (e.g., an NPSH margin of X justifies an inspection frequency of Y). This is because there may be other factors such as the observations from prior inspections/audits that can affect the determination of an appropriate frequency at which inspections/audits are conducted.

3.2.2.2.2 FIXED NON-INSULATION DEBRIS

Drywell sources of fixed non-insulation debris should also be considered. Most of the fixed debris source in the drywell is expected to come from piping insulation which is separately addressed. However, there may be plant specific instances where other fixed sources of non-insulation debris are present in the drywell. Such sources may include:

- fabric equipment covers (e.g., fire hose reel covers)
- permanent tags or stickers on plant equipment
- cloth bags used to hold equipment left in the drywell (e.g., chainfall bags)
- fire hoses
- ropes
- ventilation system filters
- cloth
- thermal insulation (other than piping insulation which is addressed separately)
- tape
- wire ties
- paper based products (e.g., signs, postings or piping diagrams normally left in containment during power operations)
- plastic (e.g., plastic sheeting or laminates covering signs)
- other potential debris sources from material stored in the drywell during power operation
- rust from unpainted steel surfaces

The amount of fixed non-insulation material within the zone of influence can be reduced either through removal of the material from the drywell and/or through use of shielding or other means that would provide protection adequate to prevent LOCA forces from generating debris.

Each licensee should consider the following when establishing a baseline value of fixed non-insulation debris:

- walkdown of the drywell to identify potential sources of fixed non-insulation debris
- review of design documents, (e.g., material specifications, drawings, modification packages, etc.)
- review of maintenance, operations or radiation protection procedures/practices which have the potential to introduce fixed non-insulation debris in the drywell

The baseline amount of fixed non-insulation debris resulting from LOCA forces, adjusted by an appropriate drywell-to-wetwell transport factor, is a design input into the strainer head loss calculations.

Another consideration for fixed fibrous non-insulation debris is implementation of controls to assure that the established baseline values are not exceeded. This may require changes to the procedures controlling the plant modification process to assure that modifications to drywell equipment do not result in adding fixed, fibrous debris sources sufficient to exceed the baseline value.

Programmatic controls (e.g., the design change and maintenance processes) should be effective at controlling the quantity of fixed non-insulation debris sources. As with transient debris, periodic inspection/audits of these programmatic controls should be conducted to assure that they are effective in preventing the baseline values of fixed debris used as design inputs to the strainer head loss calculations from being exceeded.

Consideration may be given to the margin between the ECCS pump NPSH required and the NPSH available when establishing the frequency of inspections/audits to assure the baseline values are not exceeded. A larger NPSH margin should require less frequent inspection/audit than a smaller margin.

Rust from Unpainted Steel Surfaces

A sub-category of fixed debris is the rust on unpainted steel surfaces which may be detached and transported to the suppression pool. This may include rust on miscellaneous structural components and, for some plants, the surfaces of the downcomers. Similarly to dirt/dust, it is expected that only a fraction of the rust would become detached and transport to the suppression pool.

It is the judgement of the BWROG that use of a value of 50 lbm of rust flakes in the strainer head loss evaluation conservatively addresses the amount of rust which may be removed from unpainted steel surfaces and transported to the suppression pool. This value includes rust from unpainted steel surfaces in the drywell, the main vents/downcomers, and those in the suppression chamber above the pool level which may be swept as a result of LOCA-induced pool swell. The head loss correlation for rust flakes, not suppression pool sludge, provided in Reference 3 should be used when evaluating this debris species.

As an alternative, licensees may use a value lower than the conservative value recommended by the BWROG. Should licensees choose to use such an approach, they should document the basis for the value and assure that programmatic controls exist which are adequate to assure that the value assumed for rust from unpainted steel surfaces is not exceeded.

3.2.2.2.2.1 Particulate Debris Sources

A subspecies of fixed non-insulation debris is particulate debris. The fixed particulate debris source in the drywell is expected to result from LOCA jet forces stripping off paint/coatings and eroding concrete at the point of impact. However, there may be plant-specific instances where other fixed sources of particulate debris are present in the drywell.

3.2.2.2.2.1.1 Paint/Coatings

The BWROG extensively investigated the effects of a LOCA on containment coatings. The results of the investigation are contained in a report dated November 10, 1994 "Performance of Containment Coatings During a Loss of Coolant Accident" (Reference 21) prepared by Bechtel Power Corporation for the BWROG.

The Bechtel report addresses qualified coatings as well as coatings that are of indeterminate quality or unqualified. Where a LOCA jet directly impacts a coated surface it is conservatively assumed the jet will strip off all the applied coating in the affected area without regard to coating qualification.

A bounding value of the maximum amount of different coating particulate debris was established in the Bechtel report (Reference 21, p 27). These bounding values are shown in Table 3. (See the Bechtel report for details on the basis of the bounding value).

Coating	Max Debris Volume	Max Debris Weight
Inorganic Zinc (IOZ)	0.2516 ft^3	47 lb.
IOZ Top Coated with Epoxy	0.65 ft^3	85 lb.
100% Epoxy Coating	0.755 ft^3	71 lb.

Table 3 - Bounding Values of Coating Debris

The BWROG recommends that licensees use the bounding value of particulate debris from Table 3 for the applicable coating as the maximum amount of fixed particulate debris from coatings which is available for transport to the wetwell.

Alternatively, licensees may perform a plant-specific evaluation to establish the amount of fixed particulate debris from coatings which would result from a LOCA jet.

Another consideration for fixed particulate debris is implementation of controls to assure that the baseline values that have been established are not exceeded. This may require changes to the process/procedures which control the future coatings used in containment to assure that those coatings used are similar to those which formed the basis for the bounding value shown in Table 3.

See Section 3.2.2.3.1 for guidance on evaluating additional potential effects from coatings which are either of indeterminate quality or unqualified for use in containment.

3.2.2.2.2.1.2 Concrete

Prior tests of the damage caused by LOCA jet forces indicate that some amount of concrete spalling may occur (see Reference 26, Appendix C). However, the quantity of concrete debris is not noted in the report. Unless using the BWROG recommended value for dirt/dust previously discussed (which includes consideration of concrete debris), licensees should evaluate the potential for a LOCA jet to produce concrete debris and address the amount of such debris in their analysis of strainer head loss.

3.2.2.2.3 BWROG GUIDANCE

1. Licensees should review their plant-specific situation and establish the quantity of transient non-insulation debris assumed to be available for transport to the suppression pool. Determination of the quantity of debris is not required for debris types which are not transportable from the drywell to the suppression pool.
2. A value of 150 lbm of dirt/dust may be assumed in the strainer head loss evaluation to address the quantity of debris from dirt/dust in the drywell transported to the suppression pool,

dirt/dust in the suppression chamber above the level of the suppression pool which could be washed into the pool as a result of LOCA induced pool swell, and the debris which may result should the LOCA jet impact a concrete structure. This debris source term should be added to that of the suppression pool sludge (see Section 3.2.4.3) when evaluating strainer head loss. Subsequent application of a transport factor less than 1.0 to this debris species is not allowed when using this assumption. Measurements of the quantities of dirt/dust, or inspections beyond those already specified by the FME/housekeeping programs, are not required

3. Licensees should ensure that the baseline values of transient non-insulation debris assumed in the strainer head loss calculations remain valid. Consideration should be given to the margin between the ECCS pump NPSH required and the NPSH available when establishing the frequency of verification of baseline values. A larger margin should require less frequent verification of baseline values than a smaller margin.
4. Licensees should review their plant specific-conditions and establish the quantity of fixed non-insulation debris assumed to be available for transport to the suppression pool. For coating used in containment, a licensee may elect to use the bounding values shown in Table 3 - Bounding Values of Coating Debris in lieu of establishing plant-specific values. Determination of the quantity of debris is not required for debris types which are not transportable from the drywell to the suppression pool.
5. Licensees should review, and revise as appropriate, existing programmatic controls (e.g., the design change and maintenance processes, containment coating program, etc.) to assure they are adequate in controlling the value of fixed non-insulation debris sources at or below the baseline value assumed in the strainer blockage evaluation.
6. A value of 50 lbm of rust flakes may be assumed in the strainer head loss evaluation to address the quantity of rust which may be removed from unpainted steel surfaces and transported to the suppression pool as a result of a LOCA-event. This value includes rust from unpainted steel surfaces in the drywell, the main vents/downcomers, and those in the suppression chamber above the pool level which may be swept as a result of LOCA-induced pool swell. The head loss correlation for rust flakes, not suppression pool sludge, provided in Reference 3 should be used when evaluating this debris species. Subsequent application of a transport factor less than 1.0 to this debris species is not allowed when using this assumption.

Measurements of the quantities of rust, or inspections beyond those already specified by other programmatic controls, are not required.

7. The information contained in References 1, 18, 19, 20, 34 and 35, and licensee actions/commitments in response to these NRC Information Notices and Bulletins, should be carefully considered when establishing a plant specific baseline value of transient non-insulation debris. Licensees should review commitments made in response to NRC Bulletins 93-02 and 95-02, when establishing FME and housekeeping controls and, if appropriate, revise prior commitments for consistency with the resolution of the LOCA-generated debris blockage of the ECCS pump suction strainers.

3.2.2.3 Latent Drywell Debris Sources

This section of the URG addresses latent debris in the drywell which is available for transport to the wetwell. The term latent debris refers to debris which would not be present until later in the LOCA event and includes unqualified coatings as well as other material which may become debris after exposure to a LOCA environment (e.g., adhesive backed labels).

3.2.2.3.1 Unqualified/Indeterminate Paint/Coatings

The BWROG investigated the effects of a LOCA on containment coatings. The results of the investigation are contained in a report dated November 10, 1994 "Performance of Containment Coatings During a Loss of Coolant Accident" (Reference 21) prepared by Bechtel Power Corporation for the BWROG. The Bechtel report provides information on the factors which affect the failure of coatings as well as the debris characteristics of failed coatings.

One potential source of latent debris which has been identified are coatings used in the drywell which are of indeterminate quality or unqualified. After exposure to the LOCA environment, but only after containment pressure is reduced, there is a possibility that indeterminate/unqualified coatings may detach from the surface to which they were applied and become a debris source. Refer to the Bechtel report for a discussion of the failure mechanisms of unqualified coatings.

Licensees should determine if coatings of indeterminate quality or unqualified coatings are present in the drywell. Licensees should also consider whether qualified coatings have degraded over time (due to irradiation, misapplication, etc.) to the point that their qualification is in doubt. If indeterminate or unqualified coatings are present, an evaluation should be conducted to establish the quantity of this latent particulate debris assumed to be available for transport from the drywell to the wetwell. Dependent on several plant-specific factors, it may be possible to show that the failure of indeterminate/unqualified coatings would not occur until late enough in the LOCA progression that there is no transport mechanism available to transport the failed coating from the drywell to the wetwell. The Bechtel report provides helpful information for evaluating this situation.

An alternative to establishing the quantity of unqualified/indeterminate coatings available for transport to the wetwell is to either remove the unqualified/indeterminate coatings, qualify the indeterminate coatings (e.g., via in-situ qualification tests), or to replace them with qualified coatings.

3.2.2.3.2 Other Latent Material

Another potential source of latent debris is adhesive backed tags or labels in the drywell that could become detached as a result of the failure of the adhesive due to exposure to a LOCA environment. Just as with unqualified coatings, a mechanism to transport the detached tag to the floor of the drywell and from there on to the suppression pool is required before it has the potential to affect strainer head loss.

It is not necessary to consider detachment of tags applied with adhesives qualified for a LOCA environment.

Licensees should determine if other latent debris (e.g., tags/labels with unqualified adhesive) is present in the drywell. If so, an evaluation should be conducted to establish the quantity of this

latent debris assumed to be available for transport from the drywell to the wetwell. Dependent on several plant-specific factors, it may be possible to show that the detachment of this potential debris source would not occur until late enough in the LOCA progression that there is no transport mechanism available to move this debris from the drywell to the wetwell.

An alternative to establishing the quantity of other latent debris available for transport to the wetwell is to either remove the potential debris source or to replace with materials which are qualified for a LOCA environment.

3.2.2.3.3 BWROG GUIDANCE

1. Licensees should determine if coatings of indeterminate quality or unqualified coatings are present in the drywell. If such coatings are present in the drywell, either: (a) conduct an evaluation to establish the quantity of this latent particulate debris assumed to be available for transport from the drywell to the wetwell, (b) qualify coatings of indeterminate quality (e.g., via in-situ qualification testing) or, (c) remove or replace the unqualified/indeterminate coating with qualified coating. Determination of the quantity of debris is not required for debris types which are not transportable from the drywell to the suppression pool.

2. Licensees should determine if there are other potential latent debris sources (e.g., adhesive backed tags applied with an unqualified adhesive) present in the drywell. If such other latent debris sources are present in the drywell, either (a) conduct an evaluation to establish the quantity of this latent debris assumed to be available for transport from the drywell to the wetwell or (b) remove or replace with materials which will survive the LOCA environment. Determination of the quantity of debris is not required for debris types which are not transportable from the drywell to the suppression pool.

3.2.3 Drywell Debris Transport

3.2.3.1 Introduction

Once the drywell debris source terms have been established as discussed in Sections 3.2.1 and 3.2.2, the amount of debris which is expected to transport from the drywell to the wetwell (i.e., suppression pool or torus) must be determined. The application of a transport factor less than 1.0 will reduce the amount of debris expected to reach the suppression pool. Depending on the transport within the suppression pool as discussed in Section 3.2.5, this debris would be available for deposition on the ECCS strainers.

A precise determination of debris transport from the drywell to the wetwell as a result of a LOCA is a complex undertaking and dependent on many interrelated plant specific factors. Because of the difficulty in calculating plant specific transport factors, the BWROG conducted a limited test program to determine a bounding set of transport factors for use by any plant in resolution of the strainer blockage issue. This approach has resulted in establishment of containment specific drywell-to-wetwell transport factors for several debris species of piping insulation. The transport factors recommended by the BWROG were determined by considering the results from transport tests in scaled models representative of the area in the immediate vicinity of the Mark I main vents and Mark II downcomers together with the size distribution of debris determined from the air jet impact tests conducted at the CEESI facility. Additional discussion of the BWROG recommended drywell-to-wetwell transport factors, including application to Mark III containment types, is provided in Section 3.2.3.2.

Licensees should also be aware that the NRC has research in progress to improve the understanding of factors affecting drywell-to-wetwell transport. The results of the NRC research are expected to be used to validate licensee determinations of the drywell-to-wetwell transport factors. The NRC work in this area, including possible development of a software model, is anticipated to be complete in late 1996 or early 1997. A June 28, 1996 report "BWR Drywell

Debris Transport Phenomena Identification and Ranking Table (PIRT), Reference 14, commissioned by the NRC identifies issues which should be considered if undertaking an analysis to precisely determine transport factors. If considering use of values different than described in the URG, the BWROG recommends licensees carefully consider the information in the PIRT report, and the discussion of factors affecting transport provided herein, when evaluating alternate calculational methodologies/software models. Further, the BWROG recommends that licensees obtain NRC review and approval of any such alternate calculational methodologies/software models prior to reliance upon their results in the sizing of passive strainers used to assure compliance with the requirements of 10 CFR 50.46 related to ECCS strainer blockage.

3.2.3.2 Transport Considerations - Piping Insulation

The BWROG has established a conservative approach to determine the amount of debris originating in the drywell which is transported to the suppression pool as a result of a LOCA. This approach is based on considering the results from transport tests in scaled models representative of the area in the immediate vicinity of the main vents/downcomers in combination with the size distribution of debris determined from the air jet impact tests conducted at the CEESI facility. A detailed description of the BWROG sponsored tests and the results are reported in References 5 and 6, respectively.

For ease of use in the evaluation of strainer head loss, the debris generation and transport factors have been combined, as shown in Table 5 for saturated steam breaks and Table 6 for saturated water breaks. For the material of interest, the amount of debris produced within the zone of influence, determined in accordance with Section 3.2.1.2, is multiplied by the appropriate factor from Table 5 or Table 6 to determine the amount of drywell debris evaluated to be present in the suppression pool. The bases for the values shown in Table 5 and Table 6 follow.

Transport Testing Through Main Vents/Downcomers

The BWROG sponsored tests conducted at the Continuum Dynamics, Inc. (CDI) facility in Princeton, New Jersey in order to conservatively evaluate the transport of pipe insulation debris from blowdown and washdown in Mark I and Mark II containment types. Two containment models were constructed for the test program, a Mark I model of a main vent at 1/8 scale and a Mark II model of a downcomer at 1/4 scale. The containment models were geometrically scaled based on typical full scale main vents and downcomers. The mass flow rates for steam and flashing water blowdowns were also scaled, as described in Reference 5.

Testing was conducted with various combinations of fibrous and RMI debris and with steam and flashing water blowdowns. Tests to evaluate the washdown of debris resulting from break leakage flow were also conducted.

It is important to note that the tests conditions at the CDI facility were very conservative. The conservatism in the test conditions include the following:

- The size of the fibrous debris was much finer than expected following a LOCA.

  The transport tests used fiber that was shredded into small pieces prior to being placed in the test facility. The shredded fiber was then exposed to a steam jet which resulted in further reducing the size of the fibers. In several cases, a significant portion (up to 67%) of the fiber was reduced to such small size that it could not be captured in the collection mechanism (a screen with ≤ 0.0049 inch hole size). The very small fiber sizes produced by the tests are at best representative of the small fraction of the overall fibrous debris resulting from a break where the insulation is directly on the pipe at the location where the break occurs. However, as determined from testing conducted at the CEESI facility (Reference 6), the fiber size used in the testing at CDI are much smaller than the average size distribution of fibrous debris resulting from a pipe break.

Because fines, small fiber and dust transport more readily than larger fiber pieces, a transport factor based only on the transport testing of the small fibers is very conservative and not representative of the transport factor for the range of debris sizes produced by a pipe break.

- The sub-scale size of the containment model did not allow testing of larger pieces of insulation debris typically produced by a pipe break. As previously noted, the small fiber sizes tested are not representative of the average debris size and this results in conservative transport results.

- Only the last few feet of the debris transport path through the drywell to the main vent/downcomer were modeled. Consequently, the deposition of debris on the surface area of other structures and equipment in the drywell (e.g., piping, gratings, cables, pipe hangers, valves, etc.) which would exist in an actual transport path from the break location to the main vents/downcomers is not modeled in the test. Nor was the overall surface area inside the containment model scaled to be representative of the total surface area inside a BWR containment on which fiber deposition could occur prior to reaching the main vents/downcomers. While the BWROG tests did include limited testing with gratings installed in the containment model, the test conditions did not represent the multiple levels of gratings typical of those installed in a BWR containment.

Because of the conservatism in the test conditions, the results for fibrous debris are conservative. The test results reported in Reference 5 are summarized below. The average results, expressed as a fraction of the initial mass, from the series of tests run for fine fibrous debris are:

Fine Fibrous Debris Transport Tests	Average Result	
Mark I - Large Steam Break	Blowdown	0.70
	Washdown	0.22
	Combined	0.92
Mark I - Large Saturated Water Break	Blowdown	0.66
	Washdown	0.29
	Combined	0.95
Mark II - Large Steam Break	Blowdown	0.30
	Washdown	0.20
	Combined	0.50
Mark II - Large Saturated Water Break	Blowdown	0.14
	Washdown	0.42
	Combined	0.56
Additional small fibers from leakage flow erosion of larger fiber pieces.	Mark I	0.12
	Mark II	0.23

Tests were also run to evaluate the transport for RMI debris. Again, the test conditions for RMI are conservative. From Reference 5, the average results, expressed as a fraction of the initial mass, from the series of tests run for RMI debris are:

RMI Debris Transport Tests	Average Result	
Mark I - Large Steam Break	Blowdown	0.62
	Washdown	0.37
	Combined	0.99
Mark I - Large Saturated Water Break	Blowdown	0.65
	Washdown	0.29
	Combined	0.94
Mark II - Large Steam Break	Blowdown	0.10
	Washdown	0.00
	Combined	0.10
Mark II - Large Saturated Water Break	Blowdown	0.05
	Washdown	0.00
	Combined	0.05
Additional small RMI pieces from leakage flow erosion of larger RMI pieces.		0.00

Again, the result from the tests conducted at the CDI facility are very conservative and are not representative of the actual drywell-to-wetwell transport factor that would occur should a BWR plant experience an actual pipe rupture. To arrive at a transport factor for debris that is more representative, but still conservative, of what would actually occur should a pipe break inside a BWR drywell, it is necessary to account for the size distribution of debris resulting from a given break. Application of the results from the BWROG air jet impact tests conducted at CEESI are useful in this regard.

3.2.3.2.1 DEBRIS SIZE DISTRIBUTION

As previously discussed in Section 3.2.1.2, the BWROG sponsored tests conducted at the Colorado Engineering Experiment Station (CEESI) facility in order to obtain quantitative data to determine the stagnation pressure at which insulation materials typical of those used in BWRs will not undergo damage resulting in debris which is potentially transportable. A secondary objective of the tests at CEESI, which is of interest here, was to characterize the debris generated from different insulation types. Reference 6 provides details on the BWROG sponsored tests conducted at CEESI and reports the mass of debris resulting from the tests in various size categories.

A general observation from review of the results of the testing at CEESI is that a significant portion of the debris generated during the tests was of a size large enough that it is not expected to transport from the drywell to the wetwell. Larger shreds of fibrous debris are not readily transported and tend to settle on the floor or be deposited on equipment and structures. This observation is consistent with the findings in previous studies of the issue, including NUREG/CR-6224 (Reference 22)[5]. It is also unlikely that large pieces of RMI debris would be transported to the suppression pool.

To determine the mass of fibrous debris specie in a given size category resulting from a LOCA, an approach which estimates via numerical integration the debris size for the entire zone of influence was employed. The BWROG judges this to be a reasonable engineering approximation which has the benefit of simplifying the analysis by avoiding the need to specifically determine the debris size at various distances from the break. Due to the limited data available, a bounding approach was used for debris from RMI and Min-K insulation materials. The technical basis for the numerical integration used in the determination of the fraction of fibrous debris to be considered in the strainer head loss evaluation is provided in Appendix E of Reference 5. The notes accompanying Table 4 provide the basis for other debris species. The rationale for the BWROG judgement of

[5] NUREG/CR-6224, Section B-4 'Debris Species Classification.'

the fraction of debris which may be excluded from strainer head loss evaluations is discussed later in this section.

Table 4 - Fraction of LOCA-Generated Debris for Selected Materials to Be Considered in Strainer Head Loss Evaluations[1]

Material[2]	Fraction of Total Fiber Mass[3,4,8] in ZOI	Fraction of Total RMI Debris[5,6] in ZOI
Darchem DARMET®	n/a	0.5
Transco RMI	n/a	0.5
Jacketed NUKON® with modified "Sure-Hold" Bands, Camloc® Strikers and Latches	0.15	n/a
Diamond Power MIRROR® with modified "Sure-Hold" Bands, Camloc® Strikers and Latches	n/a	0.5
Calcium Silicate with Aluminum Jacketing	0.10[9]	n/a
K-wool	0.22	n/a
Temp-Mat™ with Stainless Steel Wire Retainer	0.16	n/a
Knauf®	0.30	n/a
Jacketed NUKON® with standard bands	0.23	n/a
Unjacketed NUKON®	0.23	n/a
Koolphen-K®	0.26	n/a
Diamond Power MIRROR® with standard banding	n/a	0.5
Min-K	1.0[7]	n/a

Notes for Table 4:

1. This Table provides values that can be used in a manner similar to the "destruction factor" discussed in NUREG/CR-6224 (Reference 22) to determine a debris generation source term for input to strainer head loss evaluations. The source term from the erosion of larger debris pieces into smaller fragments as a result of break leakage flow is addressed separately in Section 3.2.3.2.2.4.
2. Application of the information to materials and/or attachment mechanisms with critical characteristics of design different from those tested by the BWROG should be justified by additional testing or analysis, as appropriate. See Reference 6 for additional descriptive information of the materials and the attachment mechanisms tested by the BWROG.
3. Except for Min-K and calcium silicate with aluminum jacketing, values shown are 1 - $\overline{\eta}_B$ where $X_a=L_a$. The values for $\overline{\eta}_B$ are provided in Appendix E of Reference 5. See Note 7 for the basis of the value of Min-K. See Note 9 for the basis of the value of calcium silicate with aluminum jacketing.
4. The value is applied to the total mass of the base material and the fabric covering or other non-metal-jacket covering material for the insulation within the zone of influence as determined in Section 3.2.1.2. For

jacketed insulation, the metallic covering materials are excluded. Note that for convenience, non-fibrous insulation materials (e.g., Koolphen-K®) are also shown in this column.

5. Values shown are solely based on the RMI material tested which produced the most limiting amount of debris (i.e., 42% of the inner foils debris from test 17-1, see Reference 6). This approach conservatively bounds the RMI debris which may be produced from the other RMI designs tested by the BWROG, which typically produced little or no debris. These values may be reduced if justified by additional test or analysis, as appropriate.
6. The value is applied to the total area of the inner foils only of the RMI cassette within the zone of influence as determined in Section 3.2.1.2. The end disks, cassette sheaths, side panels and other large pieces (but not inner foils are excluded.
7. Minimal testing of this material was performed by the BWROG so a conservative value is assumed. This value may be reduced if justified by additional test or analysis, as appropriate.
8. The fraction of the mass of debris which is large fiber pieces is determined by subtracting the value in this column from 1, except for Jacketed NUKON® with modified "Sure-Hold" Bands, Camloc® Strikers and Latches. No large fiber debris pieces are reported in Reference 6 for Jacketed NUKON® with modified "Sure-Hold" Bands.
9. For $1 - \overline{\eta}_B$ where $X_a=0$ the result is 0.02. For $1 - \overline{\eta}_B$ where $X_a=L_a$ the result is 1.0. (The values for $\overline{\eta}_B$ are provided in Appendix E of Reference 5.) Use of the $X_a=L_a$ values is not appropriate for higher strength materials such as calcium silicate with aluminum jacketing as it introduces excess conservatism i.e., 100% destruction when the tests results show that at most only 2% of the material was destroyed into debris sizes which could affect strainer debris loadings. The 2% value was from test 15-4 (see Reference 6) at 7 pipe diameters which was the closest placement to the jet nozzle for this material. It is the judgement of the BWROG that assuming 10% of the calcium silicate material within the zone of influence results in fine debris is sufficiently conservative to address the source term from this debris specie which may result should this insulation material be located closer to the break than was tested by the BWROG. Note that some larger debris pieces ("chunks") are included within the 2% value reported in test 15-4 and therefore are already addressed, and consideration of additional erosion of larger debris pieces is not required.

3.2.3.2.2 TRANSPORT CONSIDERATIONS FOR FIBROUS DEBRIS

For fibrous insulation material, the debris characterization contained in Reference 6 is typically reported in three categories:

- fines, small fibers, and dust
- large fiber pieces (i.e., greater than the hand-size)
- blankets and covering material

From the photographic evidence provided in Reference 6, it is clear that the blankets which are substantially intact and the large pieces of covering material are of such size that they are judged to be unlikely to transport past the jet deflector plates and into the main vents/downcomers in a Mark I or II containment. For a Mark III containment design there is typically a grating installed above the weir wall which should be effective at preventing blanket and covering material resulting from breaks occurring above the grating from entering the weir annulus. Although it is judged that it is unlikely for blanket and covering material to enter the weir annulus for plant of a Mark III containment design, should such an event occur, the blanket/cover would then have to be transported from the bottom of the weir annulus where it would settle. It would then need to be resuspended and transported through the horizontal vent tubes and into the suppression pool before it would have the potential to reach the ECCS strainers. Once in the suppression pool, the intact blanket/cover is expected to settle to the pool bottom where it would not contribute to strainer blockage. Therefore, it is the judgement of the BWROG that the substantially intact blankets and covering materials from fibrous debris produced by a postulated pipe break do not need to be considered in the evaluation of strainer head loss for Mark I, II, or III containment types.

As previously discussed, large debris pieces are unlikely to transport to the suppression pool. The BWROG believes this conclusion is valid for blowdown transport of insulation material in that portion of the zone of influence above the lowest level of grating. However, insulation in that

portion of the zone of influence located below the lowest level of grating (e.g., a portion of the recirculation pump piping) is expected to have a higher transport efficiency and a fraction of the larger fiber pieces in this area may be transported to the suppression pool. This is because of the short distance debris below the lowest grating would have to travel to the entrance to the main vent/downcomer and a corresponding lesser amount of deposition of fibers on drywell equipment and structures. Also, depending on the plant specific arrangement, the size of the opening between the jet deflector plates and the entrance to the main vents/downcomers may be sufficiently large that a fraction of the large fiber debris pieces could enter the main vent/downcomer as a result of either blowdown or washdown forces. However, because of the turbulent flow conditions that would exist in the area of a break low in the drywell, it is not credible to assume that 100% of both the fines, small fibers and dust as well as the large fiber pieces would be transported into the main vents/downcomers and into the suppression pool. The turbulent conditions are expected to cause some fraction of both the fines/small fibers and the larger fiber piece to be transported away from the main vents/downcomers where it would be deposited on drywell equipment and structures.

It is also recognized that a fraction of the larger fiber pieces may be eroded into smaller pieces as they are exposed to the effects of washdown over time.

3.2.3.2.2.1 Grating

One of the considerations in evaluating debris transport for all debris species is the effect of gratings. The BWROG has selected the lowest level of grating in the containment as a demarcation line in the evaluation of debris transport. A higher transport factor is applied to the insulation within the portion of the zone of influence below the lowest level of grating than is applied to insulation above the grating. The selection of the lowest level of grating was made because it is the last significant barrier (i.e., a debris interceptor) before reaching the immediate area of the main vents/downcomers and the openings in the grating are typically smaller than the size of large debris pieces. It is not required that the lowest level of grating all be located in the same horizontal plane/elevation.

3.2.3.2.2.2 Fibrous Insulation Targets Above the Lowest Level of Grating

For fibrous insulation material located in the portion of the zone of influence above the lowest level of grating in the containment, it is the judgement of the BWROG that use of the containment specific values shown below for the mass of fines, small fibers and dust assumed to be transported to the suppression pool are conservative for the purpose of evaluating strainer head loss. These values are based on a review of the results of transport testing conducted at the CDI facility which are conservative for the reasons previously discussed. Use of these conservative values are judged to be adequate to account for the small additional debris source that might result from the small fraction of larger fiber pieces should they be transported.

Containment Type	Combined Blowdown and Washdown Transport Fraction for Fines, Small Fibers and Dust	
Mark I	Steam Break	1.0
	Saturated Water Break	1.0
Mark II	Steam Break	0.5
	Saturated Water Break	0.56
Mark III[6]	Steam Break	1.0
	Saturated Water Break	1.0

The transport fractions shown above are applicable to piping insulation debris which is fibrous in nature. Although the insulation material used in the transport tests reported in Reference 5 is NUKON® insulation, it is the judgement of the BWROG that fibers from other pipe insulation materials would behave similarly and that the test conditions were sufficiently conservative to account for any minor variations in the transport efficiency of various fiber types.

[6] The BWROG has not conducted transport testing on a Mark III containment model and has therefore assumed a conservative value. This value may be reduced if justified by testing or analysis, as appropriate.

However, without further test or analysis, it is not considered appropriate to apply the transport fraction for fibrous debris determined from the testing at CDI to calcium silicate, Koolphen-K®, or Min-K insulation materials since they are primarily comprised of non-fibrous materials. For these insulation materials a transport fraction of 1.0 is assumed for fines and other small debris pieces.

3.2.3.2.2.3 Fibrous Insulation Targets Below the Lowest Level of Grating

For fibrous insulation materials located in the portion of the zone of influence below the lowest level of grating in the containment, the same values for the transport of fines, small fibers and dust as previously provided for above-the-grating should be used. In addition, because a major fraction of the larger fiber pieces are expected to remain below the lowest level of grating where they may be more readily transported to the suppression pool, it is appropriate to account for their potential effect on the strainer head loss. As previously discussed, it is not considered credible that 100% of the large fiber pieces would remain below the grating and be subject to transport. It is the judgement of the BWROG that the following values conservatively address this additional source term:

Mark I	70% of the mass of large fiber pieces
Mark II	30% of the mass of large fiber pieces
Mark III[6]	70% of the mass of large fiber pieces

The same blowdown transport factors determined from the tests conducted at the CDI facility for the transport of fine debris (which are themselves conservative for reasons previously discussed) are applied to larger fiber pieces. As previously discussed, large fiber pieces transport less readily than small fibers. Therefore, the blowdown transport factors shown above for large fiber pieces are very conservative.

The values above are also judged to be sufficiently conservative that they may be applied to large pieces of calcium silicate, Koolphen-K®, or Min-K insulation materials.

3.2.3.2.2.4 Erosion of Large Fiber Pieces Resulting From Break Leakage Flow

Additionally, it is appropriate to account for the potential increase in fibrous debris that may result from break leakage flow erosion of larger pieces. It is the BWROG judgement that no more than 25% of the remaining mass of the large fiber pieces (i.e., those not otherwise assumed to have been transported) may be exposed to the break leakage flow. This is judged to be a conservative estimate because the jet forces resulting from the break will tend to move the debris out of the jet path and away from exposure to break leakage flow. Based on the tests conducted at CDI on the effect of break leakage flow erosion of larger fiber pieces, it is the BWROG judgement that use of a factor of 25% of the mass of larger fiber pieces exposed to break leakage flow adequately bounds the amount of debris resulting from erosion of larger fiber pieces. The erosion factor assumed by the BWROG is larger than the result measured during any erosion test (see Reference 5) and also bounds the debris source term resulting from operation of drywell sprays, as discussed later.

However, without further test or analysis, it is not considered appropriate to apply the erosion factor for fibrous debris determined from the testing at CDI to calcium silicate, Koolphen-K®, or Min-K insulation materials since they are primarily comprised of non-fibrous materials. For these insulation materials a erosion fraction of 1.0 is conservatively assumed.

Therefore, the total remaining mass of large fiber pieces (i.e., those not otherwise assumed to have been transported), determined via the zone of influence evaluation in accordance with Section 3.2.1.2 and Table 4, is multiplied by 0.0625 (i.e., 0.25 X 0.25) and the resulting value considered as a debris source term in the suppression pool when performing the strainer head loss evaluation. For Koolphen-K® and Min-K insulation materials the total mass of large pieces within the zone of influence is multiplied by 0.25 (i.e., 0.25 X 1.0). For calcium silicate with aluminum jacketing, the larger debris pieces ("chunks") were included within the values reported for small debris pieces/fines when this insulation was tested and therefore consideration of additional erosion of larger debris pieces is not required.

3.2.3.2.3 REFLECTIVE METAL INSULATION TRANSPORT

For RMI, the debris characterization contained in Reference 6 is typically reported in the following categories:

- < 0.25 in^2
- 0.25 - 0.5 in^2
- 0.5 - 1.0 in^2
- 1.0 - 2.0 in^2
- 2.0 - 4.0 in^2
- 4.0 - 6.0 in^2
- > 6.0 in^2
- Intact Assembly

For each material tested, the total mass is provided for each debris category along with the percentage of that mass relative to the mass of the entire RMI cassette.

Throughout the testing of RMI materials, debris pieces in the size category of greater than 6.0 in^2 consisted mainly of much larger or whole sheets of internal reflective foils which were transported away from the exhaust nozzle intact. It was observed that, for a given RMI material, tests which resulted in separation of the inner and outer cassette sheaths conducted closer to the exhaust nozzle generated more smaller size debris, while tests conducted farther away from the exhaust nozzle generated larger sized debris with the majority of the debris consisting of large intact sheets of insulating foils. For the majority of the types of RMI materials tested, no inner foils or other debris evaluated as being transportable were produced during the tests at CEESI even when tested at distances close to the jet nozzle. In those tests where RMI debris was produced, intact sheets of foil not immediately fragmented due to their proximity to the exhaust nozzle were carried away from the jet and remained as large sheets of foil debris. Based on the results of the testing at CEESI, the BWROG has judged that strainer head loss calculations need only consider the smaller RMI debris sizes resulting from the fragmentation of inner reflective foils. The large

internal foil debris pieces may be excluded in the evaluation of strainer head loss. For Mark I or II containment designs, these large debris pieces would not be expected to pass through the opening between the jet deflector plates and the main vent/downcomers. For Mark III containment designs, in the unlikely event large pieces of RMI debris enter the weir annulus through the small opening below the grating which leads to the annulus, it further unlikely they would be transported through the horizontal vent tubes and into the suppression pool. Even if a large piece of inner foil were to enter the suppression pool it is expected that it would quickly settle to the pool bottom and not affect the head loss of the ECCS strainers.

For the same reasons large pieces of intact foils are not expected to transport, the intact RMI assemblies, end disks, cassette sheaths, side panels and other large pieces may be excluded when evaluating strainer head loss.

Note that grating is also expected to be effective at reducing the transport of both large and small RMI debris pieces generated above the lowest level of grating. However, because of limitations in the transport test data, the BWROG has not attempted to quantify the effect of gratings on reducing the transport of small RMI debris but recognizes the conservatism in the approach chosen.

3.2.3.2.3.1 RMI Targets - Any Location

For RMI insulation at any location within the zone of influence, it is the judgement of the BWROG that use of the containment specific values shown below for the small pieces of RMI debris assumed to be transported to the suppression pool are conservative for the purpose of evaluating strainer head loss. To simplify the evaluation, no credit is taken for the reduction in transport of small RMI pieces provided by gratings even though the transport tests conducted at CDI indicate gratings are effective in minimizing transport of this debris. Note that there is no additional erosion of RMI debris from break leakage flow as is the case with fibrous debris.

Containment Type	Combined Blowdown and Washdown Transport Fraction for RMI Debris	
Mark I	Steam Break	1.0
	Saturated Water Break	1.0
Mark II	Steam Break	0.1
	Saturated Water Break	0.05
Mark III[7]	Steam Break	1.0
	Saturated Water Break	1.0

[7] The BWROG has not conducted transport testing on a Mark III containment model and has therefore assumed a conservative value. This value may be reduced if justified by testing or analysis, as appropriate.

3.2.3.2.4 TRANSPORT FROM DRYWELL SPRAYS

Drywell sprays are introduced into the drywell atmosphere through spray nozzles designed to produce a fine mist. Without data to the contrary, it is assumed that there is some potential that the mist may contribute to the transport of small fibrous debris by causing the detachment of a portion of the fine debris from the drywell walls and equipment where it was deposited during the blowdown phase of a postulated LOCA. The fine debris loosened as a result of the drywell sprays would then have to be further transported past equipment and structures, which afford an additional possibility of capture, before reaching the floor of the drywell where it would then have the potential to be transported to the suppression pool. However, these fine misting sprays will not contribute to the erosion of the remaining large fibrous debris. As previously discussed, the erosion of larger fiber pieces is a result of the break leakage flow exiting the pipe break..

For the Mark I plants, it is already assumed that 100% of the fine debris is transported therefore no additional source of fiber as a result of containment sprays needs to be considered. Plants with a Mark III containment design do not have drywell spray and therefore an additional debris source term from spray washdown is not an issue for plants of a Mark III containment design.

For the Mark II plants, the use of drywell sprays may contribute to the transport of fine debris. However, drywell spray operation for Mark IIs is actuated manually, not automatically. If drywell spray is initiated it will quickly reduce containment pressure and therefore it is expected to be in operation for only a short amount of time. Further, it is expected that the small fraction of fine debris which is loosely attached would be subject to transport within the first several minutes of spray operation and that long term spray operation would not result in the transport of additional debris to the suppression pool in an amount sufficient to affect strainer head loss. Therefore, it is the judgement of the BWROG that the conservatism in the erosion factor of large fiber pieces (i.e., the erosion factor assumed by the BWROG is larger than the erosion results measured during any test as reported in Reference 5) is adequate to compensate for the small increase in the

source term of fine debris that may occur should drywell sprays result in additional transport of small fibers in a Mark II.

In summary, it is the judgement of the BWROG that the conservative approach previously described to determine the fiber source term for strainer head loss evaluations of Mark I, II, and III containment designs adequately bounds the amount of debris that may result from drywell spray operation.

3.2.3.2.5 DEBRIS GENERATION AND TRANSPORT SUMMARY

As a convenience in the evaluation of strainer head loss, the various material specific debris generation and transport factors have been combined with the containment type and insulation location specific factors into Table 5 for saturated steam breaks and Table 6 for saturated water breaks.

Table 5 - Factors for Combined Debris Generation and Transport - Steam Breaks[1]

Material[2]	Mark I	Mark II	Mark III
Darchem DARMET®	0.50	0.05	0.50
Transco RMI	0.50	0.05	0.50
Jacketed NUKON® with modified "Sure-Hold" Bands, Camloc® Strikers and Latches *(Above/Below Grating)* [3]	0.15 / 0.15	0.08 / 0.08	0.15 / 0.15
Diamond Power MIRROR® with modified "Sure-Hold" Bands, Camloc® Strikers and Latches	0.50	0.05	0.50
Calcium Silicate with Aluminum Jacketing	0.10	0.10	0.10
K-wool *(Above/Below Grating)* [3]	0.27 / 0.78	0.13 / 0.36	0.27 / 0.78
Temp-Mat™ with Stainless Steel Wire Retainer *(Above/Below Grating)*	0.21 / 0.76	0.11 / 0.35	0.21 / 0.76
Knauf® *(Above/Below Grating)* [3]	0.34 / 0.80	0.17 / 0.38	0.34 / 0.80
Jacketed NUKON® with standard bands *(Above/Below Grating)* [3]	0.28 / 0.78	0.14 / 0.36	0.28 / 0.78
Unjacketed NUKON® *(Above/Below Grating)* [3]	0.28 / 0.78	0.14 / 0.36	0.28 / 0.78
Koolphen-K®	0.45	0.45	0.45
Diamond Power MIRROR® with standard banding	0.50	0.05	0.50
Min-K	1.0	1.0	1.0

Notes for Table 5:

1. This Table is applicable to postulated pipe breaks of lines containing saturated steam.
2. Application of the values to materials and/or attachment mechanisms with critical characteristics of design different from those tested by the BWROG should be justified by additional testing or analysis, as appropriate. See Reference 6 for additional descriptive information of the materials and the attachment mechanisms tested by the BWROG.
3. The above the grating value is applied to the insulation material which is in the portion of the zone of influence above the lowest level of drywell grating. The below the grating value is applied to the insulation material which is in the portion of the zone of influence below the lowest level of drywell grating. See the discussion of grating for additional information on the identification of grating location.

Table 6 - Factors for Combined Debris Generation and Transport - Water Breaks[1]

Material[2]	Mark I	Mark II	Mark III
Darchem DARMET®	0.50	0.03	0.50
Transco RMI	0.50	0.03	0.50
Jacketed NUKON® with modified "Sure-Hold" Bands, Camloc® Strikers and Latches *(Above/Below Grating)* [3]	0.15 / 0.15	0.08 / 0.08	0.15 / 0.15
Diamond Power MIRROR® with modified "Sure-Hold" Bands, Camloc® Strikers and Latches	0.50	0.03	0.50
Calcium Silicate with Aluminum Jacketing	0.10	0.10	0.10
K-wool *(Above/Below Grating)* [3]	0.27 / 0.78	0.15 / 0.38	0.27 / 0.78
Temp-Mat™ with Stainless Steel Wire Retainer *(Above/Below Grating)*	0.21 / 0.76	0.12 / 0.36	0.21 / 0.76
Knauf® *(Above/Below Grating)* [3]	0.34 / 0.80	0.19 / 0.40	0.34 / 0.80
Jacketed NUKON® with standard bands *(Above/Below Grating)* [3]	0.28 / 0.78	0.16 / 0.38	0.28 / 0.78
Unjacketed NUKON® *(Above/Below Grating)* [3]	0.28 / 0.78	0.16 / 0.38	0.28 / 0.78
Koolphen-K®	0.45	0.45	0.45
Diamond Power MIRROR® with standard banding	0.50	0.03	0.50
Min-K	1.0	1.0	1.0

Notes for Table 6:

1. This Table is applicable to postulated pipe breaks of lines containing saturated water.
2. Application of the values to materials and/or attachment mechanisms with critical characteristics of design different from those tested by the BWROG should be justified by additional testing or analysis, as appropriate. See Reference 6 for additional descriptive information of the materials and the attachment mechanisms tested by the BWROG.
3. The above the grating value is applied to the insulation material which is in the portion of the zone of influence above the lowest level of drywell grating. The below the grating value is applied to the insulation material which is in the portion of the zone of influence below the lowest level of drywell grating. See the discussion of grating for additional information on the identification of grating location.

3.2.3.3 Transport Considerations - Other Debris

The BWROG has not developed transport factors for materials other than the insulation materials described in Section 3.2.3.2. Where an approved transport factor is not available, licensees may either assume a transport factor of 1.0 and apply it the amount of material in the zone of influence or perform the testing/analysis necessary to justify the debris generation and transport factors for the material of interest.

If a licensee elects to determine the debris generation and transport factors, the evaluation should consider the following, as appropriate:

- the strength of the material and its ability to withstand LOCA effects
- the material characteristics (debris size, weight, etc.) after exposure to a LOCA environment
- barriers to transport from the drywell to the ECCS strainers
- the transport mechanism(s) available to transport the material from the drywell to the wetwell including:
  - ⇒ break size, type (steam or water), location, and duration
  - ⇒ consideration of when during the event the material becomes a potential debris source (e.g., is it latent debris as discussed in Section 3.2.2.3)
  - ⇒ transport of the debris from elsewhere in the drywell to the drywell floor
  - ⇒ the expected flow velocities across the drywell floor resulting from break leakage flow and/or containment spray flow, if applicable
- the location of the material in the drywell
- the distribution of damaged material in the drywell
- operational controls which may limit transport (e.g., no use of containment sprays)
- other factors which can affect the transport of material

The PIRT report (Reference 14) and a summary of data related to washdown transport provide in Reference 33, also provide information which may be helpful in determination of transport factors for debris species not addressed herein.

3.2.3.4 BWROG Guidance

1. A drywell-to-wetwell transport factor of 1.0 may be conservatively assumed for any debris species.

2. For ECCS strainer head loss calculations, the amount of drywell debris for the material of interest transported to the suppression pool should be determined by multiplying the amount of the debris for the material of interest produced within zone of influence, as determined in Section 3.2.1.2, by the value from Table 5 or Table 6 as appropriate for the containment type/location and pipe break being evaluated. The guidance provided in the notes associated with Table 4 through Table 6 should be followed when making this determination.

3. Use of debris generation and transport values other than those provided herein should be supported by an evaluation which justifies their basis. The BWROG recommends licensees carefully consider the information in the PIRT report (Reference 14), and the discussion of factors affecting transport provided herein, when evaluating calculational methodologies/software models which produce debris generation or transport results different than those provided in the URG. Further, the BWROG recommends that licensees obtain NRC review and approval of any such alternate calculational methodologies/software models prior to reliance upon their results in the sizing of passive strainers used to assure compliance with the requirements of 10 CFR 50.46 related to ECCS strainer blockage.

3.2.4 Suppression Pool Debris

3.2.4.1 Introduction

LOCA-generated debris, combined with transient debris and sludge present in the suppression pool, are the principal contributors to strainer blockage. The quantity of debris and sludge considered to be present in the suppression pool and available for transport to the ECCS suction strainers are key design inputs in evaluating whether a particular strainer has sufficient capacity to assure that the required NPSH to the ECCS pumps is maintained.

3.2.4.2 Suppression Pool Debris Sources

3.2.4.2.1 INTRODUCTION

Debris and sludge in the suppression pool can come from several sources:

1. LOCA-generated Debris:
    - Debris that is transported from the drywell to the wetwell as a result of the LOCA. The amount of this debris source is addressed separately in other sections of this document.

    - The amount of dirt/dust in the wetwell (or containment for a Mark III) which is above the normal level of the suppression pool but which could be entrained in the pool volume as a result of LOCA induced pool swell. Licensees should consider the amount of debris available from this source and add it to the other debris sources when evaluating strainer head loss.

- A potential third component of the LOCA-generated debris source term in the wetwell is material that is expected to be entrained in the suppression pool water volume as a result of LOCA forces. For example, corrosion products on unpainted steel surfaces or unqualified paint in the wetwell should be evaluated to determine if they could become entrained in the suppression pool water volume as a result of the violent agitation of the suppression pool from LOCA effects. Not all plants will have this debris source but if it is present, licensees should consider the amount of debris available from this source and add it to the other debris sources when evaluating strainer head loss.

  The BWROG has investigated the effects of a LOCA on containment coatings. The results of the investigation are contained in a report dated November 10, 1994 "Performance of Containment Coatings During a Loss of Coolant Accident" (Reference 21) prepared by Bechtel Power Corporation for the BWROG. The Bechtel report provides information on the factors which affect the failure of coatings as well as the debris characteristics of failed coatings and this information should be helpful to licensees in evaluating the susceptibility of coatings in the wetwell to fail during a LOCA event.

2. Transient Debris: Transient debris is non-permanent plant material (e.g., tools, rags, sheeting, plastic bags, temporary filters, etc.). The plant design, operation and maintenance practices, the foreign material exclusion (FME)/housekeeping program, and the frequency of suppression pool inspection/cleaning will affect the amount of transient debris present in the suppression pool at the start of a postulated LOCA. Typical sources of such debris include:
   - ropes used to lower equipment into the wetwell
   - fibrous/paper mats placed over gratings during outages
   - temporary HVAC filters that are installed during outages
   - duct tape with a cloth base
   - anti-contamination personnel clothing

- cloth/rags dropped in the suppression pool

Transient debris is further subdivided into two categories.

- Fibrous transient debris in the pool volume prior to a LOCA
- Other (non-fibrous) transient debris in the pool prior to a LOCA

The quantity of transient fibrous debris assumed to be present at the outset of a LOCA is determined through a bounding analysis or through measurement of the fiber in the pool volume.

The other (non-fibrous) transient debris is further broken down as follows:

- Non-fibrous debris capable of clogging strainers
- Non-fibrous debris NOT capable of clogging strainer

Each of these other transient debris sources are discussed in further detail.

Non-Fibrous Debris Capable of Clogging Strainer

This category includes non-fibrous debris that is lightweight and flexible and can conform to the shape of a strainer and reduce/block flow. This may include items such as plastic bags/sheeting, radiation protection step-off pads, plastic tags, rubber gasket material or straps, plastic anti-contamination clothing, etc. Foreign material exclusion programs should specifically establish controls over this type of debris and limit the potential for it to enter and remain in the suppression pool.

Non-Fibrous Debris NOT Capable of Clogging Strainer

There are two types of non-fibrous debris which are not capable of clogging strainers, debris which is heavy and will sink to the bottom of the pool and debris which is light and will float on the surface.

The heavy type of debris is typically metallic objects such as nuts, bolts, nails or other heavy objects. These items generally have settling velocities much higher than the approach velocity of a strainer, and/or will not conform to the shape of a strainer even at elevated temperatures of a post-LOCA suppression pool. Therefore, these items do not have to be considered in the evaluation of strainer blockage as they will a) settle rapidly to the suppression pool floor and are not likely to be picked up from the suppression pool floor due to turbulence, and/or b) not block significant strainer surface area as they will contact at only one point and/or c) not remain attached to the strainer as the approach velocity of the strainer is not sufficient to hold them in place.

The light type of debris may be, for example, foam type anti-sweat insulation which will float. This type of insulation is typically installed on cooling water piping. Debris which will float does not have to be considered in the head loss calculation since it will not collect on the strainer surface. Care should be taken in evaluating whether a given material will float to be sure that the effects of aging, irradiation, exposure to a LOCA environment and jet forces, etc. do not substantively change the pre-LOCA floatation characteristics of the material.

3. Suppression Pool Sludge: Sludge is predominantly corrosion products from carbon steel piping systems which connect to the suppression pool and from unpainted carbon steel surfaces within the pool. Dirt/dust also contribute to suppression pool sludge. The amount of sludge present in the pool is controlled by the frequency and thoroughness of pool cleaning and the rate at which new corrosion products are generated. Additional information and guidance on suppression pool sludge can be found in Section 3.2.4.3.

Foreign material exclusion (FME)/housekeeping programs and periodic suppression pool inspections and cleanings are used to minimize the amount of transient debris and sludge that is present in the suppression pool. Licensees should recognize that FME programs and pool

cleaning frequency and scope must be adequate to ensure that the design input values of the quantity of transient debris and sludge used in the strainer sizing calculations are not exceeded. Consequently, licensees should consider the trade-off between operational flexibility and strainer size when establishing the values of transient debris and sludge considered to be present in the suppression pool. A licensee may implement FME program controls and frequent pool cleaning as a means to reduce the amount of debris and sludge present in the pool. The rigor of these controls should be consistent with the debris source term assumed in the strainer sizing analysis. Optimizing FME controls to the extent that a debris source term of zero is assumed is not practical given the effort required to maintain such a level of pristine cleanliness. Alternatively, less strict FME controls and less frequent pool cleaning may offer increased operational flexibility but with the need for a larger strainer being required because of the increased source term for debris and sludge.

The rigor of FME controls and frequency of cleaning of the sludge from the suppression pool are determined by the licensee. However, the FME controls and pool cleaning frequency must be effective at controlling the transient debris and sludge quantities such that when combined with the quantity of LOCA-generated debris the sum is less than the design input values assumed in sizing the passive strainer (or passive portion of a self-cleaning strainer).

The BWROG recognizes that a generic approach for a standard BWR FME program is not appropriate. Instead, a performance goal is established and the licensee is provided flexibility in how to meet that performance goal. This approach provides the licensee the opportunity to continuously improve their FME program over time rather than being locked into a standard program that is not readily adaptable to plant specific conditions and evolving work practices.

Because the FME program is relied upon to control transient debris sources such that the strainer will perform acceptably, licensees should have inspection techniques and procedures that reasonably assure the FME program is meeting the performance goal. For example, if a licensee sizes a strainer to perform acceptably with a design input that no more than X lbs. of transient dirt/dust from the wetwell are washed into the suppression pool as a result of LOCA induced pool

swell, the inspection techniques and procedures used to verify the effectiveness of the FME program should be capable of estimating whether more than X lbs of dirt/dust are in the suppression pool area above the normal pool level which could be swept by pool swell.

The specific approach for determining the baseline value of transient debris is left to the discretion of the licensees.

Licensees should recognize that if suppression pool debris source terms cannot be shown to be controlled at values less than assumed in the strainer sizing calculations the operability of the ECCS systems may be challenged.

3.2.4.2.2 BWROG GUIDANCE

1. Licensees should determine the quantity and composition of LOCA-generated debris transported from the drywell to the wetwell from the guidance contained in Sections 3.2.1.2 and 3.2.3 of this document.

2. Establish the amount of debris, other than that transported from the drywell during a LOCA and pool sludge which are addressed separately, that is assumed to be present in the suppression pool during a LOCA. This debris source includes:
   - Fibrous transient debris entrained in the pool volume prior to a LOCA
   - Other (non-fibrous) transient debris entrained in the pool volume prior to a LOCA
   - The dirt/dust above the pool area which is washed into the pool from pool swell
   - Other potential debris sources such as unqualified/indeterminate coatings.

   Each of these debris components are addressed separately.

Fibrous Transient Debris

Two options are offered for establishing the value of the quantity of fibrous transient debris assumed to be present in the suppression pool. These options are:

a) Assume a bounding amount of fibrous debris consistent with FME/housekeeping controls. This approach is simple and conservative. The BWROG recommends that a bounding value be assumed to be present in the suppression pool. This bounding amount of debris should be adequate to address fibrous transient debris which may be present in the pool at the outset of a postulated LOCA.

Factors which should be considered when establishing a bounding value include:

- it was learned during the industry response to NRC Bulletin 95-02 that most plants found little or no fiber in the suppression pool.
- containment type. A plant with direct access to the suppression pool during normal operations (e.g., a Mark III containment design) may select a higher bounding value to account for debris introduction over time than would a plant where there is no readily available path to introduce additional fibrous debris to the pool during normal power operations (e.g., a Mark I or II containment design)
- the rigor of FME controls during both normal operation and outages
- although all the fibrous transient debris may not be of the same species of material, the head loss caused by the bounding amount of debris assumed to be present should be sufficiently conservative to

account for variations in the head loss that might be caused by different fiber combinations

- assume an additional quantity of fibrous debris to provide margin. Such margin could be used if some debris source remained unaccounted for prior to a plant restart (e.g., a dropped rag). The margin could then be used to evaluate the safety significance of the missing material.

OR

b) Measure the amount of fibrous debris in the pool volume. This option is more burdensome but will produce a plant specific value of fibrous transient debris. Licensees should ensure that the methodology for measuring the amount of debris includes agitating the suppression pool volume so that it is well mixed and that the resulting samples accurately represent the quantity of debris in the pool. One method of ensuring this is to perform simultaneous operation of two or more systems which are aligned to recirculate the suppression pool for two or three pool turnover times.

Licensees electing to use the measurement option (instead of assuming a bounding amount) to determine the quantity of fibrous debris should do so initially to establish a baseline value. If this quantification was previously performed as a part of the Bulletin 95-02 response, those results may be used.

If at any time the sum of the measured value of debris, when added to the quantity of debris assumed from pool swell, results in a higher strainer differential pressure than the value assumed in the respective NPSH calculation, the licensee must evaluate the operability of the ECCS system and take actions as required by the operating license.

Other Transient Debris

a) Heavy suppression pool debris does not have to be considered in the evaluation of strainer blockage. However, licensees should have controls in place to remove/minimize this type of debris in the suppression pool.
b) Suppression pool debris that will float does not have to be considered in the evaluation of strainer blockage. However, licensees should have controls in place to remove/minimize this type of debris in the suppression pool. Care should be taken in evaluating whether a given material will float to be sure that the effects of aging, irradiation, exposure to a LOCA environment and jet forces, etc. do not substantively change the pre-LOCA floatation characteristics of the material.

Dirt/Dust Above the Pool Area

Licensees should include the quantity of dirt/dust which may be washed into the suppression pool as a result of LOCA induced pool swell in the overall debris source term used in sizing strainers. See Section 3.2.2.2.1 for guidance on addressing this debris source term.

Other Potential Debris Sources

Licensees should identify potential sources of debris which may result from LOCA conditions within the wetwell (e.g., corrosion products on unpainted steel surfaces or unqualified paint which could be entrained in the pool volume as a result of the LOCA). Should LOCA-generated debris sources within the wetwell be identified, the additional quantity of the debris should be considered when evaluating the acceptability of a given strainer size. Alternatively, these potential debris sources may be removed, the coating qualified (e.g., via in-situ test) or replaced with

qualified coatings. Section 3.2.2.2.2 provides guidance for addressing the rust on unpainted steel surfaces.

3. Licensees should establish FME/housekeeping program controls and a suppression pool cleaning frequency that are adequate to control the quantity of transient debris and suppression pool sludge, when combined with LOCA-generated debris, to less than the values used in the strainer sizing calculations.

4. The information contained in References 1, 18, 19, 20, 34 and 35, and licensee actions/commitments in response to these NRC Information Notices and Bulletins, should be carefully considered when establishing a plant specific baseline value of suppression pool debris. Licensees should review commitments made in response to NRC Bulletins 93-02 and 95-02, when establishing FME and housekeeping controls and, if appropriate, revise prior commitments for consistency with the resolution of the LOCA-generated debris blockage of the ECCS pump suction strainers.

3.2.4.3 Suppression Pool Sludge

Particulate material is typically present in US BWR suppression pools. Commonly termed "suppression pool sludge" or just "sludge" it consists mostly of rust particles from carbon steel. Because carbon steel piping is widely used in US BWR systems which connect with the suppression pool, US BWRs are expected have more suppression pool sludge than non-GE designed foreign BWRs which make greater use of stainless steel piping.

3.2.4.3.1 Sludge Particle Size Distribution

The size of the sludge particles, when combined with fibrous debris, will affect the strainer head loss. To determine an expected size distribution of sludge particles, a survey of domestic BWRs was conducted. Initially, data was collected from five plants. The survey results for these five plants were provided to the NRC (Reference 8). The survey results for the first five plants are summarized in Table 7:

BWROG Size Distribution of Suppression Pool Sludge		
Particle Size (μm)	Average Size (μm)	% by Number of Particles
0 - 5	2.5	81%
5 - 10	7.5	14%
10 - 75	42.5	5%

Table 7 - BWROG Size Distribution of Suppression Pool Sludge (5 plants)

The NRC staff used the sludge particle size distribution from Table 7 for head loss calculations reported in NUREG/CR-6224 (Reference 22).

Sludge particle size distribution information was subsequently compiled by the BWROG for an additional nine plants (Reference 9). The updated results for all fourteen plants are shown in

Table 8. The survey included Mark I, II, and III containment types as well as a mix of various plant vintages.

BWROG Size Distribution of Suppression Pool Sludge		
Particle Size (μm)	Average Size (μm)	% by Number of Particles
0 - 5	2.5	83%
5 - 10	7.5	11%
10 - 75	42.5	6%

Table 8 - BWROG Size Distribution of Suppression Pool Sludge (14 plants)

As can be seen from the result, the data points from the additional nine plants did not result in any substantive change in the average sludge particle size distribution. It is apparent that sludge particle size distribution is consistent between plants without regard to containment type or plant age. Because of this consistency in particle size distribution between plants, the particle size distribution shown in Table 8 - BWROG Size Distribution of Suppression Pool Sludge (14 plants) should be used by US BWRs when analyzing strainer head loss. A plant specific determination of sludge particle size distribution is not required. This data was used by the BWROG for the testing and development of head loss correlation's provided in Reference 3.

3.2.4.3.2 SLUDGE GENERATION

The rate at which sludge is generated is another factor that needs to be considered when evaluating strainer head loss. Absent the capability to clean the suppression pool during normal operations, the quantity of sludge expected to be present in the suppression pool should be the amount initially in the pool plus the amount that will be added to the pool prior to the next time the sludge is removed from the pool. Some plants have the ability to align systems to draw suppression pool water through a cleanup system which is effective at removing some of the particulate material from the suppression pool water. Other plants use a feed-and-bleed approach to reduce particulates while adding clean water to the pool. Licensees which use a cleanup

capability (including feed-and-bleed) which reduces the particulates in the suppression pool volume may credit such capability when determining the maximum amount of suppression pool sludge, provided:

1. adequate documentation of the effectiveness of the cleanup capability in removing sludge particles is available; and
2. the clean up capability is maintained and operated such that the cleanup effectiveness is equal to or better than the effectiveness assumed in the determination of the maximum sludge quantity; and
3. cleaning of the suppression pool is conducted on a frequency that ensures that the maximum quantity of suppression pool sludge used in strainer head loss calculations is not exceeded.

Each licensee should establish a sludge generation rate to be used in evaluating the ECCS suction strainers. Because establishment of the rate at which sludge is generated requires measurement over a period of time, licensees should assume an initial sludge generation rate for use in evaluation of suction strainers until a plant specific value has been established.

When using an assumed sludge generation rate, licensees should select a value that is sufficiently conservative to bound the actual sludge generation rate expected. As a point of reference, a 1995 BWROG survey was conducted to conservatively determine the sludge generation rate at various plants. The survey results included 12 BWR units of various ages and included Mark I, II, and III containment types. The median sludge generation rate at the surveyed plants was about 88 lbm. per year (dry weight) of sludge (Reference 10)[8]. The BWROG suggests licensees consider a value of 150 lbm. per year (dry weight) to be used for the assumed sludge generation rate. This value is more than 1.5 times the median sludge generation rate and is expected to adequately bound the plant specific value for sludge generation when established. However, licensees should review available data on their plant specific conditions and make a determination as to whether

[8] A few plants reported values that exceed 150 lbm per year but, because of the sampling techniques employed, the BWROG believes that these higher values are not representative and overstate the actual sludge generation rate.

the suggested 150 lbm. per year generation rate is sufficiently conservative for their plant. Each licensee should select an assumed sludge generation rate that they are confident will adequately bound the measured generation rate when it is determined.

It is recommended that a plant specific sludge generation rate be established within 90 days of the completion of the second refueling outage occurring after January 1, 1997. The 90 days after the second refueling outage should allow sufficient time for analysis of sludge samples taken during the outage. Licensees should consider adding some margin above the actual generation rate to account for uncertainties in the generation rate which may arise from operational transients (e.g., an SRV lifting which introduces additional corrosion products from scale inside the SRV line), variations in sampling techniques and equipment, and other factors which could affect the sludge generation rate.

Some plants may elect to install strainers which are capable of collecting a large quantity of debris and corrosion products while still providing adequate ECCS pump NPSH. Therefore, an alternative to establishing a plant specific sludge generation rate is provided which provides flexibility to the licensee while also assuring adequate ECCS pump NPSH. In lieu of establishing a plant specific sludge generation rate, licensees may assume a sludge generation rate of 300 lbm per year as an input to the strainer head loss evaluation and then determine the number of operating cycles before the strainer head loss would reach a point that adequate ECCS pump NPSH is no longer assured. A licensee using such an approach is required to take those actions necessary (e.g., remove sludge from the suppression pool) to assure adequate NPSH prior to reaching the point in time at which the post-LOCA head loss across the strainer under the most limiting design basis conditions causes the predicted ECCS pump NPSH available to fall below the value required.

3.2.4.3.3 SLUDGE MEASUREMENT CONSIDERATIONS

The following information on sludge measurement to quantify pool sludge amounts is included for consideration. The information outlined below does not preclude the use of alternate approaches or techniques which would also produce an accurate measurement of suppression pool sludge.

Prior to measuring the quantity of sludge on the pool bottom, the pool should be calm (i.e., no energy being added due to recirculation/pool cooling) for a sufficient period of time to allow any sludge that may have been stirred into suspension to settle on the pool floor. This will assure that samples taken from the pool floor are representative of the total sludge quantity.

One method of measuring the sludge on the pool bottom is through cleaning of a representative portion of the suppression pool and measuring the quantity of sludge collected. This same area of the pool can be cleaned again during a subsequent outage, the quantity of sludge measured, and an overall sludge generation rate determined. It is not required that the entire pool be cleaned in order to determine the sludge generation rate. The following issues should be considered when measuring sludge on the pool bottom.

- It is not expected that sludge will be uniformly distributed in the pool. Since one source of the sludge is from carbon steel piping systems connected to the pool there may be a heavier concentration of sludge near the connection points to piping systems. Flow patterns in the pool may also affect the amount of sludge which accumulates in a particular bay or area. Because of this non-uniform sludge distribution, an inspection of the pool should be conducted prior to selecting measurement locations so that the areas with the heavier and lesser concentrations of sludge are identified. The size and location(s) of areas to be measured should be selected in a manner that results in a determination of a sludge generation rate that is representative of the pool as a whole, or more conservative.

- Sludge measurements from the pool floor may be obtained by a variety of methods. The licensee should assure that, regardless of the method used, it is sufficient to accurately determine the overall sludge generation rate. The BWROG recommends the following approach:
  - ⇒ Assure the pool has been calm for a period of time sufficient to allow any sludge entrained in the pool volume to settle to the bottom.
  - ⇒ Use divers in the pool directing pump suction hoses in the areas of the pool selected for measurement. Use pumps to pump water and debris from the pool floor through a filter media to collect the sludge. Move the suction hose or nozzle slowly to avoid disturbing the settled debris. Ensure the flow rate is sufficient to suspend and transport the debris from the pool floor to the container. Take care not to disturb the settled debris.

- Collect the sludge from a representative known size area of the pool bottom. Determine the air dried weight per unit area and multiply by the ratio of total floor area to measured area to determine total weight of dry sludge on the pool floor.

- A general approach for determining the dry weight of sludge is to first pre-soak clean filters in water, allow them to drip dry, and then weigh the filter. After the sludge is collected, the filter should be allowed to drip dry and then weighed. Due to the wet debris collected in the filter, it will take longer to drip dry than was required for the clean filter. At this point a portion of the sludge should be removed from the filter, weighed, allowed to air dry in a laboratory dish and then weighed again. This process should be repeated until a consistent weight is obtained. The weight of wet sludge in the filter should then be multiplied by the ratio of the weight of dried to wet sludge from the sample to determine the overall dry weight of sludge in the filter. As an alternative to measuring the air dried weight, use the conservative wet to dry weight correlation developed by the BWROG (Reference 10). The maximum percent solids

measured was 38.5%. To conservatively estimate the dry weight multiply the wet weight by 0.385.

- Care should be taken to follow the same methodology for sludge measurement between the initial and subsequent measurements so that variations in measurement techniques do not affect the calculated sludge generation rate.

- If a pool cleanup system (or feed and bleed) has been employed between the initial and subsequent sludge measurements, the amount of sludge removed by these methods should be accounted for in the determination of the quantity of sludge expected in the suppression pool.

3.2.4.3.4 BWROG GUIDANCE

1. Use the sludge particle size distribution from Table 8 - BWROG Size Distribution of Suppression Pool Sludge (14 plants) for evaluation of strainer head loss. A plant specific determination of sludge particle size distribution is not required. This also allows use of BWROG head loss correlations provided in Reference 3.
2. The quantity of pool sludge used in head loss calculations should be based on air dried weight in order to use the head loss correlation developed by the BWROG. A conservative alternative to measuring the air dried weight is to multiply the wet weight of the sludge by 0.385.
3. Licensees should determine their plant specific sludge generation rate within 90 days of the completion of the second refueling outage which starts after January 1, 1997. Until a sludge generation rate has been established, a licensee should assume a generation rate that is expected to conservatively bound the final sludge generation rate.
4. In lieu of establishing a plant specific sludge generation rate, licensees may assume a sludge generation rate of 300 lbm per year as an input to the strainer head loss evaluation and then determine the number of operating cycles before the strainer head loss would reach a point that adequate ECCS pump NPSH is no longer assured. A licensee using such an approach is

required to take those actions necessary (e.g., remove sludge from the suppression pool) to assure adequate NPSH prior to reaching the point in time at which the post-LOCA head loss across the strainer under the most limiting design basis conditions causes the predicted ECCS pump NPSH available to fall below the value required.

3.2.5 Suppression Pool Transport and Settling

3.2.5.1 Introduction

Suppression pool transport is an assessment of how much debris in the suppression pool is transported to the suction strainers. The debris which is available for transport includes debris which is present in the suppression pool prior to the postulated LOCA (e.g., sludge, transient debris, etc.); and debris which is transported into the suppression pool as a result of a LOCA. The transport assessment considers debris suspension from the pool bottom as well as settling to the pool bottom. These two phenomena are a function of the pool kinetic energy levels. While high, pool energy levels tend to suspend materials; lower energy levels allow material to settle. In evaluating material settling and suspension, the physical characteristics of the materials and the plant-specific, pool dynamic response are used.

Testing reported in Appendix B (Section B.6) and Appendix E of NUREG/CR-6224 (Reference 22) along with NUREG/CR-6368 (Reference 13) provides evidence that:

- NUKON™ insulation debris in the pool will break up into small fibers and clumps during the high energy phase of a postulated LOCA event due to the influence of shear forces induced by eddies created by chugging
- no settling of sludge, fibrous insulation debris, or other light material will occur during the high energy phase of the event
- the sludge existing on the bottom of the pool will be resuspended during the high energy phase of a postulated LOCA event
- the flow velocity existing in a pool after the high energy phase of the event will influence the settling rate of the material of interest. This is a plant specific factor which must be addressed in order to determine the actual settling rate

This information suggests that for most plants there will be sufficient kinetic energy in the suppression pool after the high energy phase of the LOCA to minimize or prevent the settling of fibrous insulation, sludge and other light materials.

It should be noted that the testing documented in NUREG/CR-6224 and NUREG-6368 was performed using a test setup similar to a Mark I containment type. Due to differences in configuration, it may be possible to show that, on a plant specific or containment specific basis (e.g., Mark III), debris may not be lifted from the pool bottom during a blowdown event and/or that some localized settling may occur due to flow distributions within the pool. Because of the plant specific nature of whether lifting of debris from the pool bottom would or would not occur, the BWROG has not investigated this issue further.

In order to take credit for settling it is necessary to determine the plant-specific post-LOCA flow velocities which would be present in the suppression pool and then determine the rate at which debris, sludge, and other materials which may be present in the pool post-LOCA will settle under the expected conditions.

A simplified approach for many plants will be to assume no credit for settling of fibrous debris, sludge and other light materials. This avoids the expenditure of resources necessary to analyze pool conditions. The BWROG recommends this approach for light debris species.

RMI debris that reaches the suppression pool is more likely to settle but the plant specific pool velocities should be considered before crediting settling of RMI debris.

Those plants who determine that credit for suppression pool settling may be of significant benefit to them have the option of analyzing plant-specific pool conditions to determine the actual amount of settling which will occur. However, because of the calculational complexity and associated uncertainties with this approach, the BWROG recommends that licensees considering such an approach discuss it in detail with the NRC prior to adoption. Because this is not an

approach recommended by the BWROG, no effort has been made by the BWROG to determine an acceptable calculational methodology.

3.2.5.2 BWROG Guidance

For the analysis of the debris transport within the suppression pool, the following guidance is provided:

1. No credit should be taken for the settling of fibrous debris, sludge, and other light material during the high energy phase (i.e., blowdown, chugging, or condensation oscillations) of a large or medium (i.e., intermediate) break LOCA. The duration of the high energy phases is plant specific but for a large break LOCA is on the order of a few minutes and for a medium break LOCA is on the order of 10 to 30 minutes.

2. Due to the violent agitation of the suppression pool during a LOCA, fibrous insulation pieces within the suppression pool are expected to break down into small insulation fibers and clumps which are readily transportable (i.e., do not settle easily) at low flow velocities. As a result of the large or medium LOCA high energy phases, turbulence in the suppression pool will remain above the settling velocity of the fibers for a considerable length of time. A conservative assumption which simplifies the evaluation of suppression pool transport and resulting strainer head loss is to assume that suppression pool cooling (or other modes of operations which would cause recirculation within the suppression pool) precludes the settling of fibrous debris in the suppression pool, and all of the fibrous debris which reaches the pool is available for transport to the suction strainers.

   Alternatively, if credit for settling of fibrous debris is desired, it will be necessary to establish the expected flow velocities and turbulence levels in the pool subsequent to the high energy phase of the postulated LOCA. In addition to the energy added as a result of suppression pool cooling (or other modes of operation), the energy added to the pool as a result of break leakage flow or containment spray flow should be considered when determining the expected

pool flow velocities. Note that the amount of energy added to the pool may vary between plants due to differences in containment type and plant specific design features. Once the expected pool flow velocity has been established, an evaluation should be completed to determine the expected time-to-settle of debris for the flow conditions anticipated. For debris which has settled after the high energy phase of the event, consideration should be given to whether the energies added to the pool as a result of recirculation/suppression pool cooling are sufficient to resuspend the debris and allow it to be transported to the strainers.

Appendix B (Section B.6) and Appendix E of NUREG/CR-6224 (Reference 22) along with NUREG/CR-6368 (Reference 13) provide relevant information on the settling velocity of NUKON™ fibers in a calm suppression pool. This information, in conjunction with a plant specific pool turbulence evaluation, may be used to determine the settling rate for NUKON™ fibers.

3. All sludge present in the pool at the start of a large or medium break LOCA event is resuspended into a homogenous mixture with the water volume in the pool during the high-energy phase of the event. A conservative assumption which simplifies the evaluation of suppression pool transport and resulting strainer head loss is to assume that suppression pool cooling (or other modes of operations which would cause recirculation within the suppression pool), precludes sludge in the suppression pool from settling, and it is all available for transport to the suction strainers.

Alternatively, if credit for settling of sludge is desired, it will be necessary to establish the expected flow velocities in the pool subsequent to the high energy phase of the postulated LOCA. In addition to the energy added as a result of suppression pool cooling (or other modes of operation), the energy added to the pool as a result of break leakage flow or containment spray flow should be considered when determining the expected pool flow velocities. Note that the amount of energy added to the pool may vary between plants due to differences in containment type and plant specific design features. Once the expected pool flow velocity has been established, an evaluation should be completed to determine the

expected time-to-settle of sludge in the flow conditions anticipated. For sludge which has settled after the high energy phase of the event, consideration should be given to whether the energies added to the pool as a result of recirculation/suppression pool cooling are sufficient to resuspend the sludge and allow it to be transported to the strainers.

Appendix B (Section B.6) and Appendix E of NUREG/CR-6224 (Reference 22) along with NUREG/CR-6368 (Reference 13) provide relevant information on the settling velocity of simulated BWR sludge in a calm suppression pool. This information, in conjunction with a plant specific pool turbulence evaluation, may be used to determine the settling rate for sludge.

4. Other relatively light debris which may have been present in the pool prior to the event, or transported to the pool as a result of the postulated LOCA event, also has the potential to be suspended during the high energy phase of the event. A conservative assumption which simplifies the evaluation of suppression pool transport is to assume that any relatively light debris existing in the pool prior to the event will be resuspended during the high energy phase of the event. Additionally, suppression pool cooling (or other modes of operations which would cause recirculation within the suppression pool), precludes other relatively light debris in the suppression pool from settling and, unless it floats, it is all available for transport to the suction strainers.

Alternatively, if credit for settling of other light debris or credit for pre-existing debris not being picked up and resuspended from the pool bottom is desired, it will be necessary to establish the expected flow velocities and flow profiles in the pool during and subsequent to the high energy phase of the postulated LOCA. In addition to the energy added as a result of suppression pool cooling (or other modes of operation), the energy added to the pool as a result of blowdown, break leakage flow or containment spray flow should be considered when determining the expected pool flow velocities. Note that the amount of energy added to the pool may vary between plants due to differences in containment type and plant specific design features. Once the expected pool flow velocity has been established, an evaluation should be

completed to determine the expected time-to-settle or potential for resuspension of previously settled debris in the flow conditions anticipated. For debris which has settled after the high energy phase of the event, consideration should be given to whether the energies added to the pool as a result of recirculation/suppression pool cooling are sufficient to resuspended this debris and allow it to be transported to the strainers.

It will be necessary to establish the baseline settling rate information for the other debris of interest. The debris settling rate for the postulated debris should be validated analytically or experimentally. Once established, this settling rate information, in conjunction with a plant specific pool turbulence evaluation, may be used to determine the settling rate for other debris.

5. If credit is to be taken for settling, the evaluation of expected pool flow velocities should consider the flow conditions in the suppression pool assuming operations both with and without a single failure condition.

6. If certain system alignments/modes of operation are required in order for suppression pool flow velocities to be low enough that settling will occur, appropriate procedures should be in place and operators trained such that the systems will be operated in the expected alignment/mode during the event if credit is to be taken for settling.

3.2.6 Verification of Adequate ECCS Pump NPSH

3.2.6.1 Introduction

The aforementioned various factors affecting ECCS pump NPSH must be integrated to determine if adequate NPSH is available for the ECCS pumps. Adequate NPSH means the NPSH available to the pumps meets or exceeds the NPSH required by the applicable pump curves for each of the ECCS pumps throughout the LOCA event and for post-accident long-term cooling as required by the plant licensing basis.

If adequate NPSH is available to the ECCS pump being evaluated then the particular strainer assumed in the calculation will be acceptable, providing other design requirements not related to NPSH are also satisfied.

If adequate NPSH is not available, there are several alternatives to consider which may result in a passive strainer being acceptable. These alternatives include:

- refinement of the analysis conducted to determine the various debris source terms. If bounding assumptions were initially used it may be worthwhile to perform a more rigorous analysis which would result in a lower source term for one or more of the debris species
- re-calculation of the NPSH available assuming a passive strainer with increased capacity i.e., less head loss. The increased capacity may be obtained by use of a larger strainer of the same design or through consideration of a strainer of different design which has improved debris handling capacity
- take physical steps to reduce the debris source term. This may be accomplished through various actions or combination of actions such as:
  - ⇒ reduction/removal of debris sources other than pipe insulation

⇒ removal of pipe insulation where it is not needed

⇒ installation or modification of jacketing on pipe insulation

⇒ improved means of attaching insulation to pipe, e.g., improved latches/banding

⇒ replacement of existing pipe insulation with a different insulation which produces less LOCA-generated debris or lower head loss. This might be through installation of insulation of improved design from the same vendor or from a different vendor

⇒ elimination of unqualified/indeterminate coatings either through removal or qualification

⇒ increased frequency of suppression pool cleaning

⇒ implementation of more restrictive FME and housekeeping controls

- licensing/design basis changes which can result in increases in the calculated NPSH available to the ECCS pumps. This might include adoption of realistic post-accident suppression pool temperatures instead of an assumption of 212°F. Another change to consider would be to allow use of improved analysis techniques for determination of piping loads which result in increased load margins on ECCS piping penetrations. This would allow use of a larger strainer with increased debris handling capacity.

Licensees are not limited to only these alternatives. However, it is expected that one or a combination of the above alternatives will result in identification of a passive strainer design that results in a head loss which provides adequate NPSH to the ECCS pumps. Note that installation of a larger strainer which would result in loads beyond those considered in the existing containment analysis, and therefore require re-evaluation of the containment analysis, is not recommended.

3.2.6.2 Discussion

The calculation of the NPSH available to the ECCS pumps typically includes consideration of the head loss across the strainer, head loss in the piping to the pumps, the static head available to the pump for the plant specific configuration, the expected fluid temperature of the pumped fluid,

pump flow rates, and, for some plants, the containment pressure post-LOCA. All of these factors affect the inlet conditions at the pump suction. Licensees should use a methodology for calculation of available NPSH which is consistent with the plant licensing basis. For many plants this will be the methodology provided in Section 3.2.3 of NUREG-0897, Revision 1 (Reference 26).

The general approach for performing this calculation includes the following:

- Review of the current licensing basis as it relates to analysis of ECCS pump NPSH. Specifically, identify licensing basis requirements related to (1) the methodology used to analyze NPSH, (2) the expected range of fluid temperatures, (3) containment pressure, and (4) pump flow rates required to satisfy design basis requirements.
- Determine the limiting single failure assumption(s) based on plant-specific design and licensing basis requirements. Depending on the plant specific design and licensing basis it may be necessary to consider both low pressure and high pressure ECCS systems.
- For each strainer, determine the specific licensing basis LOCA scenario which will result in the maximum strainer debris loading.
- Determine the limiting debris loading for each ECCS strainer following the guidance contained in Section 3.2.6.2.2.
- Calculate the strainer head loss following the guidance contained in Section 3.2.6.2.3
- Combine the strainer head loss with other factors affecting pump NPSH, including those discussed in Sections 3.2.6.2.4 and 3.2.6.2.5, to determine whether the performance characteristics of the passive strainer being evaluated are sufficient to deliver adequate NPSH to the ECCS pump being evaluated. Section 3.2.6.3 provides guidance on performance of this calculation.

Figure 2 through Figure 4 depict the evaluation process and refer the user to the applicable sections of this document for detailed guidance. These Figures also provide reference to the corresponding sections of Regulatory Guide 1.82, Rev. 2 (Reference 2).

The following items should be considered in the NPSH evaluation, as appropriate, and may aid in the performance of the evaluation.

- Review the ECCS pump performance curves for each pump taking suction through a strainer in the suppression pool. Identify the NPSH required by these pumps for the design basis flow rates. Note that there may be variations between pump curves provided by the vendor which are specific to the pumps supplied and the more generic pump curves which may be found in other plant documents. The licensee should take care to ensure the pump curves used are those which are included in the plant licensing basis. If appropriate, a change to the plant licensing basis may be initiated so that the most accurate pump curves are employed.
- Determine suppression pool heatup transients following a LOCA.
- Determine the earliest time post accident that drywell sprays could be utilized, if applicable. Determine at what minimum pressure the drywell sprays would be secured. Determine if the suppression pool-to-drywell vacuum breakers open during these transients. Determine at which point in time ECCS flows may be reduced or pumps secured. Develop timelines depicting the above data (include temperature, pressure, and flow rate).

3.2.6.2.1 Determination of Limiting Single Failure Assumptions

An analysis should be performed to determine the assumed single failure which will result in the greatest accumulation of debris onto each strainer being analyzed. This analysis should be performed separately for each strainer, and should consider the entire range of LOCA events for which flow is required through the strainer being evaluated. Plant specific design features should also be considered. Depending on the plant specific design and licensing bases, it may be necessary to evaluate strainer blockage of high pressure ECCS systems.

For example, loss of one electrical division may be the most limiting single failure for many scenarios, as it results in loss of one train of ECCS, resulting in the accumulation of all debris on strainers associated with the functional train. However, this may not be the limiting single failure in plants with a ring header ECCS suction configuration. In this type of plant, loss of one train of ECCS reduces flow through all the ECCS suction strainers, and significantly reduces suction strainer head losses.

3.2.6.2.2 TOTAL STRAINER DEBRIS LOADING

Previously, the regulatory requirements for determination of the ECCS pump NPSH available typically required licensees to assume that 50% of the strainer surface area was blocked. This is no longer required. Instead, calculation of available NPSH is done assuming no head loss from operational debris on the strainer but considers the effect of the plant-specific debris source terms and sludge/corrosion product combinations which are predicted to collect on the strainer following a postulated LOCA. The head loss which may be attributed to operational debris potentially present on the strainer at the start of a LOCA event is accounted for in the total strainer debris loading.

Note that this will likely result in a change to the current licensing basis as it relates to determination of adequate ECCS pump NPSH.

The total debris loading for each strainer is determined by assuming that the debris present in the suppression pool is accumulated on the functioning ECCS strainers in amounts proportional to the flow rate through each strainer.

The total strainer debris loading is comprised of the debris sources terms for each of the debris species present. Use the guidance from the sections identified below to determine the quantity of each of the debris species assumed to be present in the suppression pool. Note that multiple species of debris may be present (e.g., both fibrous and RMI piping insulation) and the source term for each species should be established.

Debris Source Term	BWROG Guidance
Drywell Piping Insulation Debris[2,3]	3.2.3.2
Drywell Non-Insulation Debris[1, 2]	3.2.2.2.3
Latent Drywell Debris Sources[1, 2]	3.2.2.3.3
Suppression Pool Debris Sources[2] (other than sludge)	3.2.4.2.2
Suppression Pool Sludge[2]	3.2.4.3.4

Table 9 - Guidance for Determination of Debris Source Terms

Table 9 Notes:

1. The source term(s) for debris originating in the drywell may be reduced by application of the applicable drywell-to-wetwell transport factor in accordance with the guidance contained in Section 3.2.3.3.
2. The source term(s) for debris in the suppression pool, including those originating in the drywell, may be reduced by crediting settling in the suppression pool in accordance with the guidance contained in Section 3.2.5.2.
3. For RMI, a strainer head loss evaluation which assumes a saturation thickness of RMI debris on the strainer may be used to simplify the analysis. In this case, evaluation of RMI debris generation and transport is not required since the maximum quantity of RMI debris a strainer can retain is assumed. Appendix B of Reference 3 provides guidance on determination of the saturation thickness of an RMI debris bed.

3.2.6.2.3 Strainer Head Loss Calculations

Once the limiting quantity of debris present on each strainer has been established, the head loss across a strainer may be determined. To determine the head loss for a strainer of a given size and design follow the methodology and calculational procedures contained in Reference 3, Appendices A and B, as applicable. Use the debris source terms determined from the previous section as input to these calculations.

Care should be taken to assure that the head loss correlations provided in Reference 3 for the debris of interest are applicable to the strainer design under evaluation. Reference 3 describes the basis on which the head loss correlations were developed and their applicable requirements. If the head loss correlations provided in Reference 3 are not applicable to the strainer under evaluation, those correlations which are applicable to that strainer should be used and their basis appropriately justified.

Appendix A

Appendix A of Reference 3 provides guidance on determination of strainer head loss from fibrous debris in combination with sludge and other particulate debris. Even those plants where 100% of the installed drywell piping insulation is RMI are expected to have some quantity of transient fiber present in the suppression pool post-LOCA (see Section 3.2.2.2.1). Therefore, a calculation of the strainer head loss following the method provided in Appendix A of Reference 3 should be conducted for every BWR plant. Note that the Appendix A non-dimensional head loss curves are valid for fiber loadings up to a thickness to diameter ratio of 0.15 which is the maximum test conditions. This is equal to a thickness of 6 inches for the 40 inch diameter by 4 foot stacked disk strainer tested; and for Nukon® insulation this corresponds to a fiber volume of 20.9 cubic feet (50 lbm.). For strainer sizes larger than those tested, keeping the fiber thickness to diameter ratio less than 0.15 assures applicability of the existing non-dimensional head loss correlations. For higher fiber loadings, strainer specific testing may be required.

One of the early findings of the BWROG program to resolve the strainer blockage issue is that for certain strainer designs (i.e., flat plate strainers typical of those currently installed at many BWRs), the calculated strainer head loss results in a "bathtub curve" for different amounts of debris in combination with a given amount of sludge/corrosion products. Strainer head loss is high for the maximum fibrous debris expected when combined with available sludge/corrosion products. Strainer head loss is also high for a minimum amount of fiber (enough to cover a strainer to a depth of about 1/8") when combined with the

same sludge/corrosion product combination. Intermediate amounts of fibrous insulation result in lower head loss than either extreme. This phenomena is consistent with the strainer blockage event at the Perry plant as discussed in NRC Bulletin 93-02 (Reference 18). Note that this thin-be effect may not be applicable to strainers with low approach velocities such as a strainer with a large surface area.

Testing conducted by the BWROG (Reference 3) shows that for alternate geometry strainers (e.g., star and stacked disc strainers which are not typical of cylindrical strainers currently installed in US BWRs)) the higher head loss with a thin bed of fiber does not occur. The reason this "thin bed" effect does not occur on strainers of alternate geometry is discussed in Appendix I of Reference 3. Consequently, when evaluating the strainer head loss using the methodology from Appendix A of Reference 3 for a strainer of alternate geometry, the evaluation requires consideration of only the maximum quantity of fibrous debris available for deposition on the strainer. Conversely, if a strainer of flat plate design such as an existing truncated cone strainer is being evaluated, the determination of the strainer head loss should consider both the maximum fibrous debris source term and a fibrous debris source term which would result in a uniform coating of the strainer flow area to a depth of 1/8 inch. The calculation resulting in the higher strainer head loss should be used in the calculation of ECCS pumps NPSH.

Appendix B

Appendix B of Reference 3 provides guidance on determination of strainer head loss from RMI debris. Licensees with RMI installed in the drywell within the zone of influence for pipe breaks of interest will also need to calculate the strainer head loss resulting from RMI debris. If RMI foil materials other than those characterized in Appendix B are employed, the available data may be extrapolated for the material of interest. For example, for 1.0 mil aluminum the data for 1.5 mil and 6.0 mil aluminum is used to estimate the appropriate K factor [K for 6.0 mil = 1.3, K for 1.5 mil = 5.9, K for 1.0 mil extrapolated = 6.4].

The higher of the strainer head loss determined in accordance with Appendices A and B of Reference 3, as applicable, should be used as input to the determination of ECCS pump NPSH as described in the next section.

There may be instances where a plant expects one or more species of debris in the suppression pool (and available for deposition on the strainers post-LOCA) for which the data necessary to determine the actual head loss from that debris species is not available. In these instances, an estimated adjustment to the calculated strainer head loss should be made to account for the increased head loss from these debris species. The basis for the adjustment should be included in the documentation supporting the strainer head loss calculation.

3.2.6.2.4 Crediting Containment Pressure in NPSH Calculations

The current licensing basis relative to consideration of containment pressure in the calculation of NPSH margin should be reviewed. In some cases, older Mark I containment plants are not committed to meeting Regulatory Guide 1.1 (Reference 27), which does not allow credit for containment pressure, and (depending on their specific licensing basis) may be allowed to credit containment pressure in calculating NPSH margin.

The reasoning provided in Regulatory Guide 1.1 for not crediting containment pressure is that a lower than expected pressure (resulting from impaired containment integrity or containment heat removal at too high a rate) could affect the ability of ECCS to perform its safety functions. It has also been noted that containment pressure will be reduced over the relatively long period of interest. In addition, the deliberate continuation of a high containment pressure to maintain an adequate NPSH may result in greater leakage of fission products from containment and higher potential offsite doses (but still within licensing limits).

For some of the older BWRs with a licensing basis which does allow credit for containment pressure in NPSH determination, current design basis calculations may show that containment pressure need not be credited in order to demonstrate adequate NPSH margin given the

assumptions made regarding strainer loadings. This does not necessarily mean that containment pressure cannot be credited in the revised analysis performed as part of the resolution of the current concern with ECCS suction strainer performance. This is because design basis calculations may include assumptions which are conservative relative to the actual licensing basis commitment. Plants should carefully review their licensing bases to determine if they may credit containment pressure when calculating NPSH margin.

The BWROG recommends that plants whose licensing basis allows credit for containment pressure should consider, if practicable, use of a strainer that results in acceptable ECCS pump NPSH without reliance on containment pressure. It is also recognized that, depending on various plant specific factors such as suppression pool layout, piping load issues, etc., such an approach may not be practicable and therefore is not required.

The BWROG recommends that plants with a current licensing basis which does not allow credit for containment pressure should not pursue a change to the licensing basis to allow such credit.

3.2.6.2.5 Effect of Temperature on NPSH

There are two aspects of temperature effects discussed here. The first is consideration of the maximum expected temperature of pumped fluids. The second aspect is the effect of fluid temperature on the head loss across a strainer debris bed.

Temperature of Pumped Fluid

Existing regulatory requirements typically dictate use of the maximum expected temperature of the pumped fluid when calculating available NPSH. The decay heat curves included in the plant licensing basis have a strong effect on the maximum expected fluid temperature at the inlet to the ECCS pumps. Licensees may consider a change to the plant licensing basis to utilize decay heat curves which are more realistic of the expected conditions post-LOCA. Use of more realistic

decay heat curves should result in a lower predicted maximum suppression pool temperature with a corresponding increase in available NPSH.

The maximum fluid temperature may be calculated using industry accepted analytical tools such as Contempt, GOTHIC, Contain, etc. The models evaluated using any of these tools should employ initial containment conditions which are bounding for peak pool temperature analysis. For example, the initial suppression pool level should be at the minimum Limiting Condition for Operation and the initial pool temperature should be at the maximum Limiting Condition for Operation. Consideration should be given to heat exchanger fouling as well as the heat sink (e.g., service water) temperature when performing the analysis.

Another issue that licensees may explicitly consider is the timing of the accident progression. In general, peak pool temperatures do not occur during the time frame when full flow is required from the ECCS pumps. It may be acceptable to evaluate NPSH at reduced ECCS flows during the period of peak temperature, reducing the head losses at the strainer and again increasing NPSH available. If the NPSH analysis credits reduced ECCS flow through the strainers in order to meet pump NPSH requirements, appropriate operating and emergency procedures should be in place and operator training conducted so there is assurance that the operators will reduce pump flow at the appropriate point in the accident progression.

Effect on Strainer Head Loss

In addition to affecting the suction pressure available at the pump inlet, the temperature of the pumped fluid also has a strong effect on the viscosity of water and, therefore, on the head loss across a debris bed formed on a strainer. Previous regulatory requirements typically did not address the effect of temperature on the head loss across the strainer.

The water vapor pressure at the inlet of the pump and the strainer head loss are both dependent on fluid temperature. However, these two factors act in opposition to each other in the overall calculation of pump NPSH. As the temperature increases the strainer head loss decreases and the

vapor pressure increases. Which of these dominate the NPSH available to the pump depends on the strainer head loss early in the LOCA event. Reference 31 provides an acceptable methodology for establishing the temperature at which the NPSH is at a minimum. This temperature should be used in the calculation of the NPSH available to the ECCS pumps.

For most plants, it is expected that the maximum expected fluid temperature will result in the lowest NPSH at the pump inlet. If this is not the case for a particular plant, this will likely result in a required change to the current licensing basis as it relates to determination of adequate NPSH for the ECCS pumps.

3.2.6.3 BWROG Guidance

The following guidance is provided for evaluation of ECCS pump NPSH.

1. Calculation of pump inlet conditions should follow the methodology described in Section 3.2.3 of NUREG-0897, Revision 1 (Reference 26) with the following exceptions:

    a) plants which have a licensing basis reviewed and approved by the NRC for calculation of ECCS pump NPSH which is different than the methodology provided in Section 3.2.3 of NUREG-0897, Revision 1 should maintain compliance with their existing licensing basis, except for (a) determination of head loss across the ECCS pump suction strainers, (b) the temperature of the pumped fluid used in the calculation, and (c) the head loss caused by debris not included in the calculation of strainer head loss. The guidance provided in sub items b) through d) which follow should be used to address the exceptions.

    b) determination of head loss across ECCS pump suction strainers should be in accordance with Section 3.2.6.2.3 of this document rather than Section 3.3 of NUREG-0897, Revision 1 (Reference 26). Care should be taken to assure that the head loss correlations provided in Reference 3 for the debris of interest are applicable

to the strainer design under evaluation. If the head loss correlations provided in Reference 3 are not applicable to the strainer under evaluation, those correlations which are applicable to that strainer should be used and their basis appropriately justified.

c) the methodology provided in Reference 31 should be used to determine the temperature of the pumped fluid used in the calculation of NPSH available to the ECCS pumps.

d) where the data necessary to calculate the head loss caused by a debris species in the suppression pool and available for deposition on the strainers post-LOCA is not available, an estimated adjustment to the calculated strainer head loss should be made to account for the increased head loss caused by the debris. The basis for the adjustment should be included in the documentation supporting the strainer head loss calculation.

2. No credit for containment pressures greater than atmospheric should be taken in determination of available ECCS pump NPSH unless such credit is in conformance with the existing plant licensing basis.

3. The range of expected temperatures of the pumped fluid should be considered when evaluating the NPSH available to the ECCS pumps. In making a determination of the range of expected fluid temperatures, the following should be considered:

a) the plant licensing basis may specify the maximum expected fluid temperature. If specified in the licensing basis, this value should be used unless the plant licensing basis is changed.

b) the maximum fluid temperature may be calculated using industry accepted analytical tools such as Contempt, GOTHIC, Contain, etc. The models evaluated using any of

these tools should employ initial containment conditions which are bounding for peak pool temperature analysis. For example, the initial suppression pool level should be at the minimum Limiting Condition for Operation and the initial pool temperature should be at the maximum Limiting Condition for Operation. Consideration should be given to heat exchanger fouling as well as the heat sink (e.g., service water) temperature.

c) realistic decay heat curves may be used to determine the range of expected fluid temperature. These curves can be used in the aforementioned analytical evaluations using industry accepted computer codes. Care should be taken to ensure that use of realistic decay heat curves is consistent with the plant licensing basis. If not, it will be necessary to change the plant licensing basis in order to use realistic decay heat curves

d) the NPSH analysis should consider the expected pool temperature at different points in the accident progression with the NPSH calculated for the flow conditions and temperature expected at that point in time. Note that the peak temperature in the suppression pool may not occur until later in the accident progression and at a point where full ECCS flow is no longer necessary to ensure adequate core cooling. If the flow rate is reduced the required pump NPSH is also reduced. If the NPSH analysis credits reduced ECCS flow through the strainers in order to meet pump NPSH requirements, appropriate operating and emergency procedures should be in place and operator training conducted so that operators will reduce pump flow at the appropriate point in the accident progression. Care should be taken to ensure that changes in ECCS flow rates are consistent with the inputs and assumptions used in the evaluation model required by 10CFR 50.46 to calculate the ECCS cooling performance.

4. For alternate geometry strainers (e.g., star and stacked disc strainers which are not flat plate designs), the calculation of NPSH should be performed with the maximum expected quantity of debris combined with the maximum expected amount of sludge. For strainers of flat plate design (e.g., truncated cone strainers typical of those currently installed), the calculation of NPSH should be performed with the maximum expected quantity of debris and maximum

sludge combination and for all lesser amounts of fibrous debris when combined with the expected amount of sludge to ensure consideration of potential "thin bed" effects on ECCS pump NPSH.

5. All strainers are assumed to be clean at the start of a postulated LOCA. It is not necessary to assume pre-existing blockage (e.g., 50% of the strainer surface is blocked).

6. For a strainer to be acceptable, the NPSH available at the pump inlet must be equal to or greater than the NPSH required by the design basis pump curves for each of the ECCS pumps throughout the LOCA event and for post-accident long-term cooling as required by the plant licensing basis. Licensees are encouraged to use strainers with performance characteristics that result in additional NPSH margin above the minimum required.

7. Verify that the expected range of flow rates through the strainer which yield acceptable NPSH are comparable with the inputs and assumptions used in the evaluation model required by 10CFR 50.46 to calculate the ECCS cooling performance. If necessary, update the ECCS cooling performance model to account for changes in the expected ECCS flow rate or revise the suction strainer design under review such that the ECCS model remains valid. Updates to the plant ECCS cooling performance model will likely require NRC approval.

8. Licensees may use alternate methodologies from those provided in the URG for any portion of the evaluation of ECCS pumps NPSH. The BWROG recommends that licensees obtain NRC review and approval of methodologies which are at variance with those provided herein prior to reliance upon their results in the sizing of passive strainers used to assure compliance with the requirements of 10 CFR 50.46.

9. This document primarily addresses the issues related to debris blockage of ECCS suction strainers since it is that issue that the Barsebäck, Perry and Limerick events have shown to be of concern. There are other important issues related to the design of suctions strainers (e.g., air ingestion, size of opening in the strainers, missile protection, etc.) that are not discussed

herein. Even though these issues are included in Regulatory Guide 1.82, Rev. 2, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," May 1996 (Reference 2), the current licensing and design bases related to these other issues is considered to be adequate and these other issues do not need to be re-evaluated for purposes of resolving the ECCS strainer blockage issue.

10. The determination of pipe break locations, zone of influence, destruction factors, and other calculational bases described herein are solely for ECCS strainer design purposes and are not intended to replace the plant licensing or design basis for other purposes.

3.3 Backflush

3.3.1 Introduction

Backflushing of strainers to remove debris accumulated on the strainers is a method which is potentially effective in ensuring the capability of the ECCS systems. However, significant challenges exist to implementation of such a system which must be addressed before it may be relied upon to ensure ECCS operability.

The biggest challenge to use backflushing to clean suction strainers is the relatively short time available before strainers can become sufficiently blocked such that available ECCS pump NPSH falls below the NPSH required. This is due to the short time required to process the volume of water in the pool through the strainers. Although it varies on a plant specific basis, the typical time required to process the volume of water in the suppression pool through the strainers one time (i.e., pool turnover time) is on the order of 10 to 30 minutes. The initial pool turnover is expected to result in as much as 60% of the transportable debris available in the pool volume being deposited on the strainer surface. Additional pool turnovers result in further deposition on the strainers.

Because of the short pool turnover time, enough debris can quickly be accumulated on the strainer surface to reduce ECCS pump NPSH below that which is required. Consequently, use of backflush will be required early in the LOCA event if it is the primary means chosen to assure ECCS capability.

During investigation of backflush as a solution to the ECCS strainer blockage issue, the BWROG investigated two general approaches to backflush of ECCS strainers. One approach requires shutdown of the ECCS pump in order to backflush, the second approach allows backflush of a strainer without pump shutdown. Each of these approaches are discussed in the following sections.

Also included in the following sections is a brief discussion on the use of backflush at Swedish BWR plants.

3.3.1.1 Backflush Requiring Shutdown of ECCS Pumps

If sufficient debris and corrosion products are present in the suppression pool, unacceptable head losses across the strainer will occur. The time into the LOCA event when this occurs is fundamental in determining the value of using a backflush system and the design requirements of a backflush system. Since substantial amounts of fibrous debris and particulate would be suspended in the pool early into the accident, backflushing will be required early in the event. This can happen if the amount of the suspended material exceeds the design values of strainer debris during or soon after the blowdown transport phase of the accident. Under these conditions, unacceptable amounts of debris could reach the strainer in a matter of minutes from the start of the event. The ECCS pumps would then need to be shutdown at a time when there is high decay heat present in the core. This conflicts with the design basis of the ECCS.

Furthermore, backflushing one time will not preclude the need for subsequent backflushes within a relatively short time interval. Backflushing would have to continue until such time as enough of the debris in the pool has been removed from suspension that the remaining debris is not sufficient to cause unacceptable strainer head loss. This would also require an evaluation of pool flow conditions to determine whether debris which is backflushed off of the strainers stays on the pool floor or whether it is resuspended in the pool volume and again available to cause strainer blockage.

For plants with strainer sizes and designs typical of those currently installed throughout the industry (e.g., truncated cone) and which also have significant amounts of fibrous insulation in the drywell, use of a backflush system which requires shutting down the ECCS pumps is not, in itself, an effective resolution. The two main reasons are (1) shutting down ECCS pumps within minutes following a LOCA is not an acceptable course of action in that this may preclude adequate core cooling; and (2) increased temperature of the ECCS pump motor windings due to frequent

starting. ECCS pump motors typically are not designed for frequent starting and therefore cannot be cycled as often as required to support backflush operation.

In order for backflush requiring ECCS pump shutdown to be viable, the strainers must have sufficient capacity such that backflushing would not be required until it is safe to shutdown an ECCS system following the LOCA. Use of a timeline may be helpful in evaluation of the effectiveness of backflush. An example of how this may be done follows:

1. Demonstrate that blowdown transport of fibrous debris, in combination with pool corrosion product and other debris, is not sufficient to block the suction strainers.
2. Determine if the additional debris introduced into the suppression pool as a result of break leakage flow/containment spray-down transport will not result in unacceptable NPSH until such time that it is possible to reduce ECCS flow and conduct backflush operations without endangering adequate core cooling. For example, several hours into the event the core cooling requirements may be reduced to the point that ECCS can be secured for the amount of time necessary to conduct backflush operations.

For some plants with individual pump suctions, it may be possible to backflush one strainer while reduced core cooling is maintained via a separate flow path through another strainer/pump combination. In this case a review of the inputs and assumptions used in the evaluation model required by 10CFR 50.46 to calculate the ECCS cooling performance should be made to determine if the reduced core cooling flow that occurs while one flow path is shutoff for strainer backflush provides sufficient ECCS cooling performance. Consideration should also be given to the affect of such backflush operations on Emergency Operating Procedures (EOPs) and associated operator training requirements.

The effectiveness of backflush in cleaning the strainer surface is also an issue. Testing conducted by the BWROG (Reference 3) indicates that a smooth surface truncated cone strainers typical of those currently installed in many BWRs will backflush if sufficient flow is available. However, the

design features of alternate geometry strainers (e.g., star and stacked disk), which result in their having a higher capacity for debris, also cause them to be more difficult to backflush.

3.3.1.2 Backflushing Without Shutting Down ECCS Pumps

The possibility exists that a system could be developed to allow backflushing of the ECCS suction strainers while continuing to provide flow to the ECCS pumps, thus avoiding the need to shutdown and restart the pumps. One conceptual design would use a pressurized water source introduced in the suction line with sufficient capacity to feed the pumps and simultaneously backflush the strainers. This concept is based on designs developed by Vattenfall in Sweden. A second Vattenfall conceptual design would use compressed gas to drive water from a reservoir, backflushing the ECCS suction strainers while continuing to supply flow to the ECCS pumps.

It appears that such systems would require substantial modification of the plant, and would also likely include a complex automatic control system with operational reliability concerns which would need to be addressed.

The BWROG has not made a determination on the feasibility of these or other potential systems which could accomplish backflushing without interruption of ECCS flow.

3.3.1.3 Use of Backflush in Swedish BWR Plants

Backflush systems were either in place in Swedish BWRs as part of the original plant design, or installed as part of the actions taken after the Barsebäck event. However, it should be noted that these systems only play a defense-in-depth role in responding to a LOCA. The strainers installed at the Swedish plants are sized to provide acceptable head losses under worst case debris loadings. Further, operation for ten hours following a LOCA without use of backflush is a design criteria for the Swedish plants. Thus the backflush capability is not required as a primary success

path to assure acceptable strainer performance, but is available either as part of the original design, or as part of the "robust solution" required by the Swedish regulatory authorities.

3.3.2 BWROG Guidance

The BWROG recommends against use of strainer backflush systems as a primary means of resolving the ECCS suction strainer issue. The reasons for this recommendation are: 1) that the time frame within which backflush would be required is significantly less than 30 minutes, raising human factors concerns; 2) for many plants, repeated backflushes would be necessary within 30 to 60 minutes, which may not be feasible given limitations on ECCS pump motor starts, and 3) the NRC staff has indicated that use of backflush by itself would probably not be considered adequate[9]. Use of backflush for defense in depth rather than the primary success path may be a viable option for those plants with existing capability to align systems to backflush strainers.

However, licensees may choose to consider whether currently installed plant systems could be aligned to backflush ECCS suction strainers as a defense-in-depth measure, instead of as the primary success path. Licensees which elect to use such existing capability to backflush as a defense-in-depth measure should have in place appropriate procedural controls, operator training, and instrumentation/alarms. Consideration should also be given to the increased demands placed on operators when making a decision on whether to use backflush.

Should a licensee elect to use a backflush system as the primary success path to ensure the capability of the ECCS systems following a postulated LOCA, the following design considerations should be addressed. (This is not an all-inclusive list of applicable design requirements and is only intended to emphasize design considerations associated with a backflush system requiring shutdown of ECCS pumps):

[9] See NRC letter to R. Sgarro (PP&L) dated 7-25-96 "Comments on Draft Utility Resolution Guidance Sections 3.1.4, 3.2.1.1, 3.2.2.2, and 3.2.3.4" Enclosure 1, Comment 6 of Section 3.1.4 "Backflush" (Reference 15)

3.3.2.1 Design Considerations

1. Compliance with 10 CFR 50.46 requires the use of safety-grade equipment. Any request to deviate from this position would require an exemption with a supporting technical analysis, and must meet the specific requirements of 10 CFR 50.12. ASME Code requirements will also be applicable to a backflush system.
2. The single failure criterion should be met for design of a backflush system used to meet the requirements of 10 CFR 50.46.
3. Use of a backflush system must be supported by test data that demonstrates the design effectiveness for removal of debris entrained on the surface of the strainer. Note that Reference 3 contains results of limited testing of the effectiveness of backflushing on truncated cone and alternate geometry strainers. It is likely that further testing of a plant specific strainer design would be required.
4. A plant-specific analysis should be performed to determine the number of times and frequency at which backflush will be required in order to assure the capability of the ECCS to meet its safety related design functions.
5. Sufficient time should be available for operators to recognize the onset of strainer clogging and take appropriate action to prevent loss of ECCS, taking into consideration their other responsibilities after a LOCA.
6. If ECCS pumps shut off is required in order to backflush, then the electrical system and ECCS pump motors must have adequate capacity to be started the number of times and at the frequency required in order to accomplish the required number of backflushes.
7. A review of the inputs and assumptions used in the evaluation model required by 10CFR 50.46 to calculate the ECCS cooling performance should be made to determine if the existing model adequately predicts ECCS cooling performance given any changes introduced as a result of operation of a backflush system. If necessary, update the ECCS cooling performance model to account for changes resulting from backflush operations.

8. Instrumentation (e.g., strainer pressure differential or pump flow rate) relied upon by operators to indicate when a manual initiation of strainer backflush is required should be Type A instrumentation as defined in Regulatory Guide 1.97, "Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident," Revision 3 (Reference 17). Alarms should also be available in the control room that provides operators with an indication and audible warning of impending loss of NPSH for the ECCS pumps. This instrumentation should be included with other Type A instrumentation in the appropriate section of the technical specifications. The licensee should also provide appropriate corresponding bases.
9. Operator training and procedural guidance on recognition and mitigation of a strainer clogging event should be provided. If manual operator actions from outside the control room are required, the areas where operations take place must be accessible under LOCA conditions. The time-frame for accomplishment of actions to complete backflush operations must be consistent with the frequency and initial performance times required by the strainer head loss analysis.
10. Implementation of surveillances to ensure the operability of the strainer instrumentation and backflush system should be addressed. It is recommended that the backflush system operability be confirmed at a frequency consistent with the individual system pump operability. This frequency is recommended to ensure that the ECCS systems can provide long term cooling. Testing the pump alone ensures initial cooling, but the testing of the backflush ensures prolonged cooling. The surveillance should include any instrumentation required to identify the need to backflush the system as well as any instrumentation required to confirm a successful backflush. It should be noted that the backflush system may be common to multiple systems. If this is the case, it will not be necessary to test the backflush system with each system nor is it necessary to test it with system redundant pumps. The appropriate technical specification section should be modified to address surveillance requirements of the backflush system. These requirements will be unique to the backflush system design and as such are not specifically defined here.

11. The worst case condition should be assumed in determining the time available until strainer blockage is expected to occur. Depending on the plant specific design features, the worst case for some plants may be operation with an assumed single failure, while for other plants the worst case is with full operation of all ECCS trains.
12. The issue of re-entrainment of debris which has been backflushed off of a strainer should also be considered. Section 3.2.5 provides information on factors to consider when evaluating transport and settling of debris and corrosion products in the suppression pool.

The above design considerations are applicable to use of backflush as a primary success path to assure ECCS performance. These same considerations are good engineering practices if a licensee elects to use backflush as a defense in depth measure. However, a backflush system which is not intended as the primary success path to meet the requirements of 10 CFR 50.46 but is instead used as a defense-in-depth option does not require:

- use of safety-grade equipment
- compliance with the single failure criterion
- use of Type A instrumentation/alarms as described in Regulatory Guide 1.97 and the associated Technical Specification requirements.
- control room instrumentation providing indication and audible warning of impending loss of NPSH for ECCS pumps. Instrumentation indicating the need for strainer backflush should be provided, preferably in the control room, but may be located elsewhere
- other safety related requirements which would be applicable if backflush was used as a primary success path for assuring compliance with 10 CFR 50.46.

3.4 Self Cleaning Strainers

3.4.1 Introduction

Use of a self-cleaning strainer is one of the options investigated by the BWROG to resolve the strainer blockage issue. The main feature of interest in a self cleaning strainer is that it will continue to operate and provide a strainer surface which is essentially free from debris buildup regardless of the amount or type of debris which may be in the suppression pool. Because the self-cleaning strainer is relatively impervious to the amount of debris and sludge in the suppression pool, use of a self-cleaning strainer would provide a licensee with greater operational latitude in implementation of housekeeping controls and pool cleaning frequency than would be available if using a passive strainer option.

Different types of self-cleaning strainers and their location were considered. Few plants have adequate space available near the ECCS pumps to install a self-cleaning strainer external to the suppression pool. While strainers are commercially available that use a motor to drive the cleaning of the strainer, the complexities of equipment qualification and surveillance requirements for use of such an active device in a suppression pool under LOCA conditions were judged to be excessive and have a potentially significant impact on ECCS operability should a component fail during normal reactor power operations.

One type of self-cleaning strainer design was examined in more detail by the BWROG. The particular design evaluated uses the force of water flowing through the strainer to rotate a plow and brush assembly that keeps the flat front face of the strainer free of debris. An internal turbine powered by the water passing through the strainer rotates the plow/brush assembly.

BWROG testing of a full scale self-cleaning strainer of the above design demonstrated its effectiveness at keeping the front strainer face free of debris for the debris types and loading

tested. However, several issues remain to be resolved before such a strainer could be employed. These issues include:

- optimization of clean head loss and torque
- delayed start of rotation of the plow/brush assembly following operation with minimum flow through the strainer
- the effect of debris which passes through the strainer on downstream components
- surveillance/maintenance requirements

These issues are discussed further in Section 3.4.3.

3.4.2 BWROG Guidance

Because of the complexities of adding an active component to the ECCS system(s), the BWROG recommends that use of a self-cleaning strainer be considered only if a passive strainer solution is not viable.

Should a licensee elect to use a self-cleaning strainer as the primary success path to ensure the capability of the ECCS systems following a postulated LOCA, the following design considerations should be addressed. (This is not an all-inclusive list of applicable design requirements and is only intended to emphasize design considerations associated with a self-cleaning strainer:)

3.4.2.1 Design Considerations

1. Compliance with 10 CFR 50.46 requires the use of safety-grade equipment. Any need to deviate from this position would require an exemption with a supporting technical analysis, and must meet the specific requirements of 10 CFR 50.12.
2. The single failure criterion should be met for design of a self-cleaning strainer used to meet the requirements of 10 CFR 50.46. This is of particular concern for common suction (i.e., ring-

header) plants. For those plants with individual dedicated suction strainers, failure of the strainer would result in and be bounded by failure of the ECCS system unless redundancy of the strainers was provided in the design.

3. Use of a self-cleaning strainer must be supported by test data that demonstrates the design effectiveness for removal of debris entrained on the surface of the strainer over the mission time of the ECCS. Note that Reference 3 contains design information and test results of the effectiveness of a self-cleaning strainer developed by the BWROG. Self-cleaning strainers of a design different than that tested by the BWROG would require testing to ensure their design effectiveness, or an analysis which shows that the results of the BWROG tests are applicable.
4. A review of the inputs and assumptions used in the evaluation model required by 10CFR 50.46 to calculate the ECCS cooling performance should be made to determine if the existing model adequately predicts ECCS cooling performance given any changes introduced as a result of operation of a self-cleaning strainer. If necessary, update the ECCS cooling performance model to account for changes resulting from installation of a self-cleaning strainer.
5. Generally, the use of instrumentation and alarms which indicate the operability of a self-cleaning strainer should be provided. However, if the strainer is visible for periodic online surveillance (e.g., visual surveillance in a Mark III), then instrumentation/alarms to monitor the strainer may not be required. The issue of instrumentation and alarms on a self-cleaning strainer should be addressed with the NRC on a plant specific basis if use of such a device is anticipated.
6. Implementation of surveillances to ensure the operability of the self-cleaning strainer should be addressed. The reliability of a self-cleaning strainer along with the type and diversity of instrumentation used to indicate the rotating assembly is moving (e.g., plow/brush assembly is turning) are factors which should be considered in establishment of surveillance requirements.

Other surveillances should also address cleanliness of the suppression pool to ensure that debris sources which could damage or overload a strainer during a LOCA are not present.

7. Maintenance requirements and frequency should be considered. The bearings used in the self-cleaning strainer along with the clearances and wear on any rotating or abrasive components (e.g., the plow and brush and front strainer surface) should be specifically addressed.
8. A self-cleaning strainer and associated instrumentation located within the suppression pool are fully exposed to the effects of a LOCA and must be qualified for the anticipated environmental, seismic, mechanical and structural requirements.
9. An analysis should be conducted to determine the effects of operation under low flow conditions (i.e., flow insufficient to cause the operation of the rotating assembly such as pump operation on minimum recirculation flow, if applicable) while retaining the ability to cause the rotating assembly to turn when flow is increased to the anticipated ECCS flow rates. The methodology described in Appendix G of Reference 3 is an acceptable approach for conducting the analysis. The plant specific values of LOCA-generated/operational debris and sludge assumed to be present in the suppression pool along with the design features unique to the strainer being evaluated (e.g., locked turbine torque and passive strainer area) should be used in making the determination of low flow characteristics such as the maximum permissible time under low flow conditions.
10. The worst case condition should be assumed in determining the effects of operation under low flow conditions. Depending on the plant specific design features, the worst case for some plants may be operation with an assumed single failure, while for other plants the worst case is with full operation of all ECCS trains.
11. The effect of debris which passes through the strainer on the ECCS pumps and other downstream systems/components should be evaluated. An evaluation by General Electric (Reference 11) addresses the effects of rust, epoxy paint chips, sand, iron oxide sludge and fibrous debris on components downstream of the strainers. This evaluation concluded that there is no safety concern for the potential failure of the ECCS pumps, inadequate cooling capacity from the RHR heat exchangers, plugging of the core spray header nozzles, plugging of the containment spray nozzles, corrosion or chemical reaction with other reactor materials, or fuel bundle flow blockage.

Licensees should review their plant specific conditions to assure they are bounded by the GE evaluation and address any unresolved issues.

12. Changes to Technical Specification Limiting Conditions for Operation (LCOs) should not be required as a result of installation of a self-cleaning strainer. Because the self-cleaning strainer will be used to ensure the operability of the ECCS system, the LCOs associated with the ECCS system are appropriate. Surveillances to test operability at a specified periodicity, however, should be used to ensure continued operability of the associated ECCS system in accordance with the LCOs.

3.4.3 BWROG Self -Cleaning Strainer

One type of self-cleaning strainer design was examined in more detail by the BWROG. The particular design evaluated uses the force of water flowing through the strainer to rotate a plow and brush assembly that keeps the flat front face of the strainer free of debris. An internal turbine powered by the water passing through the strainer rotates the plow/brush assembly. (See Figure 5 and Figure 6 for side and front views of the self-cleaning strainer tested by the BWROG.)

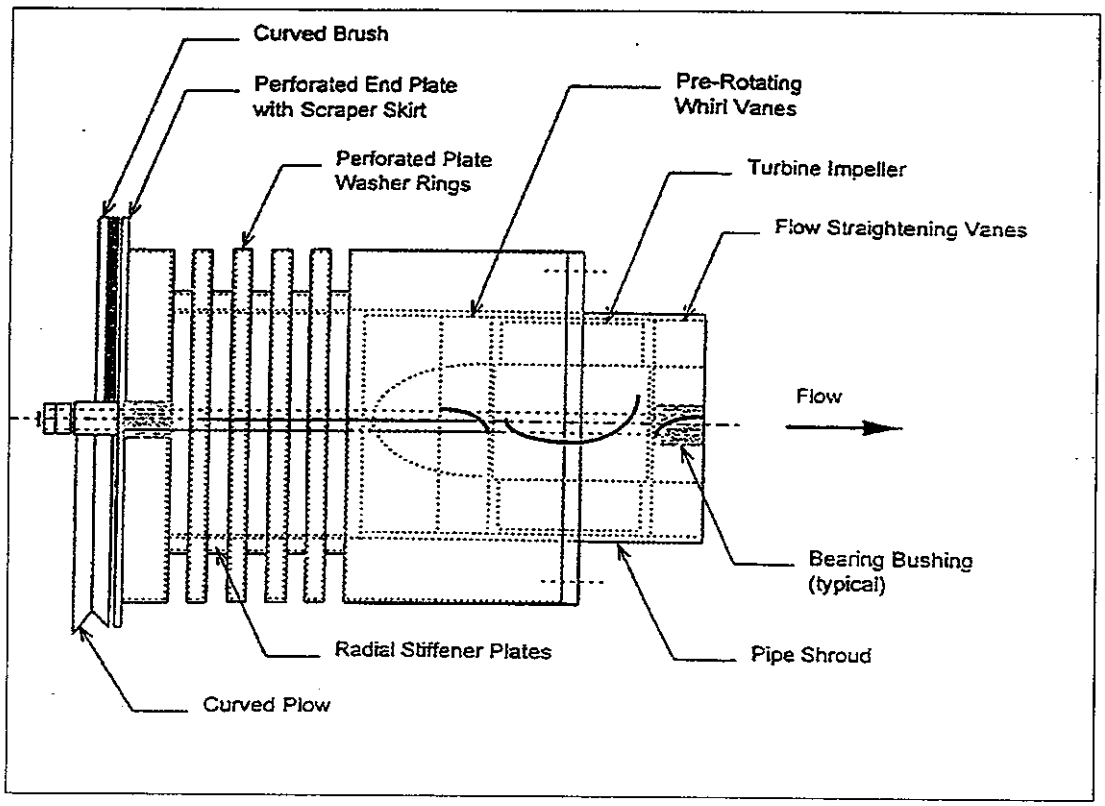


Figure 5 - Side View of Self-Cleaning Strainer

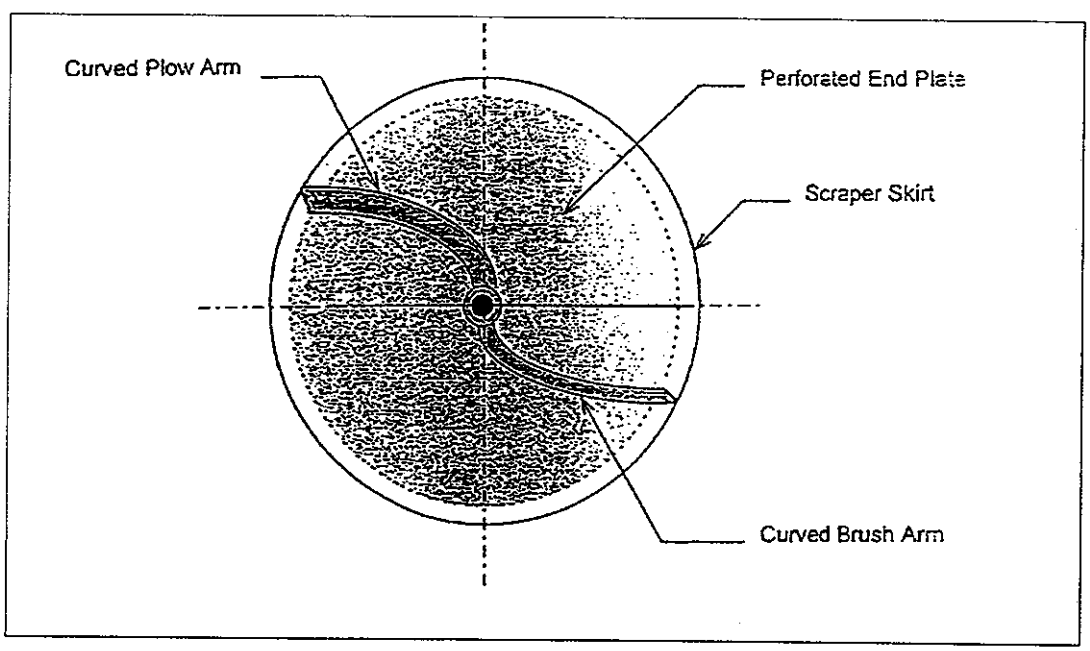


Figure 6 - Front View of Self Cleaning Strainer

Results from testing conducted by the BWROG show that, when turning, the self-cleaning strainer tested is relatively impervious to any amount of LOCA-generated/operational debris and sludge which can realistically be anticipated to be present in the suppression pool. The strainer was tested with large quantities of fibrous insulation debris, RMI debris, corrosion products, rust flakes, paint chips, sand, duct tape, tie wraps and rubber boots present in the water volume. Reference 3 discusses the test program and results in detail.

Results of the testing indicate that while a self-cleaning strainer can provide a clean strainer area when turning, several issues need to be resolved before this option can be employed.

3.4.3.1 Optimization of Clean Head Loss and Torque

The flow of water through the self-cleaning strainer is the source of power for turning the internal turbine which drives the plow/brush assembly. The turbine induces additional head loss and lowers the NPSH available at the inlet to the ECCS pump. The self-cleaning strainer initially tested by the BWROG had a clean head loss with a locked rotor of about 5.5 feet of water and produced about 390 ft-lb. of torque at a 5000 gpm flowrate. Subsequent modification of the turbine inlet turning vanes reduced the clean head loss with a locked rotor to about 2.0 ft of water but also reduced the torque to about 209 ft-lb.

The amount of clean head loss that is acceptable is a plant specific value that depends on the margin between the NPSH available and that required for ECCS pump operation.

Note that that for this specific prototype strainer tested there is a trade-off between clean head loss attributable to the turbine and the available torque which will affect the ability of the rotor to start turning after operation in a minimum flow condition.

3.4.3.2 Turbine Start after Minimum Flow Operation

When flow through a clean self-cleaning strainer begins there is not enough torque generated by the turbine to rotate the plow/brush assembly. As the flowrate through the strainer increases, the torque produced by the turbine also increases and eventually enough force is developed to begin turning the turbine and the attached plow/brush assembly. Once turning, the plow/brush assembly keeps the strainer face clean of debris.

ECCS pumps are expected to operate in a minimum flow condition for some amount of time with flow rates that may be insufficient to cause the plow/brush assembly to rotate. During the time the flow is insufficient to turn the plow/brush assembly, the self-cleaning strainer is acting as a passive strainer and debris will build up on the front face of the strainer and on the perforated plate/stacked disk areas that are receiving flow. The amount of debris that will accumulate is dependent on the time of operation with insufficient flow to cause the plow/brush assembly to turn, the flowrate through the strainer, and the LOCA-generated/operational debris and sludge present in the suppression pool. Depending on this combination of factors, and the design of the strainer, it is possible that enough debris will build up on the strainer during operation under low flow conditions that the head loss across the passive elements of the strainer will be sufficient to prevent the turbine from ever developing enough torque to turn the plow/brush assembly even when the flow rate is increased.

The plant specific values of expected debris and sludge in the suppression pool, the time of operation in low flow conditions, and the specific design of the self-cleaning strainer all need to be addressed in evaluating the use of a self-cleaning strainer.

Appendix G of Reference 3 provides guidance on analyzing the duration a self-cleaning strainer can operate under minimum flow conditions and still have sufficient torque to operate the plow/brush assembly.

3.4.3.3 Downstream Effects

When turning, the plow/brush assembly may break up insulation fibers and force them through the strainer where they then enter the pump inlet and may be subsequently carried on to downstream components.

Because a self-cleaning strainer can result in more debris passing through than would pass through a passive strainer, the effect of the debris on the ECCS pumps and other downstream systems/components should be evaluated in accordance with the current licensing basis. A report prepared by GE for the BWROG (Reference 11) shows that adequate core cooling required during a LOCA will not be compromised by the presence of rust, epoxy paint chips, sand, iron oxide sludge, and fibrous debris in the ECCS system or reactor core.

3.4.3.4 Surveillance/Maintenance Requirements

A self-cleaning strainer is an active safety-related component and will require implementation of surveillances to ensure operability. These surveillances should be included in the required surveillances for the associated ECCS train. The specific surveillances to ensure operability of the self-cleaning strainer should be proposed to the NRC on a plant specific basis. The reliability of a self-cleaning strainer along with the type and diversity of instrumentation used to indicate the plow/brush assembly is turning and capable of removing debris are factors which should be considered.

4. Additional Features Which Provide Defense in Depth

4.1 Introduction

Each plant will have a primary means of assuring that the ECCS pumps are not prevented in performance of their function in accordance with the requirements of 10 CFR 50.46. For most plants, it is expected that use of a passive ECCS pump suction strainer(s) of adequate size will be employed. However, in addition to the primary success path, licensee should consider the use of other plant features which provide defense-in-depth for a postulated LOCA. Depending on plant specific design features, the use of alternate water sources and/or backflush may provide additional defense-in-depth.

4.2 Alternate Water Sources

The BWR Owners' Group has developed an extensive set of symptom oriented Emergency Procedure Guidelines (EPGs). Revision 4 of the EPGs has been utilized to develop plant specific Emergency Operating Procedures (EOPs) by all BWR licensees. These EOPs focus the operator's attention on maintaining reactor water level under all circumstances. The procedures are based upon symptoms or operator recognition of the indications available. It is not necessary for the operator to diagnose the specific cause of any loss of reactor water level in order to take appropriate action and successfully prevent core damage.

The operators have been trained on the specific procedures developed from the guidelines. Should reactor water level decrease for any reason, the EOPs naturally lead the operator to the use of alternate sources of water. Additional operator training has been performed on the potential for ECCS strainer blockage in response to NRC Bulletin 93-02, Supplement 1. The existence of clear EOPs for response to decreasing reactor water level, with operator training

generally on these procedures and specifically on the potential for ECCS suction strainer blockage, ensures that alternate water sources will be used to prevent core damage with a high reliability should the ECCS strainers become blocked. These alternate water sources provide significant defense-in-depth capabilities.

Additional information (e.g., flow rate and discharge pressure) is available to the operator to assist with monitoring of ECCS pump performance. Operators are trained to monitor for potential pump degradation. Indication of degradation of the pump flow rate or discharge pressure would allow operators to initiate alternate water injection before EOP action statements on decreasing reactor water level are reached. Further, because of varying pump flow rates, strainer sizes, pool mixing effects and strainer locations, the pumps would not be expected to degrade uniformly or to fail simultaneously. Failure of the first pump should alert the operator to the potential failure of the other pumps.

The overall design of the BWR plant includes several alternate sources of water that would be available to the operator for core cooling in the event that ECCS suction strainers should become clogged following a LOCA event. These include sources that can be pumped to the reactor with safety grade equipment and non-safety grade or non-Class 1E equipment. These potential success paths to core cooling are capable of taking suction from sources other than the suppression pool and are independent of the strainers. The available alternate water source capabilities vary from plant to plant. The capabilities described here are typical of those available.

In the case where off-site power is available or can be restored, the non-Class 1E condensate/condensate booster pumps can be used. These can pump the condenser hotwell water to the reactor to restore water level and cool the core for breaks above the top of the active fuel. This is the normal source of water available to the operator. Additionally, the Control Rod Drive (CRD) pumps would continue to supply Condensate Storage Tank (CST) water to the reactor as long as power was available.

If the ECCS injection flow rate were to drop off, the operator could switch to an alternate suction source. The high pressure core spray pumps (BWR/5&6) have the capability of being aligned back to the non-safety related condensate storage tank. BWR 2/3/4 plant designs also have this capability with the low pressure core spray pumps. As long as the ECCS pumps are still available and operator access to any required equipment is possible, this potential source of water provides a substantial quantity of water for direct injection to the reactor.

Another source of water for injection to the reactor is the emergency RHR service water. This water source can be cross-tied to the low pressure coolant injection flow path to pump water from the ultimate heat sink. This source of water is safety related and can at some plants be initiated from the main control room. The fire water pump is another potential way of getting water to the reactor using this same flow path. This pump, either diesel or normal bus driven, can be manually aligned to supply water to the reactor vessel.

If the event that caused strainer blockage were a break in a line above the top of the active fuel, it may be possible to establish long term cooling (following reflood) using the shutdown cooling mode of the RHR system. This would provide for decay heat removal, and injection flow requirements would then be limited to make-up for the steam released through the unisolated leak until the shutdown cooling system had subcooled the reactor and terminated steaming.

With or without recognition of the decreased ECCS flow, it is highly likely that the operator will successfully act to initiate alternate water injection and protect the core. With recognition of the first pump's loss of NPSH/flow, the operator could take other actions to further increase the chances for success in this postulated accident.

System alignment to make use of alternate water sources may require manipulation of valves or other equipment that is infrequently operated. The valves and other equipment used to provide alternate water sources for injection in support of the EOPs should be considered for inclusion in the scope of the Maintenance Rule. It is expected that most if not all of the valves and other equipment will already be encompassed by the plant maintenance program. However, licensees

should review the alternate water sources available as described in the plant EOPs and ensure that all valves and other infrequently operated equipment necessary to accomplish injection from these alternate water sources are appropriately addressed by the plant maintenance program.

4.3 Backflush

The use of backflush as a defense-in-depth measure may be an option for some licensees. The information contained in Section 3.3.2 should be considered if employing backflush for defense-in-depth purposes.

4.4 ECCS Flow Management

If the flow rate through an ECCS strainer is reduced, the head loss and the required pump NPSH are also reduced. Reduced flow will also reduce the rate of accumulation of debris on the ECCS pump strainers. In order to provide additional defense-in-depth, licensees may consider reducing ECCS flow after a postulated LOCA when the core cooling requirements are lower. If the use of reduced ECCS flow is implemented, appropriate operating and emergency procedures should be in place and operator training conducted so that operators will only reduce pump flow at the appropriate time post-LOCA. Care should be taken to ensure that changes in ECCS flow rates are consistent with the inputs and assumptions used in the evaluation model required by 10CFR 50.46 to calculate the ECCS cooling performance.

5. Conservatism

The BWROG recommended methodology for demonstration of compliance with 10 CFR 50.46 requirements includes substantial conservatism. The primary sources of this conservatism are in the methods recommended for estimation of the amount of insulation debris generated and transported to the ECCS strainers. The BWROG guidance in these areas uses conservative assumptions in areas where insufficient data or analysis is currently available to support use of less bounding methods. In other areas of the BWROG guidance where sufficient data or analysis has been completed, more realistic methods are recommended. An example is in the recommended methods for calculation of ECCS suction strainer losses. These methods are based on extensive testing performed by the BWROG on several strainer designs under a variety of loading conditions, augmented by data obtained in other smaller scale experiments.

Overall, implementation of the BWROG guidance is believed to result in a conservative evaluation of ECCS pump NPSH. The most significant areas of conservatism in each major section of the BWROG recommended methodology are identified in the discussion which follows.

5.1 Selection of Break Locations

Two methods are provided for selection of pipe break locations. The first applies to plants whose licensing basis includes a detailed analysis of probable break locations in accordance with NRC guidance provided in BTP MEB 3-1, as required by Section 3.6.2 of NUREG-0800 (Reference 28), or through use of equivalent methods approved by the NRC on a plant specific basis. Typically, these analyses identify a large number of potential break locations throughout the high energy piping systems inside containment which have the highest stresses, and therefore are most likely candidates for postulated breaks. While the exact number of potential break locations varies based on the plant specific piping system design, an MEB 3-1 analysis typically includes

breaks on the main steam, feedwater, and recirculation system lines in regions which include large quantities of potential target materials.

As an additional conservatism, the BWROG guidance requires plants with MEB 3-1 analyses to verify that their licensing basis break locations do include breaks with the largest amount of debris in the zone of influence, and to ensure large breaks with two or more types of debris in the zone of influence are also included. If it is found that the MEB 3-1 defined break locations do not adequately cover these other potential (but unlikely from a pipe stress basis) break locations, the BWROG guidance recommends evaluation of additional breaks as necessary to ensure the suggested NRC approach provided in Section 2.3.1.5 of Reference 2 on the selection of pipe break locations is satisfied.

The BWROG guidance recommends that plants which do not have a MEB 3-1 analysis select pipe break locations in a manner which maximizes the amount of debris generated.

5.2 Size of the Zone of Influence

The BWROG methodology provides four acceptable approaches for identifying the zone of influence for materials of interest which may be damaged by break jet forces. These approaches vary in the level of conservatism and level of detail included in the analysis. The methods are described in Section 3.2.1.2.

Method 1 is clearly a bounding, conservative approach. All material of interest located anywhere within the drywell is assumed available for transport using this approach.

Methods 2 through 4 all make use of one fundamental assumption at varying levels of detail. The assumption is that the volume enclosed within any given dynamic pressure surface for a break jet inside the drywell will be equal to or less than the volume enclosed within the same dynamic pressure surface for a similar jet in free space. The BWROG believes this assumption is conservative, for the following reasons. Actual break jets located within the drywell will interact

with equipment, piping, and major structures as they expand. At each of these interactions, jet momentum will be lost. As a result, a smaller volume of the drywell would be exposed to dynamic pressures above the dynamic pressure determined to generate transportable insulation debris.

Also, the BWROG guidance for determination of the zone of influence and calculation of the amount of potentially transportable debris generated does not credit shadowing. All materials of interest within the calculated zone of influence are considered to be similarly affected. In actuality, and as seen in the air jet impact testing performed by the BWROG (Reference 6), materials located on the back side of piping targets (from the perspective of the break jet) are typically much less affected than materials facing the jet.

Furthermore, the assumptions included in calculating the amount of debris generated conservatively apply the results obtained from the air jet impact testing. This applies both to determination of the size of the zone of influence and to estimation of destruction factors. Due to limitations of the test configuration, no material is assumed to withstand impacts within 5 L/D of the break (or 190 psi, the equivalent dynamic pressure). This is in spite of the fact that in some cases, little destruction occurred for tests at 2.5 L/D.

In cases where data obtained from the impact testing was not sufficient to allow quantification of a destruction factor within the assumed zone of influence, conservative assumptions are used. In several cases (such as the Darchem and Transco RMI products), very little transportable debris was generated in any tested configuration. However, the BWROG guidance includes use of a 50% destruction factor for these materials within dynamic pressures of 190 psi, even though little debris was actually generated at that pressure. In cases where data was obtained sufficient to quantify destruction factors, the BWROG guidance conservatively bounds the data obtained. As an example, a destruction factor of 50% is assumed for all Diamond MIRROR® insulation within the zone of influence, even though the data obtained ranged from 42% of the internal foils, down to approximately 10%, with the majority of the test data being at the lower end of this range.

For all fibrous insulation products, a conservative assumption is made that all of the internal base insulation material is considered available for transport once the scrim holding the base wool in blankets is ripped apart. This conservatively addresses concerns with further destruction of the insulation which may occur during the blowdown or washdown phases of the LOCA event.

5.3 Drywell Debris Transport

The BWROG guidance in Section 3.2.3 recommends use of a transport factors which are very conservative. As an example, a transport factor of 1.0 is used for small fibrous debris for plants with Mark I and Mark III containment design. Assuming 100% transport is obviously conservative. The transport factors used in Section 3.2.3 are based on evaluation of the results of testing performed by the BWROG documented in Reference 5. These tests evaluated only the potential for debris capture in the lowest region of the drywell, in the vicinity of the drywell vents. As such, the values are appropriate for breaks in this region, such as breaks of the recirculation pumps suction and discharge lines. In addition, the transport test conditions test themselves were conservative, as previously discussed in Section 3.2.3.2, which adds to the overall conservatism. As a result, use of transport factors based on breaks low in the drywell for the balance of the drywell volume is very conservative in the overall analysis of NPSH suction strainer performance.

The most limiting break locations in terms of debris generation are expected to occur much higher in the drywell, where steam and feedwater piping are in close proximity to large recirculation system piping. Debris generation rates in these areas may be several times greater than those for the low recirculation line breaks. Significant deposition of debris generated in these upper regions of the drywell would be expected prior to the debris reaching the vicinity of the drywell vents. Use of the conservative transport factors in the BWROG methodology does not credit any deposition of small fiber pieces in the upper volumes of the drywell.

The transport factors for RMI debris are conservative and are also based on the transport tests conducted by the BWROG. No credit is taken for gratings in reducing the transport of small pieces of RMI debris (e.g., those less than 6 in^2) even though the gratings are expected to reduce

the amount of this debris which is transported to the suppression pool. Although not directly related to transport, an additional conservatism is provided in the manner in which the quantity of RMI debris is determined. The quantity of RMI debris to be used in the strainer head loss evaluation for any RMI material is based on a value which is higher than the quantity of debris produced for the most limiting material tested. Typically, the RMI materials tested produced little or no transportable debris even when tested at locations within a few pipe diameters of the break.

5.4 Suppression Pool Transport and Settling

The BWROG guidance recommends no credit for settling during the high energy phase of the LOCA. Further, the guidance recommends assuming that all relatively light materials present in the pool prior to the LOCA are resuspended by the LOCA. Finally, the BWROG guidance recommends use of a conservative assumption that these materials be assumed to remain suspended and available for transport to the strainers throughout the LOCA and throughout the suppression pool cooling operation. Plants which implement this guidance will have conservatively bounded this phase of the evaluation by effectively taking no credit for settling in the suppression pool.

Credit for settling is allowed by the BWROG guidance, but a detailed plant specific analysis of suppression pool velocities during the phases when settling is to be credited is required.

5.5 Demonstration of Adequate ECCS Pump NPSH

The BWROG guidance recommends use of realistic methods for calculation of ECCS Pump NPSH, while ensuring the analysis is performed within the constraints of the current plant licensing basis. Strainer head loss calculations are based on the extensive testing performed by the BWROG, as reported in Reference 3. While the overall application of the data obtained during testing of alternate strainers and materials is appropriately conservative, no additional large

factors of conservatism are introduced in the guidance for demonstration of adequate ECCS pump NPSH.

Conservatism in the result of the NPSH verification is assured through use of conservative strainer loadings determined through use of the BWROG guidance for debris generation and transport.

The BWROG guidance for calculation of strainer head loss is based on the full scale testing performed at the EPRI test facility, augmented by data obtained in the gravity head loss testing performed at CDI. These tests did not specifically address the potential for long term bed compaction. Testing performed at Alden Laboratories in 1991 (Reference 36) indicates that long term bed compaction and increased strainer head losses may occur to a greater or lesser extent dependent on the pH level of the water passing through the fibrous debris bed. The magnitude of the increase noted was not large, and is much less than the factors of conservatism included in the BWROG guidance for determining strainer loadings as input to the strainer head loss calculation.

6. References

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