NRC Project 691

Document Control 96-266

NRC Bulletin 96-03

GE Nuclear Energy

NEDO-32686, Rev. 0

Class 1

November 1996

DRF A74-00004

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 <u>any unauthorized use</u>, 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.

BWROG ECCS Suction Strainer Committee

NAME	ORGANIZATION
Rocco R. Sgarro - Chairman	**Pennsylvania Power & Light**
John Gerety	Boston Edison
David Hurd	Boston Edison
Joseph Jerz	Boston Edison
Pete Kahler	Boston Edison
George Mileris	Boston Edison
Noel Simpson	Boston Edison
Gary Anthony	Carolina Power & Light
Don Simkins	Carolina Power & Light
Wendell Triplett	Carolina Power & Light
Charles Elberfeld	Centerior Energy
Todd A. Henderson	Centerior Energy
Theodore Hilston	Centerior Energy
Hyram Reppert	Centerior Energy
Steven Brown	Commonwealth Edison

BWROG ECCS Suction Strainer Committee

NAME	ORGANIZATION
Jeffery Drowley	Commonwealth Edison
Roger Heyn	Commonwealth Edison
Robert Rybak	Commonwealth Edison
Bart Slimp	Commonwealth Edison
Robert Byer	Detroit Edison
David Jax	Detroit Edison
Gopal Sharma	Detroit Edison
Doug Wood	Detroit Edison
Brian Blanche	Entergy Operations
Ronald E. Cole	Entergy Operations
Rick Ingram	Entergy Operations
George Lee	Entergy Operations
John Lynch	Entergy Operations
Dana Smith	Entergy Operations
Paul N. Hansen	GPU Nuclear
Sylvain Schwartz	GPU Nuclear
Steven Huebsch	IES Utilities
Jim Kinsey	IES Utilities
Paul Wojtkiewicz	IES Utilities
John Kaczmarek	Illinois Power
Mike Baldwin	Nebraska Public Power District
Jim Drasler	Nebraska Public Power District
Ron Ullmann	Nebraska Public Power District
Darren Deretz	New York Power Authority
T. DeWees	New York Power Authority
Jan Lefter	New York Power Authority
Pat Bartolini	Niagara Mohawk
Michael Jones	Niagara Mohawk

BWROG ECCS Suction Strainer Committee

NAME	ORGANIZATION
Paul Politzi	Niagara Mohawk
George Cornelius	Northeast Utilities
Tom Hanowski	Northern States Power
Pat Tobin	Northern States Power
Ed Hosterman	PECO Energy
Ardaine Giangiulio	PECO Energy
Kimberly R. Leone	Pennsylvania Power & Light
Mark R. Mjaatvedt	Pennsylvania Power & Light
William D. Maher	Public Service Electric & Gas
Jeff Branum	Southern Nuclear/Georgia Power
Bernie Matthews	Southern Nuclear/Georgia Power
Ken McElroy	Southern Nuclear/Georgia Power
Jim Wade	Southern Nuclear/Georgia Power
Bill Crouch	Tennessee Valley Authority
Eugene Gillian	Tennessee Valley Authority
James Callaghan	Vermont Yankee
James Brower	Washington Public Power Supply System
Scott Wood	Washington Public Power Supply System
THOMAS A. GREEN - PROJECT MANAGER	GE NUCLEAR ENERGY
Alan J. Bilanin	Continuum Dynamics
J H. Munchausen	Continuum Dynamics
William H. Houston	Sequoia Consulting Group
Daniel L. Maret	Sequoia Consulting Group

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.

Utility Resolution Guidance Working Group

NAME	ORGANIZATION
Ronald E. Cole - Chairman	**Entergy Operations**
Theodore Hilston	Centerior Energy
Robert Rybak	Commonwealth Edison
Thomas A. Green	General Electric
Paul N. Hansen	GPU Nuclear
George Cornelius	Northeast Utilities
Kimberley R. Leone	Pennsylvania Power & Light
William D. Maher	Public Service Electric & Gas
William H. Houston	Sequoia Consulting Group
Daniel L. Maret	Sequoia Consulting Group

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.

Table of Contents

TABLES

FIGURES

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.

Overview of Potential Resolution Options

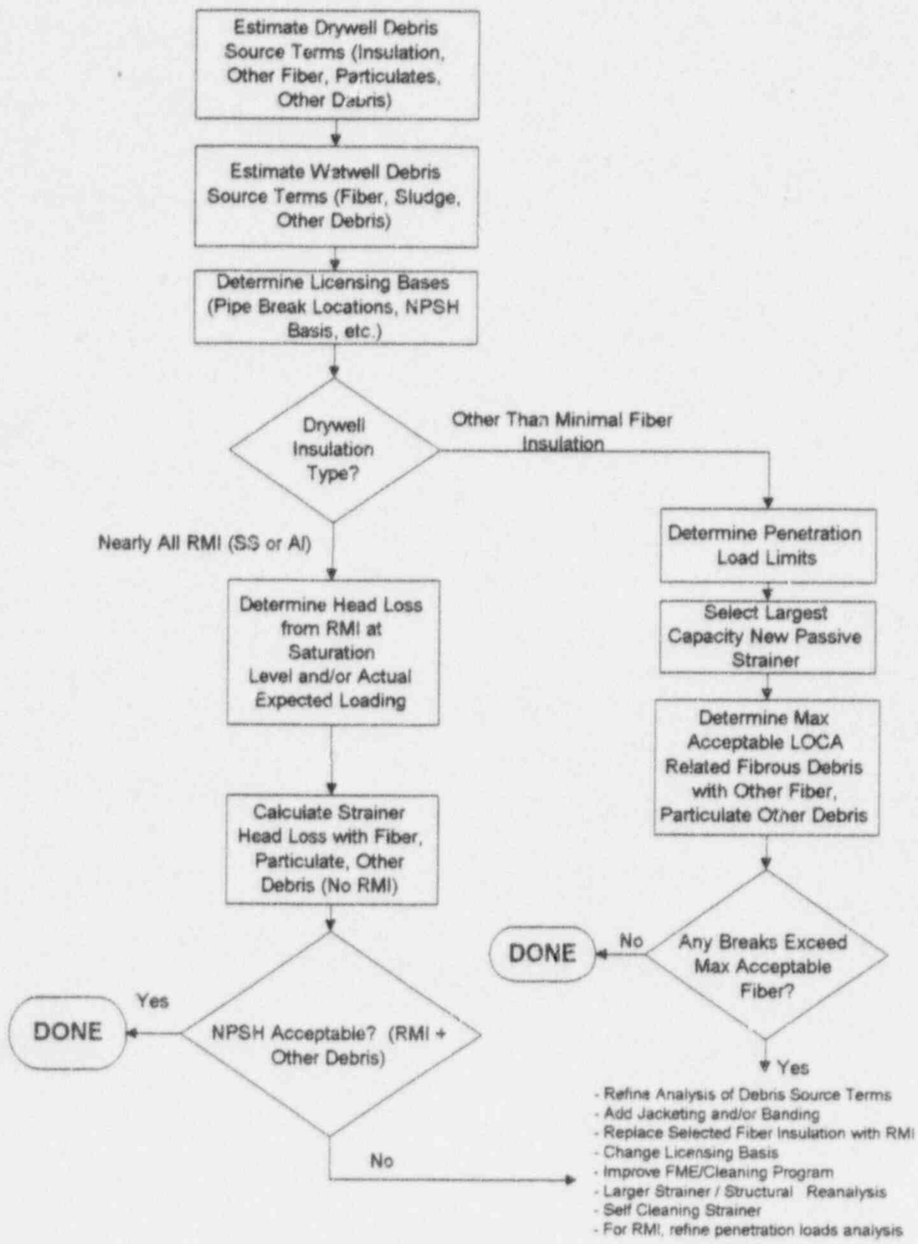


Figure 1 - Overview of Potential Resolution Options

1

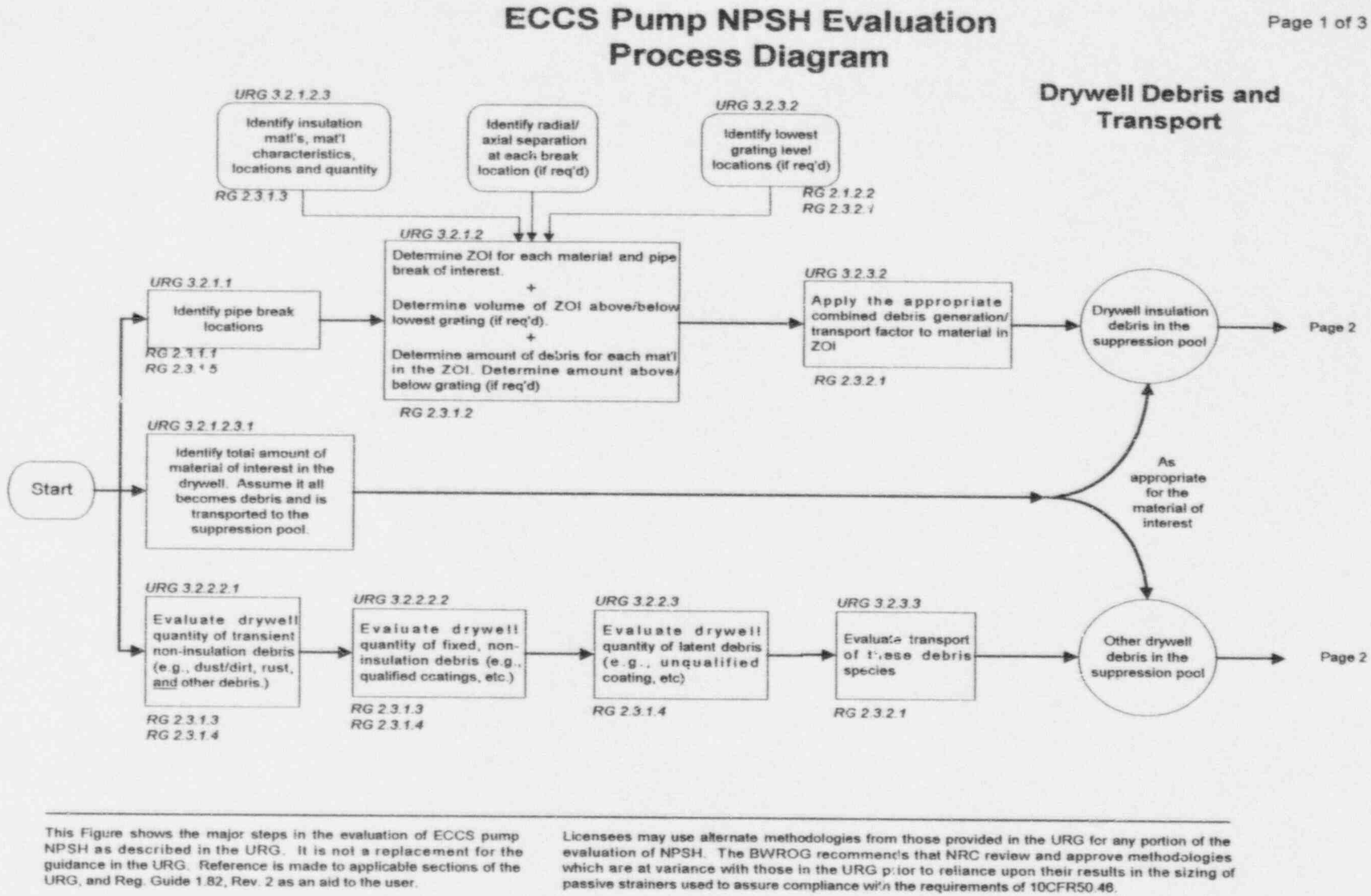


Figure 2 - Evaluation Process Diagram - <u>Drywell Debris and Transport</u>

ECCS Pump NPSH Evaluation Process Diagram

Suppression Pool Debris and Transport

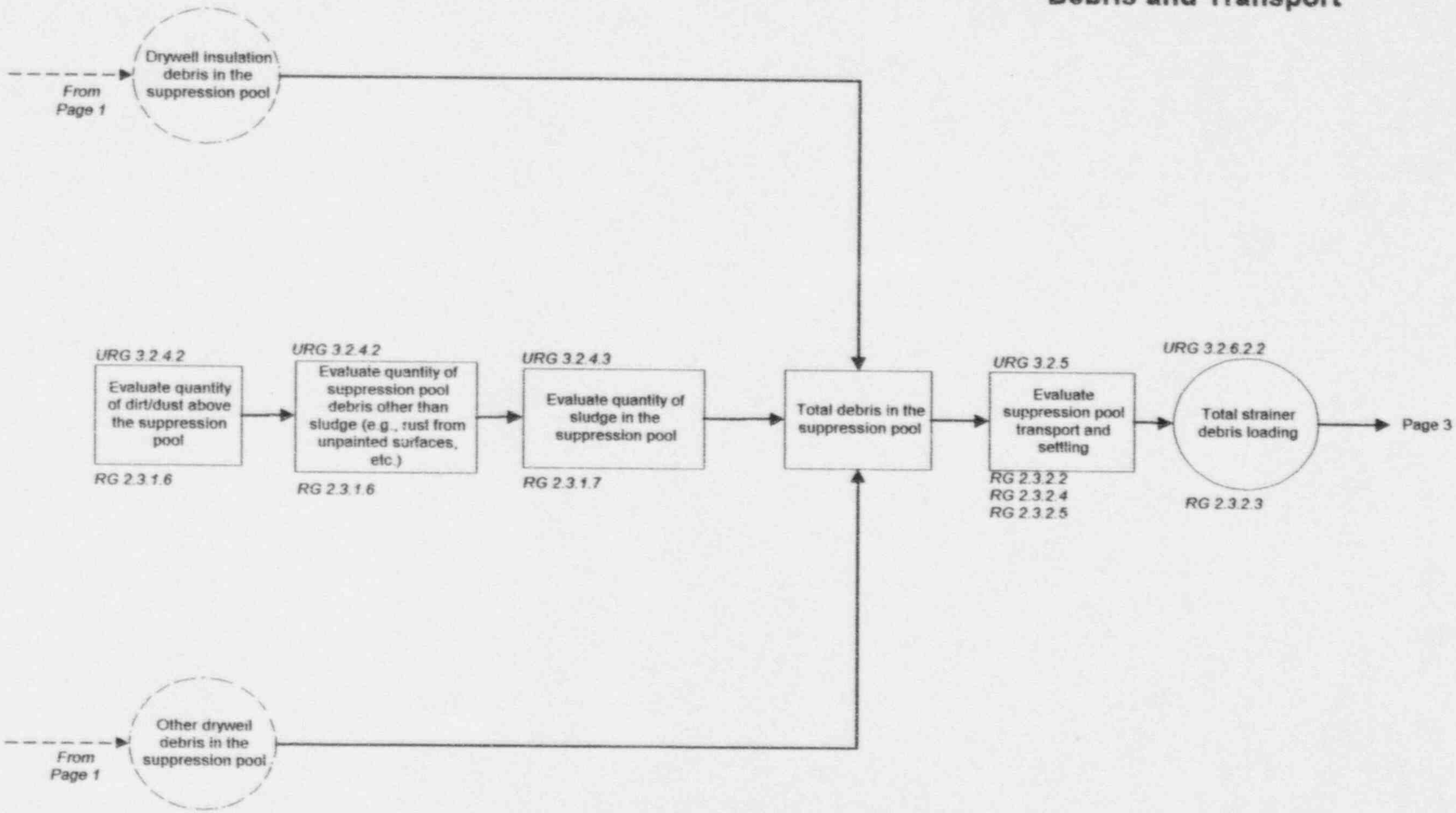
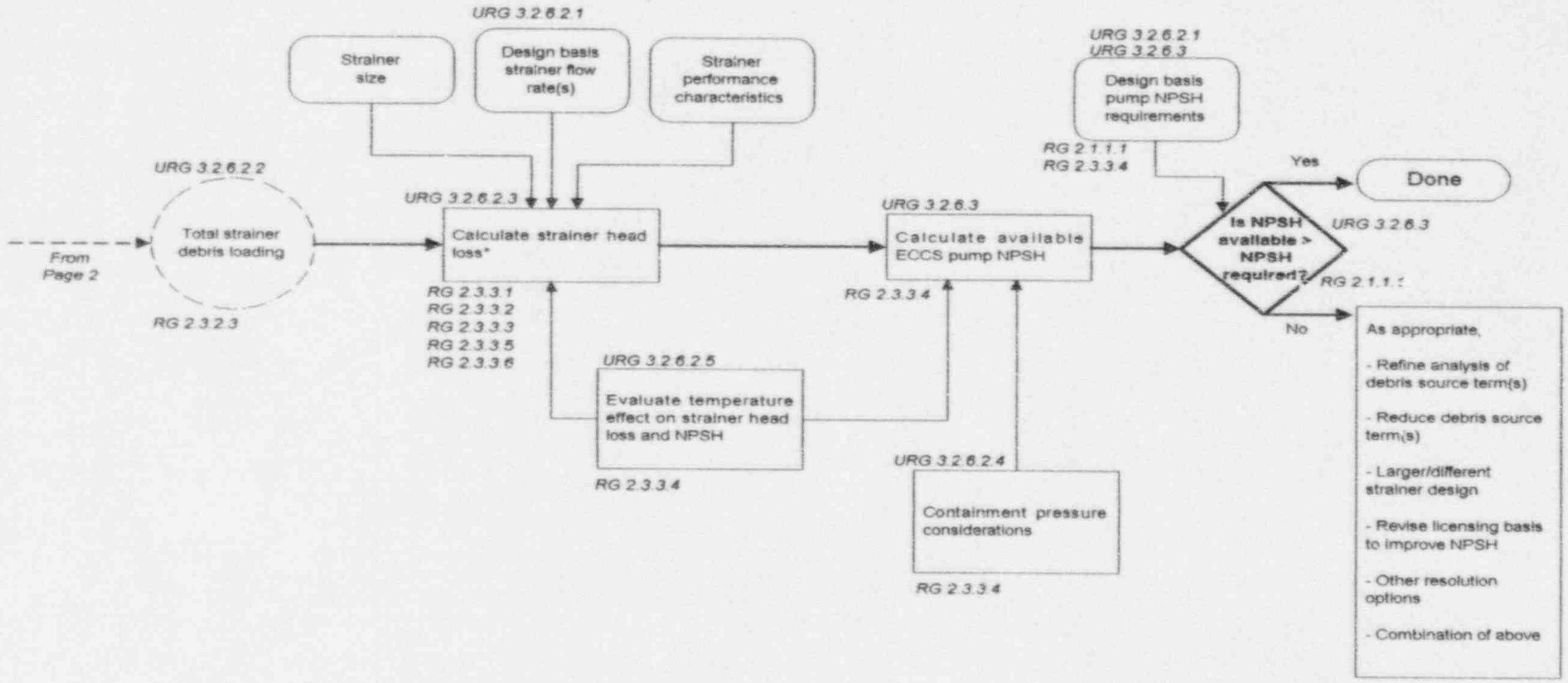


Figure 3 - Evaluation Process Diagram - <u>Suppression Pool Debris and Transport</u>

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 - <u>NPSH Evaluation</u>

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:

$\rho = 0.106$ 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 <u>above</u> the lowest elevation of floor grating and the quantity located <u>below</u> 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 (lb_m) 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

	Axial Separation				
p (psid)	*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

	Axial Separation				
p (psid)	*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

	Axial Separation				
p (psid)	*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	10[illegible].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.

<u>Dirt/Dust</u>

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.

<u>Appendix A</u>

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.

<u>Appendix B</u>

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.)

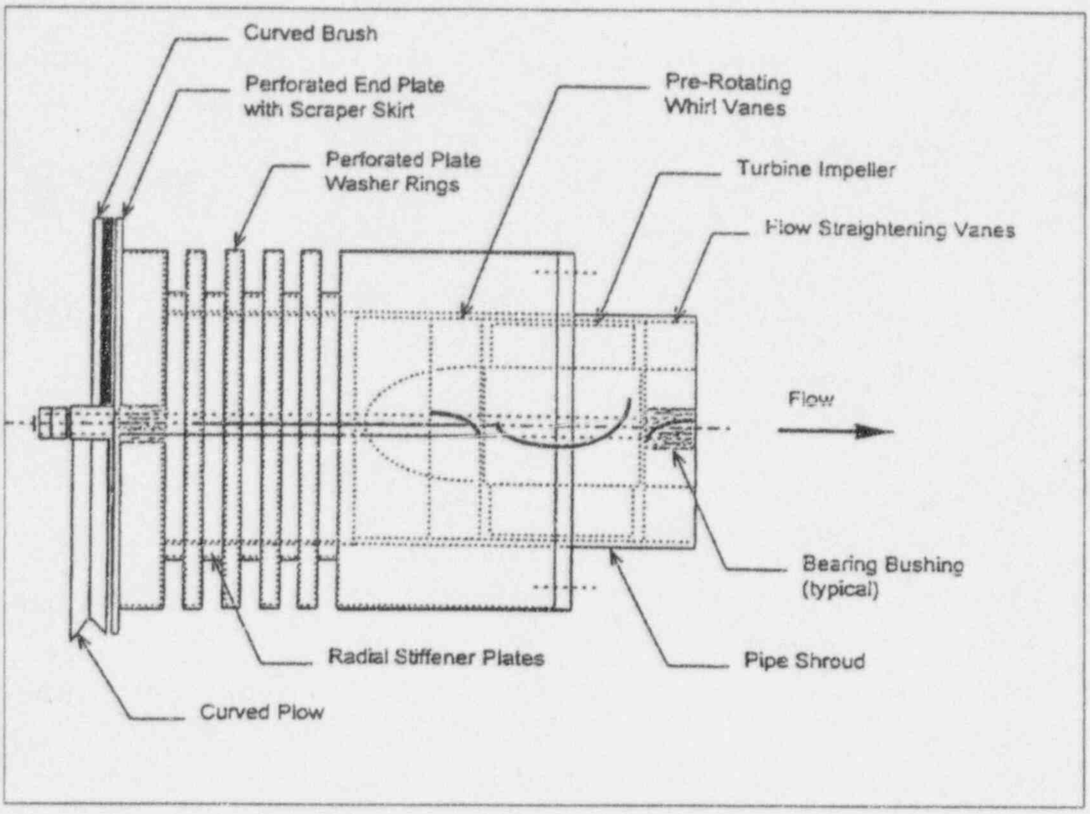


Figure 5 - Side View of Self-Cleaning Strainer

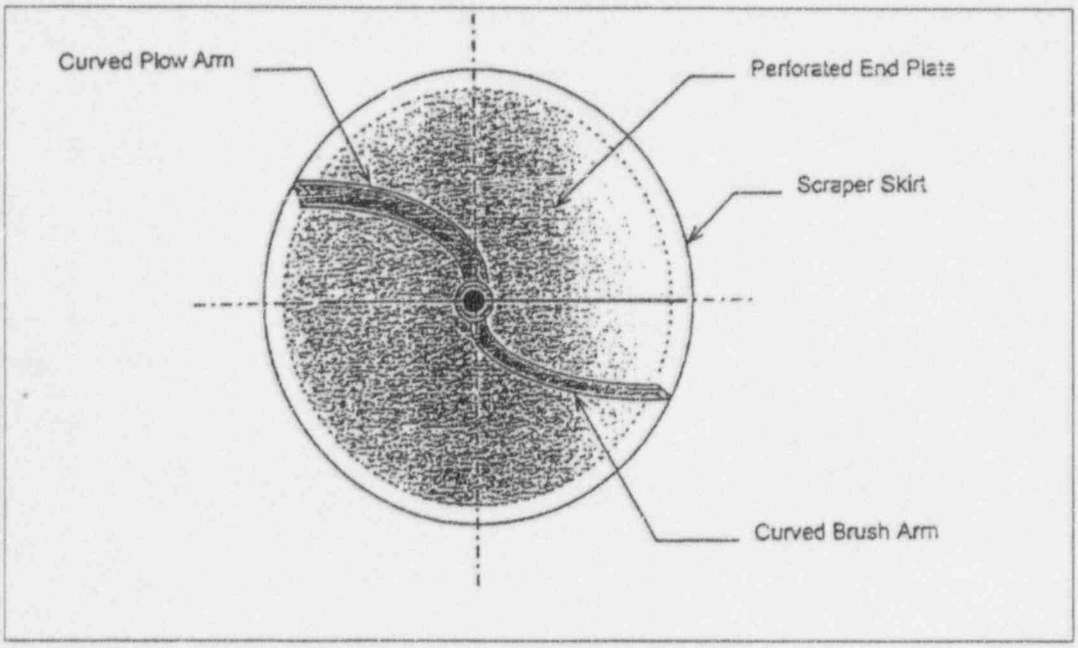


Figure 6 - Front View of Self Cleaning Strainer

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 scurces 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

1. NRC Bulletin 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling-Water Reactors," May 6, 1996
2. Regulatory Guide 1.82, Rev. 2, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," May 1996
3. Continuum Dynamics Report 95-09 Rev. 4,"Testing of Alternate Strainers with Insulation Fiber and Other Debris," November 1996
4. Continuum Dynamics Report 96-01 Rev. 3, "Zone of Influence as Defined by Computational Fluid Dynamics," October 1996
5. Continuum Dynamics Report 96-05 Rev. 1, "Testing of Debris Transport Through Downcomers/Vents Into the Wetwell," October 1996
6. Continuum Dynamics Report 96-06 Rev. A, "Air Jet Impact Testing of Fibrous and Reflective Metallic Insulation," September 1996
7. GE Report "BWR Drywell Floor Flow Modeling Following Pipe Break Loss-of-Coolant Accident," September 1996
8. BWROG Letter OG94-661-161, "BWR Owners' Group ECCS Suction Strainer Committee Suppression Pool Sludge Particle Size Distribution," dated September 13, 1994
9. BWROG Letter OG-96-321-161, Attachment 2 "Suppression Pool Sludge Particle Size Distribution Data - Average Distribution Calculation, " dated April 26, 1996
10. BWROG Letter OG95-388-161, Attachment 4 "BWR Owners' Group Suppression Pool Sludge Generation Rate Data," dated June 12, 1995
11. GE-NE-T23-0700-15-21, Revision 1, "Evaluation of the Effects of Debris on ECCS Performance", March 1996
12. NUREG/CR-6367, "Experimental Study of Head Loss and Filtration for LOCA Debris," February 1996

13. NUREG/CR-6368, "Experimental Investigation of LOCA-Generated Fibrous Debris and Sludge in BWR Suppression Pools," December 1995

14. NRC Letter Report, "BWR Drywell Debris Transport Phenomena Identification and Ranking Table (PIRT), June 28, 1996

15. NRC Letter from C. Berlinger to R. Sgarro (PP&L), "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

16. NRC Letter from C. Berlinger to R. Sgarro (PP&L) "Comments on Draft Utility Resolution Guidance Sections 3.1, 3.2.2, 3.2.4 and 3.4," August 20, 1996

17. 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

18. NRC Bulletin 93-02, "Debris Plugging of Emergency Core Cooling Suction Strainers", May 11 1993, and Supplement 1, February 18, 1994

19. NRC Information Notice 93-34 and Supplement 1, "Potential for Loss of Emergency Core Cooling Function Due to a Combination of Operational and Post-LOCA Debris"

20. NRC Information Notice 94-57, "Debris in Containment and the Residual Heat Removal System", August 12, 1994

21. Bechtel Report 22754094.12A, "Performance of Containment Coatings During a Loss of Coolant Accident," November 10, 1994. (Also included as Appendix III to BWROG Interim Report, Reference 25)

22. NUREG/CR-6224, "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris," Final Report, October 1995

23. Draft Report for Comment, NUREG/CR-6224, "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris," August 1994

24. ANSI/ANS-58.2-1988, "Design Basis for Protection of Light Water Nuclear Power Plants Against the Effects of Postulated Pipe Rupture", October, 1988

25. Interim Report of the Boiling Water Reactor Owner's Group ECCS Suction Strainer Committee, December 1994.

26. NUREG-0897, Rev. 1, "Containment Emergency Sump Performance," October, 1985

27. Regulatory Guide 1.1/Safety Guide 1, "Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal System Pumps," November 1970

28. NUREG-0800, Rev. 4, "Standard Review Plan," October 1985

29. GE Report "Evaluation for Existence of Blast Waves Following Licensing Basis Double-Ended Guillotine Pipe Breaks," August 1996

30. GE Report "Total Pressure Topography and Zone of Destruction for Steam and Mixture Discharge from Ruptured Pipes," September 1996

31. CDI Technical Memorandum 96-13, Rev. A "Effect of Temperature on Net Positive Suction Head Including Strainer Head Loss," September 1996

32. Pipe Break Probabilities in Boiling Water Reactors, November 1993

33. Summary of Debris Washdown Experience, September 1996

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

35. NRC Information Notice 96-59 "Potential Degradation of Post Loss-of-Coolant Recirculation Capability as a Result of Debris," October 30, 1996

36. Alden Research Laboratory Report 52-91/M670F, "Investigation of the Effect of pH on Headloss of NUKON® Insulation Base Wool," April 1991