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# REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

## REGULATORY GUIDE 1.82

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# WATER SOURCES FOR LONG-TERM RECIRCULATION COOLING FOLLOWING A LOSS-OF-COOLANT ACCIDENT

## A. INTRODUCTION

This guide describes methods that the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for use in implementing requirements regarding the sumps and suppression pools that provide water sources for emergency core cooling, containment heat removal, or containment atmosphere cleanup systems. It also provides guidelines for evaluating the adequacy and the availability of the sump or suppression pool for long-term recirculation cooling following a loss-of-coolant accident (LOCA). This guide applies to both the pressurized water reactor (PWR) and boiling water reactor (BWR) types of light water reactors.

The regulatory framework that the NRC has established for nuclear power plants, as pertains to loss of coolant accidents (LOCAs), consists of regulations and supplemental guidance documents. The applicable regulations include, General Design Criterion (GDC) 4, “Environmental and Dynamic Effects Design Bases,” in Appendix A, “General Design Criteria for Nuclear Power Plants,” to Title 10, of the *Code of Federal Regulations*, Part 50, “Domestic Licensing of Production and Utilization Facilities” (10 CFR Part 50) (Ref. 1), which requires that systems important to safety be designed to accommodate LOCAs, as well as GDC 35, “Emergency Core Cooling”; GDC 38, “Containment Heat Removal”; and GDC 41, “Containment Atmosphere Cleanup,” which require that systems be provided to perform specific functions (i.e., emergency core cooling, containment heat removal, and containment atmosphere cleanup) following a postulated design basis accident (DBA). Furthermore, under GDC 36, “Inspection of Emergency Core Cooling System”; GDC 39, “Inspection of Containment Heat Removal System”; and GDC 42, “Inspection of Containment Atmosphere Cleanup Systems,” these systems must be designed to permit the appropriate periodic inspection of important components.

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Under GDC 37, "Testing of Emergency Core Cooling System"; GDC 40, "Testing of Containment Heat Removal System"; and GDC 43, "Testing of Containment Atmosphere Cleanup Systems," these systems must be designed to permit appropriate periodic testing to ensure their integrity and operability. The NRC also requires that licensees of domestic nuclear power plants provide long-term cooling of the reactor core in accordance with 10 CFR 50.46(b)(5). In addition, GDC 1, "Quality Standards and Records," requires that structures, systems, and components important to safety be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. Also, the criteria in Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50 applies to all aspects of suction strainer design, fabrication, testing, and operation. Criterion XI, "Test Control," is particularly important to the emergency core cooling system (ECCS) suction strainers. In accordance with 10 CFR 52.48, "Standards for Review of Applications," these GDC and quality assurance criteria also apply to nuclear power reactor licenses issued under 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants" (Ref. 2). For nuclear power plants licensed before the GDC were developed, the licensee's Updated Final Safety Analysis Report (UFSAR) provides the applicable design criteria.

This regulatory guide contains information collection requirements covered by 10 CFR Part 50 and 10 CFR Part 52 that the Office of Management and Budget (OMB) approved under OMB control number 3150 0011 and 3150-0151, respectively. The NRC may neither conduct nor sponsor, and a person is not required to respond to, an information collection request or requirement unless the requesting document displays a currently valid OMB control number. This regulatory guide is a rule as designated in the Congressional Review Act (5 U.S.C. 801-808). However, the NRC has determined this regulatory guide is not a major rule as designated by the Congressional Review Act and has verified this determination with the OMB.

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# B. DISCUSSION

## Background

The primary safety concerns about long-term recirculation cooling following a LOCA are (1) LOCA-generated and pre-LOCA debris materials transported to the ECCS strainers, the downstream components in the ECCS, the containment spray system (CSS), and the reactor core, resulting in adverse heat transfer, blockage, or wear effects or some combination of all three effects, (2) post-LOCA hydraulic effects, particularly air ingestion (e.g., through vortexing or deaeration) and flashing,[1] and (3) the combined effects of items 1 and 2 on long-term recirculation pumping operability (i.e., effect on net positive suction head (NPSH) available at the pump inlet). These ECCS safety concerns extend to the CSS for plants with containment designs in which the CSSs draw suction from the water supply used for long-term recirculation. In some plant designs (e.g., PWR subatmospheric containments), the CSSs would draw from the recirculation sump significantly earlier than the ECCS would. Some other plant designs result in the CSS switching the pump suction to the recirculation sump after the ECCS pumps switch.

For some plant designs, high energy line breaks (HELBs) that are not LOCAs, such as main steam line breaks, require recirculation from the long-term water source. For these plants, non-LOCA HELBs that require recirculation should be evaluated using the same criteria and methodology (as appropriate for the HELB conditions, duration, and consequences) as those for pipe breaks that result in a LOCA.

Debris that could affect long-term recirculation cooling can be divided into the following categories:

a. debris that is generated directly by the LOCA blowdown (e.g., insulation, coatings, and other materials near the break) and that is subject to transport by blowdown forces,
b. preexisting debris or debris created by adverse environmental conditions (e.g., latent debris or dirt and unqualified coatings not influenced by the LOCA blowdown) that may be transported to the long-term recirculation water source primarily by washdown,
c. other debris that existed before a LOCA, such as in a BWR suppression pool or other storage tanks (e.g., suppression pool sludge), and that may become suspended in the containment sump pool or suppression pool at the start of a LOCA, and
d. chemical reaction products generated within the containment or the reactor vessel.

Licensees/applicants[2] should evaluate debris generation, debris transport, upstream and downstream effects, and attendant blockage of ECCS strainers to ensure that they do not jeopardize the ability of the ECCS to provide long-term, post-LOCA core cooling. Licensees should also evaluate all potential debris sources, including, but not limited to, insulation materials (e.g., fibrous, particulate, and metallic), fire barrier materials, filters and other fiber-bearing materials, latent debris, shielding blankets, corrosion products, chemically reactive materials and their reaction products, and paints or coatings. Section C and Appendix A to this guide provide relevant information for such evaluations. Further

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[1] Gas that may exist in system piping downstream of the strainers could be a concern when recirculation is initiated. Activities in response to Generic Letter (GL) 2008-01, "Managing Gas Accumulation in Emergency Core Cooling, Decay Heat Removal, and Containment Spray Systems," dated January 11, 2008 (ADAMS Accession No. ML072910759), addresses this issue, and the NRC plans to address this issue in future regulatory guidance.

[2] Throughout this RG, the term 'licensee' is used in a generic sense. The user of this document may be a nuclear power plant licensee, an applicant for a license, or a vendor performing evaluations on behalf of a licensee or applicant.

information appears in NUREG/CR-6808, "Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance," issued February 2003 (Ref. 3), which summarizes research on the BWR and PWR ECCS suction strainers that was conducted before 2003. Other, more recent technical guidance appears in the NRC's letter to the Nuclear Energy Institute (NEI) entitled, "Revised Guidance for Review of Final Licensee Responses to Generic Letter 2004-02, 'Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors,'" dated March 28, 2008 (Ref. 4).

It is desirable to use ECCS suction strainers to protect the pump inlets and NPSH margins from debris that may block restrictions in the systems served by the ECCS pumps or damage components. The strainer can be a passive suction strainer or an active strainer. A passive suction strainer is a device that prevents debris from entering the ECCS pump suction line by accumulating it on a porous surface. An active strainer is a device or system that will take some action to prevent debris from entering the ECCS pump suction lines, remove debris from the flow stream upstream of the ECCS pumps, or mitigate any detrimental effects of debris accumulation.

ECCS and CSS pumps are normally centrifugal pumps. For a centrifugal pump to perform its safety function, an adequate margin must exist between the available and the required NPSH[3] (NPSHr). Failure to provide and maintain adequate NPSH for the ECCS pumps could cause cavitation and subsequent failure to deliver the amount of water assumed in design basis LOCA safety analyses. Because the safety of a nuclear power plant depends on the performance of the centrifugal pumps in the ECCS and the containment heat removal system, it is important to maintain adequate margin between the available and required NPSH under all potential conditions.

The available NPSH (NPSHa) is the total suction head of liquid absolute, determined at the first-stage impeller datum, less the absolute vapor pressure of the liquid. The required NPSH, as defined in American National Standards Institute/Hydraulic Institute (ANSI/HI) 1.3-2009, "American National Standard for Rotodynamic (Centrifugal) Pumps for Design and Application" (Ref. 5), is the amount of suction head, over vapor pressure, required to prevent more than a 3-percent loss in total head of the first stage of the pump at a specific capacity.

The predicted performance of the ECCS and the containment heat removal pumps and their associated strainers should be independent of the calculated increases in containment pressure caused by postulated LOCAs to ensure reliable operation under a variety of possible accident conditions. For example, if the proper operation of the ECCS or the containment heat removal system depends on containment pressure being above a specified minimum amount, operation of these systems at a containment pressure less than this amount (e.g., resulting from impaired containment integrity or operation of the containment heat removal systems at too high a rate) could significantly affect the ability of this system to accomplish its safety functions.

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3 The term "required NPSH" is not an NRC regulatory requirement. ANSI/HI 1.3-2009 defines NPSH parameters, including required NPSH.

However, for certain operating reactors, some credit for containment accident pressure may be necessary to demonstrate that adequate pump NPSH margins exist, that unacceptable deaeration will not occur at the strainer, or that sump fluid will not flash to vapor after undergoing a pressure drop at the strainer. This should be minimized to the extent possible. [4]

ANSI/HI 1.3-2009 (Ref. 5) specifies a method of accounting for the decrease in required NPSH with an increase in the temperature of the pumped fluid. This method is subject to restrictions specified in the standard dealing with experience with the specific pump, the amount of air dissolved in the fluid, and the transient nature of the pressure and temperature of the pumped fluid. The staff considers it prudent to avoid taking credit for the reduction in required NPSH that results from the temperature of the pumped fluid because of the uncertainty in these factors. Transient NPSH calculations should be performed to ensure that the most limiting conditions are chosen and that the results are conservative.

The calculation of NPSH margin should include head loss caused by debris by subtracting the total debris laden strainer head loss from the available hydraulic head. The total debris laden strainer head loss, including chemical reaction products, should be determined by prototypical strainer testing. The strainer testing methodology should be similar to that used for the testing performed for the resolution of Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on PWR Sump Performance" (Ref. 6), and GL 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004 (Ref. 7). Section C of this guide, as well as the NRC document entitled, "NRC Staff Review Guidance regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing," dated March 28, 2008 (Ref. 8), discuss this issue in more detail.

The analyses and testing for head loss effects should include all debris and chemical reaction products that are transportable to the ECCS strainer. Fine debris that is small enough to pass through the strainer should be included for head loss effects if it can be filtered by the debris bed on the strainer. ECCS system components and flow restrictions inside the reactor vessel should be evaluated for the erosion, wear, and potential blockage caused by the debris and chemical precipitates that bypass or flow through the debris strainers. Blockage of the ECCS strainer and other debris interceptors is a function of the types, combinations, sizes, shapes, and quantities of insulation debris that can be transported to these components.

The size of openings in the strainer should consider the physical restrictions that may exist in the systems that are supplied with coolant from the ECCS sump, including the size of the openings in the containment spray nozzles; coolant channel openings in the core fuel assemblies; the presence of fuel assembly inlet debris screens; components with small clearances within system flowpaths (e.g., high-pressure safety injection (HPSI) throttle valves); pump design characteristics, such as seals, bearings, and impeller running clearances; clean screen head loss; and the consequences of the downstream accumulation of debris passing through the sump strainer. The amount of debris that passes through or

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4 As of the date of the publication of revision 4 of this RG, the staff is in the process of implementing SRM SECY-11-0014-"Use of Containment Accident Pressure in analyzing Emergency Core Cooling System and Containment Heat removal System Pump Performance in Postulated Accidents" (Adams Accession No. ML110740254), which addresses containment accident pressure and ECCS pump NPSH. Additional guidance for review of information in license amendments and applications regarding containment accident pressure is available in draft form in letters transmitted to the BWROG and PWROG. This draft guidance will be augmented by work in progress as of issuance of the RG and revised guidance will be issued in the future

bypasses a strainer also depends on the strainer area, the strainer layout, debris arrival sequence, the concentration of debris at the strainer, and the properties of the nearby fluid field approaching the strainer.

As noted above, a number of factors, including plant design and layout, can cause degraded pump performance. In particular, debris blockage effects on ECCS strainers, sump outlet configurations, and post-LOCA hydraulic conditions (e.g., air ingestion) should be considered in an integrated manner. Small amounts of ingested gas during steady-state pump operation (typically 2 percent by volume when the ratio of flow rate to best efficiency flow rate is between 40 and 120 percent and 1 percent when outside of this range) will not lead to severe pumping degradation if the required NPSH from the pump manufacturer's curve is increased based on the calculated air ingestion. Thus, it is important to use the combined results of all post-LOCA effects to estimate NPSH margin at the pump inlet. Appendix A to this guide provides information for estimating NPSH margins in ECCS strainer designs in which estimated levels of air ingestion are low (2 percent or less). NUREG-0897, Revision 1, "Containment Emergency Sump Performance (Technical Findings Related to Unresolved Safety Issue A-43)" (Ref. 9), and NUREG/CR-2792, "An Assessment of Residual Heat Removal and Containment Spray System Pump Performance under Air and Debris Ingesting Conditions" (Ref. 10), provide additional technical findings relevant to NPSH effects on pumps performing the functions of residual heat removal, emergency core cooling, containment cooling, and containment atmosphere cleanup. When air ingestion is 2 percent or less, compensation for its effects may be achieved without redesign if the available NPSH is greater than the required NPSH plus a margin based on the percentage of air ingestion. A 2-percent limit on allowed air ingestion was selected because data show that air ingestion levels exceeding 2 percent have the potential to produce significant head degradation; therefore, redesign of one or more of the recirculation loop components may be necessary.

Gas intrusion and accumulation issues in plant safety systems have been an ongoing concern for many years. The NRC issued GL 2008-01 (Ref. 11) to request each licensee evaluate its emergency core cooling, decay heat removal, and containment spray systems for licensing basis, design, testing, and corrective actions regarding pump response to suction voids. In addition, the NRC requested that licensees demonstrate that the subject safety-related systems comply with the applicable regulatory requirements to ensure that gas void accumulation and transport as the result of deaeration or air ingestion, or both, is maintained less than the amount that challenges operability of these systems and that appropriate action is taken when conditions adverse to quality are identified. Licensees should evaluate and address deaeration, flashing, and other air entrainment mechanisms, as discussed in GL 2008-01 (Ref. 11) and Appendix A to this guide.

The NRC developed this regulatory guide using insights from operating PWRs and BWRs, and the guide provides common regulatory positions applicable to both PWRs and BWRs. In certain areas, however, the guide provides separate guidance for PWR and BWR plants based on the design features of currently operating reactors. New or advanced PWR or BWR designs may employ design features that differ from the operating reactors that formed the basis of this regulatory guide, and adjustments may be necessary. For example, a plant with passive features will have to make adjustments regarding pump NPSH, and PWRs with in-containment refueling water storage tanks may need to use features of both the PWR and BWR guidance. Therefore, for a new or advanced reactor designs, this document provides guidance for both PWRs and BWRs, recognizing that some sections may need adjustment based on the particular plant features.

## Pressurized-Water Reactors

In PWRs, the containment emergency sumps serve as water sources to support long-term recirculation for residual heat removal, emergency core cooling, containment cooling, and containment atmosphere cleanup. These water sources, the related pump suction inlets, and the piping between the sources and suction inlets are important safety components. In this guide, the term ECCS implicitly includes the CSS, and the sumps or strainers (or both) servicing the ECCS and the CSS are referred to as ECCS sumps or ECCS strainers.

The design of PWR strainers and their outlets should consider the avoidance of air ingestion, gas void intrusion, flashing, accumulation of deaerated air, and other undesirable hydraulic effects (e.g., circulatory flow patterns and outlets leading to high head losses). The location and size of the sump outlets within ECCS sumps are important to minimize air ingestion caused by vortexing at the pump suction inlets because this phenomenon depends on the submergence level and velocity in the outlet piping. Experiments for PWRs have determined that air ingestion and gas void intrusion caused by vortexing at the pump suction inlets can be minimized by following the sump hydraulic design considerations provided in Appendix A to this guide. NUREG-0897, Revision 1 (Ref. 9), and NUREG/CR-2758, "A Parametric Study of Containment Emergency Sump Performance" (Ref. 12), provide additional technical information relevant to sump ECCS hydraulic performance and original design guidelines. The hydraulic design guidelines provided in Table A-1 of Appendix A apply to designs that do not have a complete water seal over the strainer or that otherwise could have a free surface inside the strainer volume. For example, the sump design could include a vent, the strainer might not be fully submerged, or a pocket of gas could accumulate inside the strainer. For fully submerged, unvented strainers, licensees should evaluate the possibility of vortex formation at the strainer surface using other analytical or empirical means.

Air or gas voids can also be generated downstream of the strainer surface as the result of dissolved gas coming out of solution within the sump fluid after undergoing a pressure drop across the debris bed on the strainer or across flow restrictions within the ECCS piping. Excessive deaeration resulting from the passage of flow through the debris bed or internal system flow restrictions could significantly increase the head loss and impair pumping performance. A similar increase in head loss could occur because of the flashing of sump fluid to vapor as a result of undergoing a differential pressure drop at the strainer or inside the ECCS. Both sump fluid flashing and the generation of air or gas voids through deaeration should be avoided by providing sufficient strainer submergence relative to the expected pressure drop. In general, flashing across or within the strainer should be avoided.

Placement of the ECCS strainers at the lowest floor level practical ensures maximum use of available recirculation coolant. Areas within the containment in which coolant could accumulate during the containment spray period should be provided, as necessary, with drains or flowpaths to the sumps to prevent coolant holdup. Debris may also block the drains or flowpaths themselves, either totally or partially, thus preventing water from reaching the active sump region. Drains and other upstream flowpaths necessary to ensure adequate performance of the ECCS sumps that may be susceptible to debris blockage should be protected by trash racks or other design features to ensure that they will satisfy their intended function. Because debris can migrate to the ECCS strainers through these drains or paths, they are best terminated in a manner that will prevent debris from being transported to, and accumulating on or within, the sumps.

Containment drainage sumps collect and monitor normal equipment leakage flow for leakage detection systems within containments. They are typically separated from the ECCS water sources and are located at an elevation lower than the ECCS pools to minimize inadvertent spillover into the ECCS from minor leaks or spills within containment. The general floor area adjacent to the ECCS strainers normally slopes downward, away from the ECCS strainers, toward the drainage collection sumps. This downward slope away from the ECCS strainers reduces the tendency for the transport and collection of debris against the ECCS strainers. Another method used to reduce the quantity of larger pieces of debris from accumulating on the strainer may be elevating the sump strainers slightly above the floor level, on a pedestal. NUREG/CR-6772, "GSI-191: Separate-Effects Characterization of Debris Transport in Water"

(Ref. 13), provides test results for the transport of various types, sizes, and shapes of debris with variables of flume water depth, turbulence intensity, flow patterns, fluid temperature, simultaneous presence of combinations of debris, types of obstructions, and extent of congestion and height of curbs. NUREG/CR-6916, "Hydraulic Transport of Coating Debris," (Ref. 14), provides test results for the transport of protective coating debris.

The flow may sweep debris pieces too large or dense to remain in suspension along the floor toward the ECCS strainer. Trash racks, debris curbs, and debris interceptors upstream of the ECCS strainers may decrease the amount of such debris reaching the strainer. Some debris interceptor designs may also be effective at reducing the transport of fine, suspendable debris; however, demonstrating the effectiveness of such interceptors in capturing fine debris can be complex. Debris blockage of the ECCS strainers may also be mitigated by placement of a device or system that performs an active function to prevent debris from entering the ECCS pump suction lines, to remove debris from the strainer and flow stream upstream of the ECCS pumps, or to mitigate any detrimental effects of debris accumulation.

ECCS strainers and any trash racks, debris interceptors, or similar design features credited in the strainer performance analysis should be of sufficient strength to withstand the vibratory motion of seismic events, to resist jet impingement loads and impact loads that could be imposed by missiles that are generated by the LOCA, and to withstand the differential pressure loads imposed by the accumulation of debris. Considerations for selecting materials for ECCS strainers, debris interceptors, and other design features include long periods of inactivity (i.e., no submergence) and periods of operation involving partial or full submergence in a fluid that may contain chemically reactive materials.

Isolation of the ECCS strainers from high-energy pipelines is an important consideration in protection against internally generated missiles, and it is necessary to shield the ECCS strainers, debris interceptors, and other credited design features from impacts of ruptured high-energy piping and associated jet impingement loads. ECCS strainers should be designed to prevent adverse blockage effects from large pieces of debris (e.g., partially torn insulation blankets or damaged reflective metallic insulation cassettes) that collect on them and block a large fraction of the available surface area. For example, despite their large and complex surface area, some ECCS strainers located in a pit below the containment floor grade could be susceptible to blockage by large pieces in a circumscribed accumulation at the relatively restricted opening to the pit if trash racks or interceptors are not installed. Consistent with the plant licensing basis single-failure criterion, redundant ECCS strainers should be separated to the extent practical to reduce the possibility that a single event could render more than one train inoperable.

It is generally expected that the water surface will be above the top of the ECCS strainer after completion of the injection phase and before the ECCS recirculation phase begins. However, the uncertainties about the extent of water coverage on the strainer, the amount of floating debris that may accumulate, and the potential for early clogging do not favor the use of a strainer that is oriented horizontally. Therefore, in the computation of available strainer surface area, no credit may be taken for any horizontal strainer surface unless plant evaluations that adequately account for inherent water source uncertainties demonstrate that the horizontal surface will be submerged at the time of recirculation. For certain sump designs, the top of the sump structure should preferably be a solid cover plate that will provide additional protection from LOCA-generated loads and the direct impact of water drainage. If there is a cover plate, it should be designed to provide for the venting of any trapped air. It is possible that ECCS sump strainers in some plants may not be submerged completely at the time of recirculation, either because of unique designs or because of uncertainties in water-level estimates. ECCSs and CSSs with partially submerged strainers may be subject to failure criteria other than NPSH margin, as discussed in Section C.1.3.11.3 and Appendix A to this guide. In the case of partially submerged strainers, credit should only be given for the portion of the strainer that is expected to be submerged as a function of time.

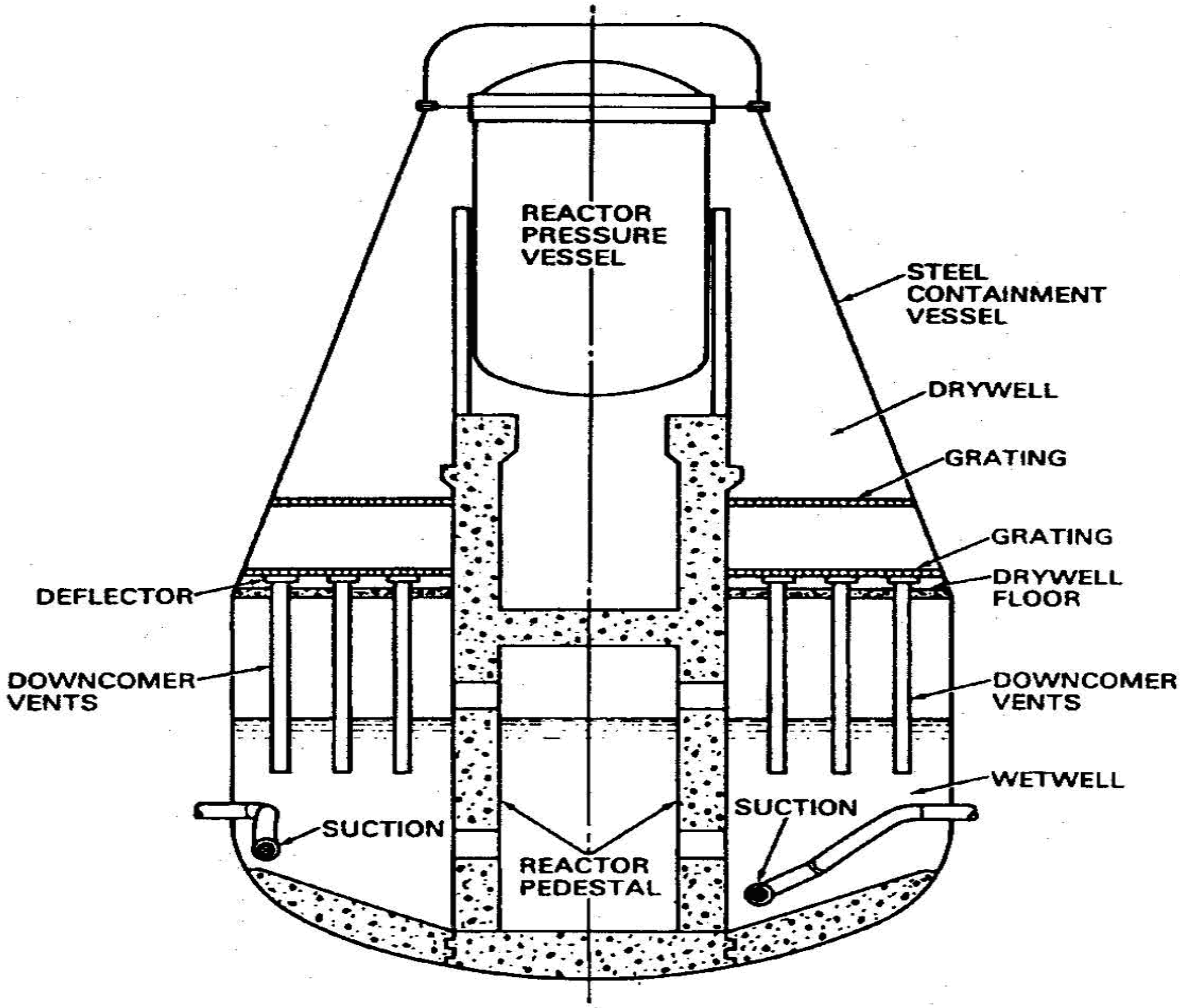
A strainer with a complex geometry design that is located on the containment floor level would reduce the deposition or settling of debris on strainer surfaces and thus help to ensure the greatest possible free flow through the strainer.

## Boiling-Water Reactors

In BWRs, the suppression pool, also referred to as the wetwell, serves as the water source for effecting long-term recirculation cooling. This source, the related pump suction inlets, and the piping between them are important safety components. Figure 1 shows the features and relationships of the suppression pool or wetwell pertinent to this guide.

**Figure 1. Conceptual features of a BWR Mark II containment**

**(Other BWR containments are similar in function.)**




Note: Variations in suppression pool features (e.g., number, design and location of suction screen and down comer vents) exist but are not shown.

Concerns with the performance of the suppression pool hydraulics and ECCS pump suction strainers include consideration of air ingestion effects, blockage of suction strainers by debris, and the combined effects of these items on the operability of the ECCS pumps (e.g., the impact on NPSH available at the pump inlets). NUREG-0897, Revision 1 (Ref. 9), provides data on the performance and air ingestion characteristics of some types of BWR suction strainer configurations. Currently operating

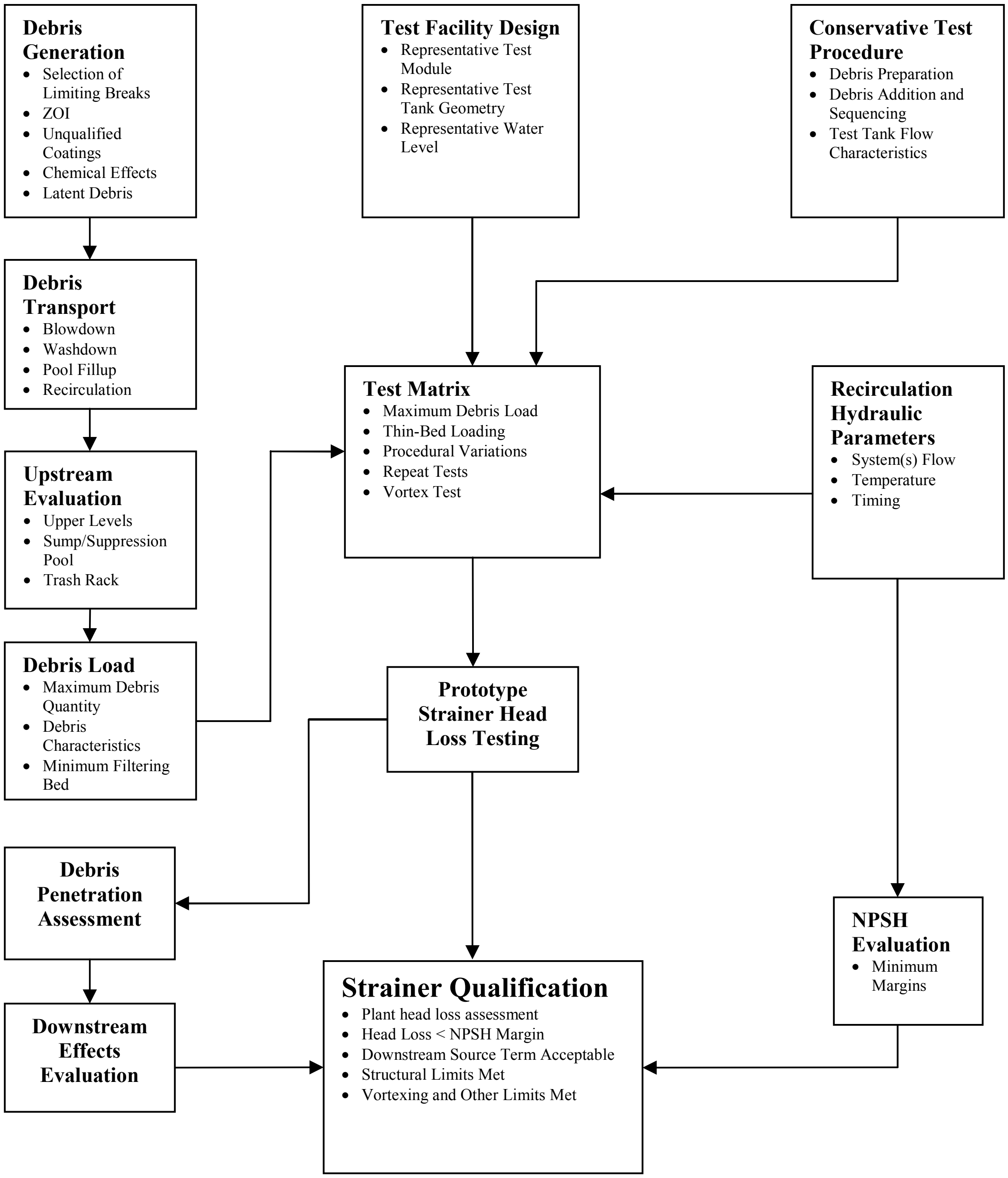
BWR strainer designs are based on guidance from sources such as the BWR Owners Group Utility Resolution Guidance (Ref. 15), the accompanying safety evaluation (SE) found in Volume 1 of Ref. 15, and NUREG/CR-6224, "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris" (Ref. 16). In future evaluations, BWR strainer designs should consider subsequent guidance developed during the resolution of GSI-191 and GL 2004-02 including chemical and downstream effects and strainer head loss and vortexing. For details, refer to the recent NUREG-series publications, several industrial topical reports and their accompanying SEs, and other technical guidance listed in the reference section of this guide.

The safety analyses, including debris transport in and to the suppression pool, should include the effects of the LOCA progression because LOCAs of different sizes will affect the duration of LOCA-related hydrodynamic phenomena (e.g., condensation oscillation, chugging, and blowdown). The LOCA-related hydrodynamic phenomena and long-term recirculation hydrodynamic conditions will affect the transport of debris in the suppression pool.

Debris that is transported to the suppression pool during a LOCA or that is present in the suppression pool before a LOCA could block or damage the suction strainers and should be evaluated for head loss effects through prototypical strainer testing (see Information Notice (IN) 94-57, "Debris in Containment and the Residual Heat Removal System," dated August 12, 1994 (Ref. 17); IN 95-06, "Potential Blockage of Safety-Related Strainers by Material Brought inside Containment," dated January 25, 1995 (Ref. 18); and IN 95-47, "Unexpected Opening of a Safety/Relief Valve and Complications Involving Suppression Pool Cooling Strainer Blockage," dated October 4, 1995 (Ref. 19)). The strainer testing methodology should be similar to that used for the testing performed for the resolution of GSI-191 and GL 2004-02, as discussed in Section C.1.3 of this guide. This head loss evaluation should consider the filtration of particulate, fibrous, chemical, and coating debris by the accumulated debris bed. The head loss characteristics of a debris bed will be a function of the types and quantities of the debris, suction strainer approach velocities, and LOCA-related hydrodynamic phenomena in the suppression pool. Chemical reaction products (e.g., precipitates) are also to be considered in determining total debris load. Those plants that credit the standby liquid control system or equivalent to inject boron into the primary system as a DBA mitigating system should also include in the head loss evaluation the potential chemical reaction products resulting from the use of that system.

The flow chart (Fig 2) on the following page illustrates the input logic and information required for head loss testing and design of an ECCS suction strainer. Guidance for each step in the process can be found in the applicable Regulatory Positions in Section C.

**Figure 2. Flow chart for steps in qualification of a suction strainer**



The International Atomic Energy Agency (IAEA) has established a series of safety guides and standards constituting a high level of safety for protecting people and the environment. IAEA safety guides present international good practices and increasingly reflect best practices to help users striving to achieve high levels of safety. Pertinent to this regulatory guide, IAEA Safety Guide NS-G-1.9, "Design of the Reactor Coolant System and Associated Systems in Nuclear Power Plants" (Ref. 20), issued in 2004, addresses design considerations for the ECCS in Sections 4.68 through 4.91. The NRC has an interest in facilitating the harmonization of standards used domestically and internationally. In this case, there are many similar elements between this regulatory guide and the corresponding section of the safety guide. This regulatory guide consistently implements and details the principles and basic safety aspects provided in IAEA Safety Guide NS-G-1.9.

# C. STAFF REGULATORY GUIDANCE

## 1. General

This section includes regulatory positions on design criteria, performance standards, and analysis methods that relate to all water-cooled reactor types (Section C.1.1) and to specific light-water reactor types (PWRs in Section C.2 and BWRs in Section C.3). As stated in the introduction to this guide, the purpose of the guidance is to identify information and methods that the NRC staff considers acceptable for use in evaluating analytical techniques and implementing regulations related to water sources for long-term cooling of both existing and future reactor systems.

### 1.1 Regulatory Positions Common to All Water-Cooled Reactors

Research, analysis, and lessons learned have shown that similar approaches are appropriate for water-cooled reactors in a number of areas when the long-term recirculation capability evaluation is performed. These areas include NPSH evaluation, selection of limiting pipe breaks, debris generation, debris transport, coating debris, latent debris, sump structure, downstream effects, chemical effects, structural analyses, and head loss testing.

#### 1.1.1 Emergency Core Cooling System Sumps, Suppression Pools, Suction Strainers, and Debris Interceptors

The ECCS sumps or suppression pools, which are the source of water for functions such as ECCS and containment heat removal following a LOCA, should contain an appropriate combination of the features and capabilities listed below to ensure the availability of the water sources for long-term cooling.

1.1.1.1 A minimum of two independent ECCS suction strainers should be provided, each with sufficient capacity to accommodate the full plant debris loading while providing sufficient flow to one train of the ECCS and containment heat removal pumps. To the extent practical, the redundant suction strainers should be physically separated from each other by structural barriers to preclude damage resulting from a LOCA, such as whipping pipes or high-velocity jet impingement.

1.1.1.2 The containment floor in the vicinity of floor-mounted ECCS strainers should slope gradually downward away from the strainers to retard floor debris transport and reduce the fraction of debris that might reach the suction strainer. Similar floor sloping should be used in the vicinity of a sump pit if the ECCS strainers are installed in a pit configuration. Debris interceptors or curbs can also be used to retard debris transport.

1.1.1.3 The inlet of pumps required for long-term cooling should be protected by a suction strainer placed upstream of the pumps to prevent the ingestion of debris that may damage components or block restrictions in the systems served by the pumps.

1.1.1.4 All drains from the upper regions of the containment should terminate in such a manner that direct streams of water will not directly impinge on, or discharge in close proximity to, the ECCS strainers. Streams of drainage from upper containment may contain entrained debris and could also result in air ingestion and other issues if they directly impinge on the strainers. The drains, drain piping internal clearances, and other pathways that connect containment compartments with potential break locations to the sump or suppression pool should be designed to ensure that they would not become blocked by the debris; this will ensure that water needed for an adequate NPSH margin could not be held up or diverted from the pool.

1.1.1.5 Trash racks, suction strainers, and debris interceptors should be capable of withstanding the loads imposed by expanding jets, missiles, the accumulation of debris, and pressure differentials caused by post-LOCA blockage under design-basis or realistic flow conditions, whichever causes the greater loads. When evaluating the impacts from potential expanding jets and missiles, licensees should justify credit for any protection offered by surrounding structures or credit for remoteness of trash racks and strainers from potential high-energy sources.

1.1.1.6 ECCS strainers, trash racks, and debris interceptors should be designed to withstand the inertial and hydrodynamic effects caused by the vibratory motion of a safe-shutdown earthquake following a LOCA without loss of structural integrity.

1.1.1.7 Licensees should select materials for debris interceptors, trash racks, and suction strainers that do not degrade during periods of inactivity or operation and that have a low sensitivity to stress-assisted corrosion or general corrosion that may be induced by chemically reactive spray or by the containment or suppression pool liquid during a LOCA.

1.1.1.8 Licensees should choose a suction strainer design (i.e., size and shape) that will prevent unacceptable loss of NPSH margin from debris accumulation during the period that the ECCS and CSS are required to operate in order to maintain long-term cooling or to maximize the time before the loss of NPSH caused by debris blockage when used with an active mitigation system (see Section C.1.1.4).

1.1.1.9 Licensees should assess the possibility of debris clogging narrow flow passages downstream of the ECCS strainer to ensure adequate long-term recirculation cooling, containment cooling, and containment pressure control capabilities. The size of the openings in the strainer should be determined by considering the flow restrictions of systems served by the containment pool. Licensees should consider the potential for long, thin slivers passing axially through the suction strainer and then reorienting and clogging at any flow restriction downstream.

1.1.1.10 Licensees should consider the buildup of debris and chemical reaction products at downstream locations, including containment spray nozzle openings, HPSI throttle valves, coolant channel openings in the core fuel assemblies, fuel assembly inlet debris screens, ECCS pump seals, bearings, and impeller running clearances. The design of the ECCS pumps is a large factor in determining the sensitivity of the pump operability to ingestion of debris. Three aspects of pump operability—hydraulic performance, mechanical shaft seal assembly performance, and pump mechanical performance (vibration)—must be considered when evaluating the ECCS pumps for operation with debris-laden water. Westinghouse Commercial Atomic Power (WCAP)-16406-P-A, "Evaluation of Downstream Sump Debris Effects in Support of GSI-191"[5] (Ref. 21), and its SE (Ref. 22) provide evaluation methods and criteria that the NRC considers acceptable. If wear or internal blockage evaluations indicate that a component may not be able to accomplish its design function throughout its mission time and that it is not practical to install a suction strainer with openings small enough to filter out debris that cause excessive damage to ECCS pump seals or bearings, the NRC expects licensees to modify the ECCS pumps or procure new ECCS pumps that can operate long term under the postulated conditions. WCAP-16793-NP, Revision 2, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and Chemical Debris in the Recirculating Fluid," issued October 2011 (Ref. 23), discusses a method for use in evaluating the downstream impact of debris on the fuel assemblies, as discussed further in Section C.1.3.8.b of this guide. (At the time this guide was revised, the NRC staff had not yet completed its review of WCAP-16793-NP). WCAP-16530-NP-A, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids To Support GSI-191," issued March 2008 (Ref. 24), provides a general approach to conducting chemical effects evaluations, as discussed in Section C.1.3.10 of this guide.

1.1.1.11 ECCS strainers and suction inlets for pumps required for long-term ECCS, CSS, or suppression pool cooling functions should be designed to prevent degradation of pump performance through air ingestion, flashing, and other adverse hydraulic effects (e.g., circulatory flow patterns, high-intake head losses, and gas void intrusion).

1.1.1.12 Advanced strainer designs have demonstrated capabilities that are not provided by simple flat plate or basket type strainers or screens. The performance characteristics and effectiveness of such designs should be supported by appropriate test data for any particular intended application.

1.1.1.13 Prototypical head loss testing should be done to verify suction strainer designs. Section C.1.3.12 provides guidance on prototypical head loss testing.

1.1.2 Minimizing Debris

The debris and chemical reaction products (see Sections C.1.3.3 and C.1.3.10) that could accumulate on the suction strainer should be minimized.

1.1.2.1 Licensees should maintain debris source terms to less than the amount assumed in the strainer performance analysis. For example, cleanliness programs should ensure that the assumed latent debris and suppression pool sludge loading is not exceeded, and controls should be

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5 WCAP-16406-P-A, Revision 1, contains information proprietary to Westinghouse Electric Company, LLC and is not publicly available.

maintained to ensure that problematic debris (e.g., insulations, signage, coatings, foreign materials, and chemically reactive materials) are not introduced into containment to an extent that would exceed the analytically assumed values. In addition, permanent plant changes inside containment should be programmatically controlled so as to not change the analytical assumptions and numerical inputs of the licensee analyses.

1.1.2.2 When latent debris is a significant source of debris (i.e., latent debris contributes more than a minimal amount to strainer head loss) that can affect strainer performance or create downstream effects, periodic containment surveys or sampling should be performed to verify that the amount of latent debris is within the assumed limits. Such periodic monitoring may not be necessary if the latent debris evaluation incorporates sufficient conservatism to account for the substantial uncertainties associated with latent debris sampling (See section 1.3.6 for more information regarding latent debris).

1.1.2.3 Licensees should adequately assess any new or unanalyzed potential debris sources (e.g., fiber and coatings) resulting from future equipment modifications inside containment against assumptions of debris quantities and types inside containment, as specified in the post-accident sump/pool analysis. Additionally, licensees should assess tags and labels, which can fail and be transported to the strainer, and determine a sacrificial strainer area to account for the strainer area that could become fully blocked by these transportable tags, labels, and other miscellaneous debris.

1.1.2.4 Licensees should consider using insulation types (e.g., reflective metallic insulation) that transport less readily and cause less severe head losses once deposited onto the strainer in place of insulation types (e.g., fibrous and microporous) that can become debris which can more readily transport to the strainer and cause higher head losses. If insulation is replaced or otherwise removed during maintenance, abatement procedures should be established to avoid generating latent debris in the containment.

1.1.2.5 To minimize potential debris caused by the chemical reaction of the pool water with metals in the containment, licensees should reduce as much as practical the exposure of bare metal surfaces (e.g., aluminum and uncoated carbon steel) to containment cooling water through spray impingement or immersion either by removal or by chemical-resistant protection (e.g., qualified coatings or jacketing).

### 1.1.3 Instrumentation and Operator Actions

If a licensee relies on operator actions to mitigate the consequences of the accumulation of debris on the ECCS suction strainer, it should ensure that safety-related instrumentation that provides operators with an indication and audible warning of impending loss of NPSH for ECCS pumps is available in the control room.

If a licensee relies on operator actions to prevent the accumulation of debris on ECCS suction strainers or to mitigate the consequences of the accumulation of debris on the ECCS strainers, it should evaluate whether the operator has adequate indications, training, time, procedural guidance, and system capabilities to perform the necessary actions.

### 1.1.4 Active Systems

An active device or system may be provided to prevent excessive accumulation of debris on the ECCS strainers or to mitigate the consequences of debris accumulation on the strainers. An active system should be able to prevent the accumulation and entry into the system of debris that may block restrictions found in the systems served by the ECCS pumps. The operation of the active component or system should not adversely affect the operation of other ECCS components or systems. Under some operational modes, an active system may allow more debris to pass through the strainer. If this is the case, then the downstream effects analysis should be performed accordingly. Performance characteristics of an active system should be supported by appropriate test data that address head loss performance. Active systems should meet the requirements for redundancy for active components.

#### 1.1.5 Inspection

To ensure the operability and structural integrity of the ECCS strainers and associated structures, access openings may be necessary to permit inspection of the ECCS strainers and associated structures, sump pits, and pump suction piping inlets. On a regular basis, licensees should inspect (including visual examination) strainers, trash racks, vortex suppressors, and pump suction piping inlets for evidence of structural degradation, potential for debris bypass, and presence of corrosion or debris blockage. The licensee should conduct similar inspections for drainage flowpaths (e.g., refueling cavity drains and floor drains), debris interceptors, trash racks, and other design features upstream of the ECCS strainers that are credited in the strainer performance analysis. Inspection of the ECCS strainer, associated structures, and upstream components is best conducted late in a refueling outage to ensure the absence of debris generated by construction or maintenance in the vicinity of the ECCS strainers and upstream design features.

### 1.2 Evaluation of Alternative Water Sources

Licensees should establish emergency operating procedures to use alternative water sources, either safety related or non-safety related, that will be activated if unacceptable head loss renders the ECCS strainers inoperable. For some plant designs, the use of alternative water sources may involve replenishing the inventory of the water storage tank that served as the source of inventory for core cooling during the injection phase of the LOCA. In this case, if the flow rate of the makeup supply to the alternative water source is not larger than the core boiloff rate, procedures should direct replenishment of the water storage tank with alternative water sources following the switchover to recirculation. This flowpath should have a sufficient flow rate to ensure that an adequate water supply will be available in the water storage tank if excessive debris blockage subsequently renders the ECCS strainers inoperable. Licensees should periodically inspect and maintain the valves needed to align the ECCS, CSS, and suppression pool cooling pumps from the recirculation water source to an alternative water source. The impact of adding water volume to containment should be evaluated, if this step is to be used.

### 1.3 Evaluation of Long-Term Recirculation Capability

a. To demonstrate that a combination of design features and operator actions are adequate to ensure long-term cooling and that the criteria of 10 CFR 50.46(b)(5) will be met following a LOCA, licensees should evaluate the long-term recirculation capability. The techniques, assumptions, and guidance described below should be used in a plant-specific evaluation to ensure that any implementation of a combination of the features and capabilities listed in Section C.1.1 are adequate to ensure the availability of a reliable water source for long-term recirculation following a LOCA. These assumptions and guidance can also be used to develop conditions for the suction strainer testing.

b. Licensees should evaluate (1) ECCS strainer hydraulic performance (e.g., geometric effects, air ingestion, flashing, and gas void accumulation), (2) debris effects (e.g., break selection, debris generation, debris transport, latent debris, chemical precipitation, upstream, downstream, interceptor blockage, strainer head loss, and structural integrity), and (3) the combined impact on NPSH available at the pump inlet to confirm and ensure that long-term recirculation cooling can be accomplished following a LOCA. Such an evaluation should demonstrate adequate strainer and pumping performance (e.g., adequate pump NPSH margins, adequate strainer structural strength, and no excessive air ingestion). Licensees should also assess the susceptibility to debris blockage of the containment drainage flowpaths to the recirculation sump or suppression pool. A holdup of water to the pool could affect the NPSH available, flashing and/or air ingestion evaluations. In addition, licensees should assess the structural adequacy of any interceptors or trash racks used to prevent debris blockage of these flowpaths to protect against a reduction in available NPSH if substantial amounts of water are held up or diverted away from the sump or suppression pool. A susceptibility assessment should also be made of the flowpaths and components downstream of the strainers to failure from debris blockage, particulate ingestion, and abrasive effects to protect against long-term degradation.

1.3.1 Net Positive Suction Head of the Emergency Core Cooling System and Containment Heat Removal Pumps

1.3.1.1 The design of the emergency core cooling and containment heat removal systems should ensure that sufficient available NPSH is provided to the system pumps, assuming the maximum expected temperature of the pumped fluid and no increase in containment pressure from that present before the postulated LOCA.[6]

a. It is conservative to assume that the containment pressure equals the vapor pressure of the pool water. This ensures that credit is not taken for containment pressurization during the transient.

b. For PWR subatmospheric containments, this guidance should apply after termination of the injection phase. For these subatmospheric containments, before termination of the injection phase, NPSH analyses should include conservative predictions of the containment atmospheric pressure and sump water temperature as a function of time.

1.3.1.2 For certain operating reactors in which it is not practicable to alter the design, conformance with Section C 1.3.1.1 may not be possible. In these cases, the determination of available NPSH should not include containment pressure above that which is necessary to preclude pump cavitation. The calculation of available containment pressure and sump/pool water temperature as a function of time should underestimate the expected containment pressures and overestimate the sump/pool water temperatures when determining available NPSH for this situation.

1.3.1.3 If credit is taken for operation of an ECCS or containment heat removal pump in cavitation, licensees should conduct prototypical pump tests along with a posttest examination of the pump to demonstrate that pump performance will not be degraded and that the pump continues to meet

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6 As of the date of the publication of revision 4 of this RG, the staff is in the process of implementing SRM SECY-11-0014-"Use of Containment Accident Pressure in analyzing Emergency Core Cooling System and Containment Heat removal System Pump Performance in Postulated Accidents" (Adams Accession No. ML110740254), which addresses containment accident pressure and ECCS pump NPSH. Additional guidance for review of information in license amendments and applications regarding containment accident pressure is available in draft form in letters transmitted to the BWROG and PWROG. This draft guidance will be augmented by work in progress as of issuance of the RG and revised guidance will be issued in the future

all of the performance criteria assumed in the safety analyses. The time period in the safety analyses during which the pump may be assumed to operate while cavitating should not be longer than the time period for which the performance tests demonstrate that the pump meets the performance criteria.

1.3.1.4 Because high water temperatures reduce available NPSH and can affect the potential for flashing and impacts fluid properties, such as density and viscosity, the determination of the water temperature should include the decay and residual heat produced following accident initiation. This calculation should include the uncertainty in the determination of the decay heat (uncertainty in decay heat is typically included at the 2-sigma level). The licensee should calculate the residual heat with margin.

1.3.1.5 The correction factor for pumping high-temperature fluid discussed in ANSI/HI 1.3-2009 (Ref. 5) to determine the margin between the available and required NPSH for the ECCS and the containment heat removal systems should not be used.

1.3.1.6 The calculation of available NPSH should take into account the minimum calculated height of water above the pump suction and strainer surfaces. The calculated height of water should not consider quantities of water that do not contribute to the sump or suppression pool (e.g., atmospheric steam, pooled water on floors and in refueling canals, spray droplets and other falling water, holdup in containment coolers, water held up by upstream obstructions, and the volume of empty system piping). Licensees should not credit non-leaktight structures, such as ducting for heating, ventilation, and air conditioning, for the displacement of water for the purposes of determining the minimum water level. The calculated height of water available should not include the amount of water in enclosed areas that cannot readily be returned to the sump or suppression pool. Minimum water level calculations should consider worst-case break locations (e.g., breaks at high elevations) that could lead to a minimum quantity of reactor coolant reaching the sump or suppression pool. Licensees should consider volume shrinkage of the reactor coolant inventory as it cools in terms of crediting the contribution of spilled coolant to the sump or suppression pool and in terms of the volume reduction of the coolant remaining in the primary system that will allow the ECCS to inject additional inventory into the primary system before filling it. Licensees should explicitly consider the limiting small-break LOCA water level because elevated break locations may be possible and certain sources of inventory (e.g., PWR accumulators) may not inject.

1.3.1.7 Licensees should calculate the pipe and fitting resistance and the nominal strainer resistance without blockage by debris in a recognized, defensible method or determine it from applicable experimental data. The clean strainer head loss (i.e., the friction head loss caused by the passage of flow through the strainer and any associated connecting pipes and plenums) calculations should consider the distribution of flow through the strainer that produces the highest head loss. For some curvilinear-type strainer designs, this occurs with a filtering debris bed near the strainer outlet and a clean strainer where the unobstructed flowpath is longer. If the strainer were partially covered with a filtering debris bed, much of the strainer flow could occur through the unblocked strainer surfaces, which could be more limiting for some designs.

1.3.1.8 Licensees should use Sections C 1.3.10 and 1.3.11 to determine strainer head loss caused by blockage from LOCA-generated debris and its chemical reaction products or from foreign material in the containment that is transported to the suction intake screens.

1.3.1.9 Licensees should calculate available NPSH as a function of time until it is clear that the available NPSH will not decrease further.

1.3.2 Pipe Break Characterization

a. A sufficient number of high-energy pipe break locations resulting in ECCS recirculation should be considered to reasonably bound variations in debris generation by the size, quantity, and type of debris. The objective of the break selection process is to identify the break location and size that results in debris generation that produces the maximum head loss across the sump screen. Licensees should consider all aspects of the accident scenario for each postulated break location, including debris generation, debris transport, latent debris, coating debris, chemical effects, upstream and downstream effects of debris accumulation, and sump screen head loss.

b. The objective of strainer head loss testing is to simulate the debris from the break location that transports the maximum amount of debris to the sump strainer or the combination of debris types that produces the maximum head loss. At a minimum, licensees should consider the postulated break locations and pipe break characteristics described in the following sections.

c. Section 3.3.3 to 3.3.5 of NEI 04-07 (Ref. 26) and the associated SE (Ref. 27) and Section 3.2.1.1 of Ref. 15 provide additional guidance in break selection criteria.

1.3.2.1 Licensees should consider breaks where debris is most easily transported to the suction strainer (e.g., breaks in areas with the most direct path to the sump strainer or suppression pool).

1.3.2.2 Licensees should consider a spectrum of breaks, including the breaks with the largest quantity and greatest variety of debris within the expected zone of influence (ZOI).

1.3.2.3 Licensees should consider medium and large breaks that have the greatest potential ratio of particulate to fibrous insulation debris by weight and breaks that generate an amount of fibrous debris that, after its transport to the strainer, could form a thin layer that could subsequently filter sufficient particulate debris to create a relatively high head loss (called the "thin-bed effect"). A "thin bed" is a relatively thin layer of debris on a screen or strainer that causes a large flow resistance and, consequently, a large pressure drop for flowing liquid.

1.3.2.4 Licensees should disregard break exclusion zones in their evaluations (i.e., pipe breaks must be postulated in break exclusion zones).

1.3.2.5 Licensees should exclude NRC Branch Technical Position (BTP) 3-4, "Postulated Rupture Locations in Fluid System Piping inside and outside Containment" (Ref. 25), as a basis for selecting break locations because limiting conditions for ECCS strainer performance are not related to the pipe vulnerability issues addressed in BTP 3-4.

1.3.2.6 Licensees should consider locations that result in a unique debris source term (i.e., not multiple, identical locations). Particular consideration should be given to breaks that result in the destruction of materials known to cause high head loss, such as microporous insulation (e.g., calcium silicate, Min-K, and Microtherm).

1.3.2.7 If the LOCA blowdown does not generate a significant amount of fibrous debris, the contribution of latent debris sources may become the limiting factor in ECCS strainer and downstream evaluations.

1.3.2.8 If long-term cooling requires recirculation flow through the ECCS strainer for non-LOCA HELBs (e.g., main steam and feedwater line breaks), then licensees should use the same selection criteria for break locations as those specified for a LOCA.

1.3.3 Debris Generation/Zone of Influence

An initial pressure wave and erosion associated with the jet impingement can generate debris from the blowdown of a ruptured pipe. Insulation, coatings, fire barriers, shielding blankets, and other materials that are located within a material-dependent range of distances from the pipe rupture location can become debris as the result of the LOCA blowdown. The volume of space affected by this impact, or ZOI, is modeled to define and characterize the debris generated.

1.3.3.1 Zone of Influence Model

a. The size and shape of the ZOI should be consistent with experiments performed for specific debris sources (e.g., insulation, coatings, and fire barrier materials). The ZOI should extend until the pressure wave impulse and jet pressures decrease below the experimentally determined damage pressures appropriate for the debris source.

b. Licensees should use the volume of material contained within the ZOI to estimate the amount of debris generated by a postulated break. The size distribution of debris created in the ZOI should be determined from applicable experiments. It is noted that if robust barriers intersect the postulated jet zone, the extended volume may be truncated within the limitations of NEI 04-07, "PWR Sump Performance Evaluation Methodology," Section 3.4.2.3, and its associated SE (Ref. 26 and 27).

c. Licensees should use the pressure wave impulse and jet impingement generated during the postulated pipe break as the basis for estimating the amount of debris generated and the size or size distribution of the debris generated within the ZOI.

d. Licensees should perform debris generation testing to determine the ZOI in a manner that is prototypical of the plant condition. Test scaling is complicated because material destruction may result from both pressure waves and jet impingement. Scaling considerations for debris generation testing include the test fluid used (e.g., air or saturated water), the initial thermodynamic conditions of the test fluid, the rupture disk opening time, the blowdown period, the size and orientation of the test nozzle relative to the target, and the specific configuration of the target material to the various plant materials to which it is being applied (e.g., insulation jacketing seam, jacketing thickness, and banding and latching strength The staff has not developed specific guidance for the performance of ZOI testing. Methods and results are reviewed on a case-by-case basis. One example is the Air Jet Impact Tests documented in the Section 3.2.1 of the URG (Ref. 15).

e. If the evaluation uses simplified ZOI models, such as the spherical ZOI models that are discussed in Section 3.2.1of NEDO-32686-A (Ref. 15) and Section 3.4.2 of NEI 04-07 (Ref. 26 and 27), licensees should apply sufficient conservatism to account for simplifications and uncertainties in the model. For example, a spherical ZOI model assumes that the blowdown from a LOCA is evenly distributed in all directions radiating from the break location. Although, with sufficiently conservative inputs, a spherical model may be appropriate for estimating the loadings of debris within a ZOI, such a model does not account for non-uniform blowdown that could create damage in a particular direction at much greater distances from the break. Therefore, such a spherical model would likely be non-conservative when specifying an exclusion zone for particularly problematic materials (e.g., calcium silicate insulation for a PWR with a trisodium phosphate buffer or fibrous debris for a plant with a limited strainer area that intends to demonstrate that a fibrous debris bed cannot be formed).

1.3.3.2 Certain types of material used in small quantities inside the containment can, with adequate justification, be demonstrated to make a marginal contribution to the debris loading for the ECCS sump. If debris generation and debris transport data have not been determined experimentally for such material, the material may be grouped with another material with similar physical and chemical characteristics existing in large quantities. For example, a small quantity of fibrous filtering material may be grouped with a substantially large quantity of fibrous insulation debris, and the debris generation and transport data for the filter material need not be determined experimentally. However, such analyses are valid only if the small quantity of material treated in this manner does not have a significant effect when combined with other materials (e.g., combining a small quantity of calcium silicate with fibrous debris may not be valid).

1.3.3.3 All insulation (e.g., fibrous, calcium silicate, and reflective metallic); painted surfaces; fire barrier materials; and fibrous, cloth, plastic, or particulate materials within the ZOI should be considered as potential debris sources. Licensees should use applicable test data as the basis for predicting the size of the postulated debris. For breaks postulated in the vicinity of the containment penetrations, licensees should also consider the potential for debris generation from the packing materials used in the penetrations. In addition, licensees should consider breaks that could destroy the insulation installed on the pressure vessel. The potential for particulate debris to be generated by the action of pipe rupture jets stripping off paint or coatings and erosion of concrete at the point of impact should also be considered.

1.3.3.4 In addition to debris generated by jet forces from the pipe rupture, the analyses should consider (1) debris existing before the pipe rupture that is transported to the suppression pool, (2) debris created by the reactor pressure vessel environment (i.e., thermal and chemical), (3) debris created by the atmospheric environment (i.e., thermal and chemical), and (4) debris created by the environment of the submerged containment or suppression pool, as appropriate. Examples of debris created by the environment include disbonded coatings in the form of chips and particulates or the formation of chemical products caused by chemical reactions in the containment pool or the suppression pool or the reactor vessel (see Sections C.1.3.5 and C.1.3.10).

1.3.3.5 The analyses should consider debris erosion that results from continued degradation of insulation and other debris when subjected to turbulence caused by cascading water flows from upper regions of the containment or that result from the flows in the sump or suppression pool or chemical decomposition. The determination of eroded quantities for various types of debris should be based on testing that is prototypical of plant conditions. In the absence of applicable testing, demonstrably conservative assumptions should be used. (For example, the SE for NEI 04-07 Appendix III (Ref. 27) recommends using a bounding value of 90% erosion for fibrous debris).

1.3.4 Debris Transport

The debris transport evaluation determines the fraction of containment debris that is transported to the ECCS strainer.

1.3.4.1 The calculation of debris quantities transported to the ECCS strainers should consider all modes of debris transport, including blowdown transport, spray transport, washdown transport, and transport within the containment pool. Consideration of containment pool debris transport should address (1) debris transport during the pool fill phase, as applicable, and during the recirculation phase, (2) the velocity and turbulence in the sump, suppression pool, or storage tank (i.e., turbulence caused by the flow of water to the ECCS strainers, water splashing down from the break, containment spray drainage, and the discharge of pressure-relief flowpaths such as from downcomers, vents, and safety/relief valve spargers), and (3) the density, characteristic size, and other properties of the debris. Section 3.2.3 of the SE for NEDO-32686-A, (Ref. 15), and Section 3.6 of the SE for NEI-04-07 (Ref. 27) discuss staff accepted methods to evaluate debris transport. NUREG/CR-6369 (Ref. 28) is also a useful reference document for debris transport evaluations. Section 3.6.4 of NEI 04-07 (Ref. 26) contains a sample calculation for debris transport that the staff finds acceptable

1.3.4.2 Transport analyses within the containment pool should include debris that may transport through the following modes: (1) floating along a water surface, including debris that may float temporarily because of air entrapment, (2) traveling with the containment flow (i.e., debris suspended within the flow) because of neutral buoyancy or turbulence (e.g., individual fibers and fine particulates), and (3) settling to the floor and tumbling along the floor to reach the strainer.

1.3.4.3 The debris transport analyses should consider each type of insulation (e.g., fibrous, calcium silicate, and reflective metallic), other debris such as chemical precipitates, coatings, latent debris, and debris size (e.g., fine, readily suspendable, small, large, and intact). The analyses should also consider the potential for further decomposition of the debris as it is transported to the ECCS strainers.

1.3.4.4 An acceptable analytical approach to predict debris transport resulting from fluid flows caused by long-term recirculation or pool fill is to use appropriately verified computational fluid dynamics (CFD) simulations in combination with experimental debris transport data. The CDF simulations can be used to predict fluid flows, while debris transport thresholds can be determined experimentally. Section 4.2.4 of NEI 04-07 (Ref. 26) and Section 4.2.4 and Appendix III in the associated SE (Ref. 27) provide guidance and an example of this approach. Alternative methods for debris transport analyses are also acceptable, provided that they are supported by adequate validation of analytical techniques using experimental data to ensure that the debris transport estimates are conservative with respect to the quantities and types of debris transported to the strainer.

1.3.4.5 The analysis may credit curbs for removing heavier debris that has been shown analytically or experimentally to travel by sliding along the containment floor and that cannot be lifted off the floor within the calculated water velocity range. Curbs around the ECCS strainers may reduce or prevent some types of debris from transporting to floor- or pit-mounted strainers during the pool fill phase (see NUREG/CR-6772 (Ref. 13) for limitations).

1.3.4.6 If transported to the containment pool, all debris that would remain suspended because of turbulence (e.g., fine fibrous and particulates) should be considered to reach the ECCS strainers. However, if settlement of fine fibrous and particulate debris is credited during recirculation or pool fill, licensees should provide adequate theoretical and experimental basis to demonstrate that such settling is prototypical of plant conditions. This settlement analysis should include the potential for natural convection through the water column providing a motive force to keep the material in suspension.

1.3.4.7 In lieu of performing detailed blowdown and washdown debris transport analyses, licensees can conservatively assume that all debris entering or originating in the sump or suppression pool is transported to the ECCS strainers when estimating strainer debris bed head loss.

1.3.4.8 The effects of floating or buoyant debris on the integrity of the ECCS strainers and on the strainer head loss should be considered during the initial filling of the sump (if applicable) and during recirculation. For strainers that are not fully submerged or are only shallowly submerged, floating debris could contribute to the debris bed head loss. Entrapped air may cause some types of debris to temporarily float; the debris may then be transported to the vicinity of the ECCS strainers by surface currents and then sink on top of the strainers. A design feature (e.g., use of trash racks and solid cover plate) that keeps floating debris from reaching the sump or suppression pool strainer could reduce head loss caused by floating or buoyant debris.

1.3.4.9 Use of Debris Interceptors

a. Credit for the performance of debris interceptors upstream of the ECCS strainers should be based on results of tests that are demonstrated to be either conservative or representative with respect to the plant condition.

b. If the interceptors are credited with capturing fine debris to reduce the ECCS strainer debris load, licensees should perform time-dependent analyses and tests that consider the conditions that would lead to minimum debris capture fractions. This analysis also should include the potential of trapped debris further eroding into fines that could then pass through the interceptors. Iterative analyses of the flow in the sump or suppression pool (e.g., multiple computational fluid dynamics simulations that have been acceptably verified) may be necessary if the blockage of the interceptors has a significant impact on the containment pool flow pattern.

1.3.5 Coating Debris

Coating debris is generated from the postulated failure (destruction) of both DBA-qualified and unqualified coatings within the ZOI and from the postulated failure of unqualified coatings outside the ZOI. NRC reports entitled, “NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Coatings Evaluation,” issued March 2008 (Ref. 29), and “Revised Guidance Regarding Coatings Zone of Influence For Review of Final Licensee Responses To Generic Letter 2004-02, ‘Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents At Pressurized-Water Reactors,’” dated April 6, 2010 (Ref. 30), provide a general approach to conducting plant-specific coatings evaluation.

1.3.5.1 Licensees should use a ZOI for coatings that is determined by applicable testing and plant-specific analysis. The fluid used for the test, i.e., steam, air, two-phase water, should be representative of the plant exposure conditions.

1.3.5.2 All (100 percent) unqualified coatings should be assumed to fail. However, licensees may also be able to demonstrate the performance of their unqualified coatings through plant-specific and coating-specific testing.

1.3.5.3 Licensees should determine the debris characteristics (e.g., size, shape, density) of failed coatings separately for each coating within containment.

1.3.5.4 Licensees may determine coating chip debris transportability in flowing water by using the results in NUREG/CR-6916 (Ref. 14) to the extent they apply to a licensee's plant-specific coating types.

1.3.6 Latent Debris

a. Latent debris present in containment during operation may contribute significantly to head loss across the ECCS strainers. Licensees must determine the types, size, quantities, and locations of latent debris. NEI 04-07, and its associated SE (Ref. 26 and 27), provide general considerations for latent debris in terms of its potential impact on strainer blockage and some plant-specific variables. In collecting latent debris samples for analysis, licensees should use a sampling technique with demonstrated collection efficiency for fine particulate and fibrous debris. NEI 02-01, "Condition Assessment Guidelines: Debris Sources inside PWR Containments," dated September 30, 2002 (Ref. 31), provides an accepted approach for determining latent debris quantities.

b. Applicants or licensees should not assume that their (existing) foreign material exclusion programs have entirely eliminated miscellaneous debris. Results from plant-specific walkdowns should be used to determine a realistic amount of latent debris in containment and to monitor cleanliness programs for consistency with committed estimates. Evaluation of the results of latent debris walkdowns should include sufficient conservatism to account for substantial uncertainties inherent in the debris sampling and collection process. In lieu of plant-specific walkdowns, 10 CFR Part 52 applicants may perform conservative analyses that are based on latent debris measurements made for operating plants.

1.3.7 Upstream Effects

a. Section 7.2 of the staff's SE on NEI 04-07 (Ref. 27) provides guidance on evaluating the flowpaths upstream of the PWR containment sump for the holdup of inventory, which could limit flow to, and possibly starve, the suction strainer. A similar approach may be used for BWRs.

b. Licensees should use the results of their debris assessments to estimate the potential for water inventory holdup. Based on these assessments and the mapping of probable flowpaths, licensees should determine whether trash racks or debris interceptors are necessary to protect flowpaths in upper containment to prevent the holdup of water upstream of the sump, storage tank, or suppression pool. Licensees should also evaluate the effect that the placement of curbs and debris interceptors may have on the holdup of water en route to the sump, storage tank, or suppression pool.

1.3.8 Downstream Effects

a. Debris may be carried downstream of the ECCS strainer, thus causing downstream blockage or wear and abrasion. The three areas of concern identified are (1) blockage of system flowpaths at narrow flow passages (e.g., containment spray nozzles, some pump internal flow passages, and tight-clearance valves), (2) wear and abrasion of surfaces (e.g., pump running surfaces) and heat exchanger tubes and orifices, and (3) blockage of flowpaths through fuel assemblies.

b. The quantity and size characteristics of this strainer bypass debris will be unique to each strainer vendor and plant-specific debris mixtures and should be determined during strainer head loss tests, as discussed in Section 1.3.12.g. WCAP-16406-P-A (Ref. 21) provides a method that the NRC considers acceptable for PWR licensees to use in evaluating the downstream impact of sump debris on the performance of their ECCSs, CSSs, and components following a LOCA. The NRC has received WCAP-16793-NP (Ref. 23) for review.[7] This report provides a method and reference for PWR licensees whose plants are bounded by its input assumptions to use in evaluating the downstream impact of sump debris on the performance of fuel following a LOCA, subject to the conditions and limitations specified in the NRC SE to be prepared for WCAP-16793-NP, Revision 2. Neither of these reports applies to BWRs at this time.

1.3.9 Strainer Structural Analysis (This Regulatory Position Also Applies to Trash Racks and Debris Interceptors, If Used.)

1.3.9.1 General items identified for consideration in the structural analyses should include (1) the verification of maximum differential pressure caused by the combined clean strainer and worst-case debris scenario at rated flow rates or maximum realistic flow rates, whichever is greater, (2) geometry concerns (i.e., mesh and frame versus perforated plate), (3) ECCS strainer material selection for the post accident environment (i.e., corrosion-resistant materials that can withstand the post-LOCA environment), and (4) the addition of hydrodynamic loads.

1.3.9.2 Licensees should compute structural loads on a strainer using the maximum pressure drop across the strainer. Licensees should also evaluate the limiting conditions corresponding to the break location and debris source term that induce the maximum total head loss at the ECCS strainer.

1.3.9.3 For some licensees, the minimum structural design criterion for the ECCS strainer can depend on the plant's NPSH margin. Plant-specific licensing bases may dictate the structural capacity of the ECCS strainer for supporting water flow through a debris bed under recirculation velocities, depending on strainer geometry (i.e., fully submerged versus partially submerged or vented designs).

1.3.9.4 Load combinations (e.g., safe-shutdown earthquake, deadweight, crush pressure, thermal, and live loads) used for structural analysis should be performed in accordance with the specific plant licensing basis requirements and the applicable design code of record. Licensees should also reference Regulatory Guide 1.92, "Combining Modal Responses and Spatial Components in Seismic Response Analysis" (Ref. 32), when analyzing the seismic loading conditions during the structural analyses of the strainers.

1.3.9.5 Licensees should include the effects of the fluid temperature and containment ambient temperature (e.g., restrained thermal growth, temperature dependent material properties) in determining the structural integrity of the strainer.

1.3.9.6 Licensees should perform an evaluation to determine the possibility for dynamic loading on the strainers caused by HELBs and other structures, systems, and components that could produce missiles, pipe whipping, or jet impingement loads. Chugging and condensation oscillation loads can be a significant contributor in some BWR designs. This evaluation should be done in

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7 The NRC staff is currently reviewing WCAP-16793-NP, Revision 2, which had not yet received NRC approval when the staff developed this guide.

accordance with GDC 4 and should be based on the plant's design basis for postulated dynamic effects within the region of the strainers. Based on the SE for NEI 04-07 (Ref. 27), in general, if a postulated pipe break is located more than 10 pipe diameters away from the strainer, the dynamic effects of such a break may be neglected with respect to the structural integrity effects on the strainer.

1.3.10 Chemical Reaction Effects

a. Chemical reaction products in the post-LOCA environment of containments can contribute to blockage of the ECCS strainers and increase the associated head loss. The final SE by the Office of Nuclear Reactor Regulation on WCAP-16530-NP-A (Ref. 24), and the NRC report entitled, "NRC Staff Review Guidance Regarding Generic Letter 2004-02, Closure in the area of, Plant-Specific Chemical Effect Evaluations" (Ref. 33), provide a general approach to conduct plant-specific chemical effects evaluation.

b. During a LOCA, materials in the ZOI of the break can become debris that may transport to the containment pool where spray solution, spilled reactor coolant, and water from other safety injection sources accumulate. Subsequently, the combination of spray chemicals, insulation, corroding metals, and submerged and unsubmerged materials can create a potential condition for the formation of chemical substances that may impede the flow of water through the ECCS suction strainers or downstream components in the ECCS, CSS, or reactor coolant system.

c. New reactors with configurations different than those of operating PWRs (e.g., different containment materials and lack of buffering agents) may require additional evaluation.

1.3.11 Debris Accumulation, Head Loss, and Vortexing

a. In a letter to NEI dated March 28, 2008 (Ref. 4 and 8), the NRC provided guidance for evaluating the potential for debris accumulation and its impact on strainer head loss during a LOCA that could impede or prevent the ECCS or CSS from performing its intended safety functions.

b. Testing and analyses performed to address GL 2004-02 indicate that the maximum head losses for the ECCS strainers in some plants can occur when a layer of fiber just thick enough to fully cover the strainer accumulates on the strainer along with a bounding quantity of fine particulate matter. This case may result in a thin, dense debris bed with low porosity that could maximize head loss. The thickness of the fiber layer necessary to filter fine particulate cannot be specified in general, but it is dependent on a number of factors, including the strainer design, the strainer geometry and orientation, the approach velocity, the type and size of the fibrous debris, the type of particulate debris, and the presence of chemical effects. Appendix A, Section 6 of Ref. 8 provides testing methods acceptable to the NRC staff to evaluate thin bed effects.

c. Other testing and analyses have shown that the maximum debris loading case can also be a limiting head loss condition for strainers. Therefore, licensees should test for both the thin-bed and maximum loading cases. If the maximum debris loading case can result in a circumscribed debris accumulation, licensees should ensure that the strainer design and head loss test scaling accounts for this effective reduction in the strainer surface area.

1.3.11.1 Debris accumulation on the ECCS strainers for the head loss evaluation should be based on the amount of debris generated and the formation of different combinations of fibers and particulate mixtures (e.g., a fiber bed with a minimum thickness necessary to effectively filter particulate debris, as well as maximum debris loading) using the guidelines described in Section C.1.3.3 and on the debris transported to the strainers in accordance with Section C.1.3.4. The evaluation should be based on plant-specific debris loads determined in accordance with these regulatory positions.

1.3.11.2 The degree of ECCS strainer submergence (full or partial) at the time of switchover to recirculation should be considered in calculating the available (wetted) screen area. For plants in which certain pumps take suction from the ECCS strainers before the switchover of other pumps, the available NPSH for these pumps should consider the submergence of the strainers at the time these pumps initiate suction through the strainers. Unless otherwise shown experimentally, licensees should assume that debris is uniformly distributed over the available strainer surface

1.3.11.3 Strainer submergence should be adequate to preclude vortexing, sump fluid flashing, and deaeration induced by excessive differential pressure drop. Vortexing can cause the ingestion of unacceptable quantities of air into the ECCS and CSS pumps, potentially resulting in unacceptable pump performance. Water, when flashing to steam, can result in recirculating coolant that transforms a portion of the fluid into the vapor phase if the strainer pressure drop is sufficiently large. For partially submerged strainers, licensees should evaluate the potential for vortex formation internal to the strainer. Deaeration can similarly result in ingested air and unacceptable pump performance, whereas both deaeration and sump fluid flashing can result in an unacceptable increase in strainer head loss caused by the increased resistance associated with two-phase flow.

1.3.11.4 Licensees should validate the adequacy of ECCS strainer designs through testing applicable to plant-specific conditions. Analytical or empirical head loss correlations should not be used to validate plant-specific debris bed head losses. However, correlations may be useful in conducting scoping evaluations for conditions and debris loads with the range of applicable test data.

1.3.12 Prototypical Head Loss Testing

a. The methodology to predict the key inputs to the head loss testing has been conservatively developed and documented in NEI 04-07, referred to as the guidance report and its associated SE (Ref. 26 and 27). Additionally, the NRC staff review guidance (Ref. 8) provides a general approach to conducting plant-specific prototype head loss testing. This guidance report document discusses the staff positions on various aspects of head loss testing including scaling of the plant strainer design to the test strainer module, similitude considerations for debris transport and debris accumulation on the strainer, surrogate debris similitude requirements, and posttest data processing extrapolation.

b. The objective of prototypical head loss testing is to determine the potential peak or bounding head loss that could occur across a suction strainer debris bed during a postulated LOCA scenario. If the test facility is scaled properly and the testing procedures are conservative, the measured head loss is also expected to be conservative. To ensure adequate strainer function, licensees should design the test facility properly and conduct testing following conservative testing procedures. The conditions within the test tank should be prototypical or conservative with respect to the plant, including the postulated debris loading, the recirculation system hydraulics, and key aspects of various accident scenarios. The primary scaling parameters include the screen area, the dimension of the strainer elements (e.g., disks), and the submergence level, the number of strainer elements, the debris amounts, and the local fluid flow conditions, as applicable. These parameters affect the flow velocities approaching the test strainer and the velocities through accumulated debris.

c. The test specifications should be designed to determine a reasonably bounding head loss from all of the possible types of debris beds that could accumulate on the strainer considering the plant specific debris quantities that would transport.

d. Post-test evaluations are required to validate the head loss results, apply the results to the proposed strainer, and ensure that the debris penetrating the strainer cannot cause adverse effects to downstream equipment. Licensees that want to scale the results of head loss tests conducted using colder water to the plant water temperatures should ensure that boreholes, bed degradation, open strainer area, or other phenomena that could affect the head loss response of the debris bed do not have a non-conservative effect when the temperature is scaled. The NRC does not recommend scaling of head loss results to alternate approach velocities or debris loadings because the theoretical debris bed head loss behavior is not well understood and the results of experiments examining these parameters have varied.

e. Licensees may need to extrapolate the results of head loss testing for a time period matching the mission time of the ECCS. The method of extrapolation used should be one that conservatively fits the data (e.g., linear, log, quadratic) over the time period of interest.

f. Because of the complexity of modeling and scaling multiple, complex physical phenomena in a single test, licensees should conduct head loss tests in a manner that ensures complete transport of debris (as determined by transport analysis) to the test strainer. Agitation of the test fluid with stirrers may be necessary to achieve conservative debris transport. If desired, licensees may conduct separately testing to credit reductions in debris transport (i.e., settling) to the strainer under conditions that are conservatively or prototypically scaled to the plant condition. However, strainer head loss testing that credits debris settlement within the test tank should carefully evaluate the flow characteristics (e.g., velocity and turbulence) in the test to ensure that the simulated flows are prototypical or conservative with respect to the plant condition. Licensees should consider scaling of debris per unit area of floor in the flume versus debris per unit floor area of the plant with respect to effects on debris transport caused by potential piling up of debris in areas of flow restrictions. The quantity of debris per unit width of the flume relative to the flow passages in the plant is also an important scaling parameter. Licensees should also give special consideration to the adequacy of other aspects of the test protocol, such as debris preparation, addition sequencing, debris concentration in the flume, and test flume geometry, to conclude that similar or larger amounts of debris settling would occur in the plant containment. Consideration should also be given to how debris settlement during a head loss test impacts other aspects of the analysis. For example, allowing debris to settle in the test tank can lead to a failure to account for erosion of this settled debris in the analysis. Because of the practical inability to simultaneously scale multiple, complex phenomena associated with debris transport and head loss in a rigorous way, licensees should apply conservatism to tests that model both transport and head loss. Section 4.0 of Appendix A of Ref. 8 provides more details on this topic.

g. Licensees may sample the flows downstream of the test strainer to determine the amount of debris passing through the strainer. The sampling should be performed on a frequency that ensures adequate characterization of the total bypass content. This debris could potentially damage or clog components, such as pumps, throttling valves, or components within the reactor core. Licensees may use the downstream debris characteristics to determine the likelihood that downstream blockage or wear and abrasion could threaten long-term core cooling or impact heat transfer of the fuel cladding. The conditions for the limiting downstream sampling tests will typically differ from the conditions for the limiting debris bed head loss tests because a filtering debris bed will tend to reduce the quantity of debris that passes through the strainer. A large strainer surface area, higher ECCS flow rates, low rate of debris introduction into the water, or thinner debris beds can result in higher quantities of bypass debris. Licensees may need to conduct separate strainer pass-through tests for fibrous and particulate debris to avoid crediting filtration caused by one debris type that might affect the other debris type. Collecting bypass debris in a filter with very small pore size, downstream of the strainer has also been successfully used to characterize the bypass content[8].

h. The analyses and testing should consider worst-case single failures. For example, licensees with plant designs that include low-pressure safety injection (LPSI) pumps that shut down during the switchover from the refueling water storage tank to the sump

[8] Additional NRC staff guidance on acceptable methods of determining the quantity of bypass debris is currently being developed and will be included in a future revision of this RG.

should consider one LPSI train failure to stop. This assumption leads to a conservatively calculated maximum flow rate to and through the screen.

i. The time dependence of debris arrival at the strainer is difficult to model in a practical number of head loss tests. A conservative assumption is that all of the LOCA debris is present on the strainer at the beginning of recirculation. This debris should include the debris generated from the LOCA blowdown, failed unqualified coatings, eroded fine debris, chemical precipitates, and all other debris predicted to transport to the strainer.

j. Head loss testing for complex combinations of debris that typically result from limiting plant debris loads has, in some cases, shown significant variation for the same debris loading. As a result, licensees should ensure that head loss test results have been demonstrated to be sufficiently repeatable, in light of known margins, uncertainties in debris quantities, the collective body of knowledge from tests on similar strainers, and other relevant information.

k. Proper debris introduction procedures should take into account the fact that variations in the sequence and rate of debris introduction can potentially affect the head loss measurement. The approach that is considered most conservative is to introduce the debris slowly into the test tank with the pump running and prototypical hydraulic conditions established. The most transportable debris should be added first and the least transportable last. Licensees may also use other approaches, if justified. Testing that takes credit for near-field settlement should either realistically or conservatively simulate the strainer upstream flow and turbulent conditions. Licensees should conduct proper analytical evaluation of the similitude between the test tank and the actual plant condition. The NRC staff considers computational fluid dynamic codes to be useful tools to assist the evaluation. Surrogate debris materials used in head loss testing should be either the actual plant materials or suitable substitutions. Licensees should justify substitutions by comparing the important characteristics of the plant debris sources and the surrogate to ensure that the debris preparation creates prototypical or conservative debris characteristics.

## 2. Regulatory Positions Specific to Pressurized Water Reactors

Any evaluation of the susceptibility of a PWR to debris blockage should address the considerations and events shown in Figure 3 (see page 33).

### 2.1 Emergency Core Cooling System Sumps, Strainers, and Debris Interceptors

Distribution of water sources and containment spray between the sumps should be considered in the calculation of boron concentration in the sumps for evaluating post-LOCA subcriticality and shutdown margins. Typically, these calculations are performed assuming minimum boron concentration and maximum dilution sources. Similar considerations should also be given in the calculation of time for hot-leg switchover, which is calculated assuming maximum boron concentration and a minimum of dilution sources.

Additionally, the evaluation of debris transport to the sump screen should consider the time to switch over to sump recirculation and the operation of containment spray.

2.1.1 The ECCS strainers should be located on the lowest general area floor elevation in the containment, exclusive of the reactor vessel cavity and the normal drainage sump, to maximize the pool depth relative to the strainers. Design considerations for recirculation strainers should ensure that they protect the pump inlets for which they supply water. A curb could be provided upstream of the strainers to prevent high-density debris from being swept along the floor into the sump strainer. To be effective, the height of the curb should be appropriate for the pool flow velocities and plant debris types because debris can be carried over a curb if the velocities are sufficiently high. Estimation of pool flow velocities should include both the pool fill (as applicable) and recirculation phases of the event. Licensees should also consider that turbulence in the pool may keep some debris in suspension that would otherwise settle. Experiments documented in NUREG/CR-6772 (Ref. 13) and NUREG/CR-6916 (Ref. 14) demonstrated that some types of settled debris could transport across the containment pool floor to the suction strainer by sliding or tumbling at typical containment pool velocities.

The ECCS strainer structures should include access openings and other design features, as required, to facilitate inspection of the strainer structures, any vortex suppressors, and the pump suction piping inlets. Where consistent with overall design and functionality, the top of the ECCS strainer structures should be a solid cover plate that is designed to be fully submerged after a LOCA and completion of the ECCS injection from the water storage tank. The cover plate is intended to provide additional protection to debris interceptor structures from LOCA-generated loads and from water drainage from upper containment. However, the design should also provide a means for venting any air trapped underneath the cover.

## Figure 3. PWR LLOCA accident progression in a large, dry containment (from NUREG/CR-6762, Figure 2-2)

| TIME > LOCA (seconds) | LOCA EVENT PROGRESSION | DEBRIS GENERATION | CONTAINMENT PHENOMENA | SUMP/POOL PHENOMENA | CONTAINMENT POOL TRANSPORT | ECCS RESPONSE |
|---|---|---|---|---|---|---|
| 0 | • Dynamic piping response<br>• RCS blowdown as quasi-steady jet<br>• Flow quality < 0.05; increase with time | • Impulse load on insulation<br>• Peeled covers<br>• Insulation destroyed<br>• Pieces wetted | • Pressurization<br>• Recirculating vapor flows<br>• Vapor flow velocity in excess of 100 ft/s | • Water probably in suspension or on walls | • Resuspension of concrete dust, etc. | • Initiation on containment high pressure<br>• Accumulator inject |
| 10 | • Two-phase jet<br>• Flow quality > 0.1 (increasing)<br>• RCS pressure < 1,000 psia | • Destruction under steady loads<br>• Erosion of solid insulation<br>• Concrete spallation and paint dust/chips | • Cont spray actuat. pressure > CS setpoint<br>• NaOH additive for iodine, high pH<br>• Pressure and temp reach peak values | | • Fully mixed conditions<br>• Debris break up | • HPSI inject<br>• RPV pressure > LPSI shutoff head |
| End Blowdown | • ECCS injection from RWST commences | • Termination of debris generation by jet impingement | | • Pool starts forming<br>• Thin sheets of fast moving water | | • LPSI inject<br>• Ramps to design flow |
| 100 | • Flooded R-X core<br>• Design injection flow from break | | • Depressurization and cooldown of cont.<br>• Vapor flow velocity btwn compartments minimal<br>• Sprays form a thin liquid film on struct. | • Turbulent pool dynamics, gradually decreasing turbulent intensity<br>• Increasing height | • Washdown of insulation<br>• Start of sedimentation | • Design flow out of the break<br>• Borated water (2,000 ppm) |
| 1,000 / End Injection | • Switchover to sump (t < 1800 s) | • Generation by erosion/corrosion<br>• Paint chips and delaminating | • Cont. sprays terminated in large dry (at 2 hours)<br>• Fan coolers operate | • Flow through sump<br>• Recirculation flow patterns<br>• Steady pool height | • Transport to sump strainer<br>• Accumulation | • Suction from sump<br>• RHR H-X |
| 10,000 | • Cooldown of cont.<br>• Licensing issues | | | • Several pool turnovers<br>• Low turbulence | | • Hot-leg injection |

2.2 Chemical Reaction Effects

a. The Westinghouse report, WCAP-16530-NP-A, and the limitations discussed in the associated SE (Ref. 24) provide an acceptable approach for PWRs to evaluate chemical effects that may occur in a post accident containment sump pool.

b. Plant-specific information should be used to determine chemical precipitate inventory in containment. However, plant specific chemical effect evaluations should use a conservative analytical approach. Additionally, "NRC Staff Review Guidance Regarding Generic Letter 04-02 Closure in the Area of Plant-Specific Chemical Effect Evaluations" (Ref. 33) provides a general approach for PWR licensees to conduct plant-specific chemical effect evaluations.

c. WCAP-16793-NP "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," (Ref. 23) is still under review by the NRC staff. When approved by the staff, it, along with the SE, will provide guidance for evaluation of chemical debris within the reactor.

3. Regulatory Positions Specific to Boiling Water Reactors

Any evaluation of the susceptibility of a BWR to debris blockage should address the considerations and events shown in Figures 4 and 5. These Figures are from NUREG/CR-6224 (Ref. 16). This NUREG report contains more detail on the information in these Figures. Additional guidance is contained in the BWR Owners Group document, NEDO-32686-A, "Utility Resolution Guide for ECCS Suction Strainer Blockage" (referred to hereafter as the URG) (Ref. 15). This document contains the NRC staff SE, as well.

3.1 Suppression Pools and Debris Interceptors

3.1.1 For the purposes of evaluating strainer performance, licensees should assume that the level of water in the suppression pools or wetwell is the minimum value given in the technical specifications reduced by the drawdown caused by suppression pool water in the drywell and the sprays.

3.1.2 Debris interceptors in the drywell in the vicinity of the downcomers or vents may serve effectively in reducing debris transport to the suppression pool. Additionally, debris interceptors between the drywell and wetwell should not reduce the suppression capability of the containment.

3.2 Debris Sources, Generation, and Transport

3.2.1 Licensees should consider the amount of particulates estimated to be in the suppression pool before a LOCA to be the maximum amount of corrosion products (i.e., sludge) expected to be generated since the last time the pool was cleaned. The size distribution and amount of particulates should be based on plant samples. The quantity and size distribution of suppression pool sludge has been analyzed for BWRs participating in the URG.

3.2.2 Licensees should not take credit for debris settling until LOCA-induced turbulence in the suppression pool has ceased. This should include addressing the effect of the automatic depressurization system for small-break LOCAs. Section C.1.3.4.6 & C.1.3.4.7 are applicable with regard to the settlement of fine debris.

3.3 Chemical Reaction Effects

3.3.1 BWR licensees have post-LOCA containment conditions that may result in different chemical interactions than those analyzed in WCAP-16530-NP-A and in other experimental and analytical efforts that considered chemical interactions for operating PWRs. Therefore, the consideration of chemical effects for BWRs requires additional evaluation.

**Figure 4. Debris blockage considerations for BWR LOCA sequences**

(See NUREG/CR-6224, Figure 1-1 (Ref. 16))

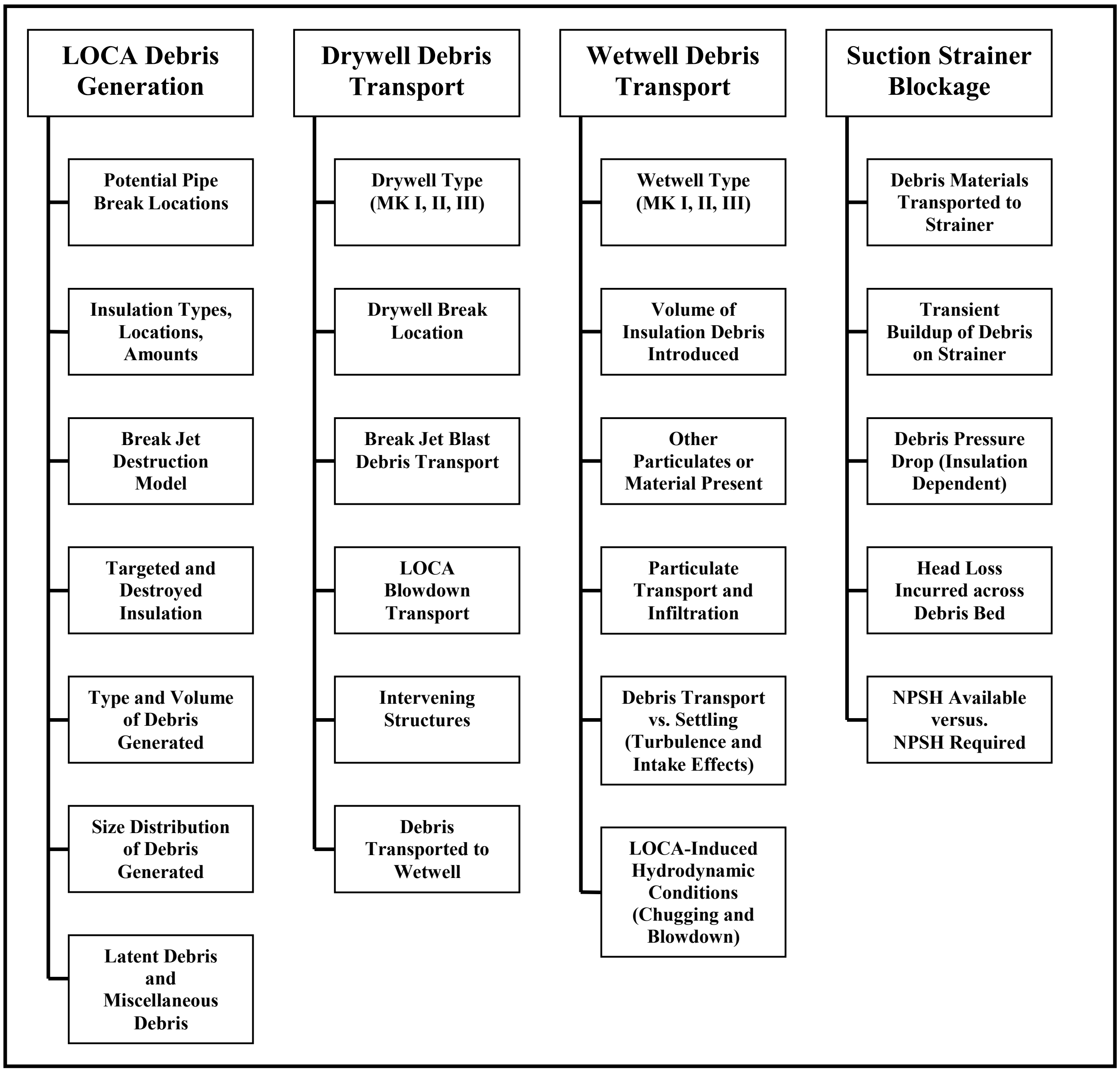
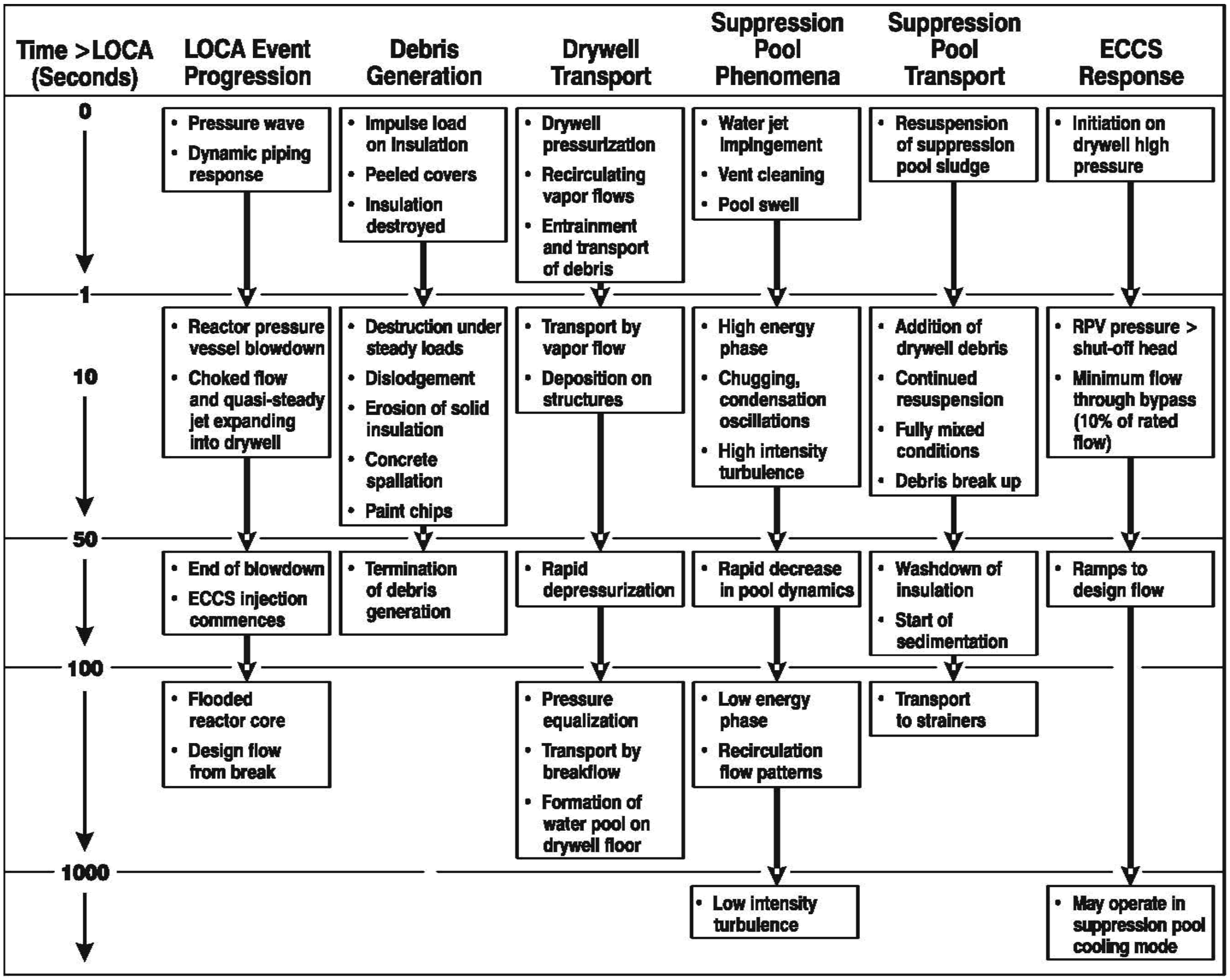


**Figure 5. Events that may affect debris blockage for BWR LOCA sequences**
(See NUREG/CR-6224, Figure B-1)



# D. IMPLEMENTATION

The purpose of this section is to provide information on how applicants and licensees[9] may use this guide and information regarding the NRC's plans for using this regulatory guide. In addition, it describes how the NRC staff complies with the Backfit Rule (10 CFR 50.109) and any applicable finality provisions in 10 CFR Part 52.

**Use by Applicants and Licensees**

Applicants and licensees may voluntarily[10] use the guidance in this document to demonstrate compliance with the underlying NRC regulations. Methods or solutions that differ from those described in this regulatory guide may be deemed acceptable if they provide sufficient basis and information for the NRC staff to verify that the proposed alternative demonstrates compliance with the appropriate NRC regulations. Current licensees may continue to use guidance the NRC found acceptable for complying with the identified regulations as long as their current licensing basis remains unchanged.

Licensees may use the information in this regulatory guide for actions which do not require NRC review and approval such as changes to a facility design under 10 CFR 50.59. Licensees may use the information in this regulatory guide or applicable parts to resolve regulatory or inspection issues.

**Use by NRC Staff**

During regulatory discussions on plant specific operational issues, the staff may discuss with licensees, various actions consistent with staff positions in this regulatory guide, as one acceptable means of meeting the underlying NRC regulatory requirement. Such discussions would not ordinarily be considered backfitting even if prior versions of this regulatory guide are part of the licensing basis of the facility. However, unless this regulatory guide is part of the licensing basis for a facility, the staff may not represent to the licensee that the licensee's failure to comply with the positions in this regulatory guide constitutes a violation.

If an existing licensee voluntarily seeks a license amendment or change and (1) the NRC staff's consideration of the request involves a regulatory issue directly relevant to this new or revised regulatory guide and (2) the specific subject matter of this regulatory guide is an essential consideration in the staff's determination of the acceptability of the licensee's request, then the staff may request that the licensee either follow the guidance in this regulatory guide or provide an equivalent alternative process that demonstrates compliance with the underlying NRC regulatory requirements. This is not considered backfitting as defined in 10 CFR 50.109(a)(1) or a violation of any of the issue finality provisions in 10 CFR Part 52.

The NRC staff does not intend or approve any imposition or backfitting of the guidance in this regulatory guide. The NRC staff does not expect any existing licensee to use or commit to using the guidance in this regulatory guide, unless the licensee makes a change to its licensing basis. The NRC staff does not expect or plan to request licensees to voluntarily adopt this regulatory guide to resolve a

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9 In this section, "licensees" refers to licensees of nuclear power plants under 10 CFR Parts 50 and 52; and the term "applicants," refers to applicants for licenses and permits for (or relating to) nuclear power plants under 10 CFR Parts 50 and 52, and applicants for standard design approvals and standard design certifications under 10 CFR Part 52.

10 In this section, "voluntary" and "voluntarily" means that the licensee is seeking the action of its own accord, without the force of a legally binding requirement or an NRC representation of further licensing or enforcement action.

generic regulatory issue. The NRC staff does not expect or plan to initiate NRC regulatory action which would require the use of this regulatory guide. Examples of such unplanned NRC regulatory actions include issuance of an order requiring the use of the regulatory guide, requests for information under 10 CFR 50.54(f) as to whether a licensee intends to commit to use of this regulatory guide, generic communication, or promulgation of a rule requiring the use of this regulatory guide without further backfit consideration.

Additionally, an existing applicant may be required to comply with new rules, orders, or guidance in accordance with 10 CFR 52.109 or one of the finality provisions in 10 CFR 52.

**Conclusion**

This regulatory guide is not being imposed upon current licensees and may be voluntarily used by existing licensees. In addition, this regulatory guide is issued in conformance with all applicable internal NRC policies and procedures governing backfitting. Accordingly, the NRC staff issuance of this regulatory guide is not considered backfitting, as defined in 10 CFR 50.109(a)(1), nor is it deemed to be in conflict with any of the issue finality provisions in 10 CFR Part 52.

If a licensee believes that the NRC is either using this regulatory guide or requesting or requiring the licensee to implement the methods or processes in this regulatory guide in a manner inconsistent with the discussion in this Implementation section, then the licensee may file a backfit appeal with the NRC in accordance with the guidance in NUREG-1409 and NRC Management Directive 8.4.

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[1] Publicly available NRC published documents are available electronically through the NRC Library on the NRC's public Web site at: http://www.nrc.gov/reading-rm/doc-collections/. The documents can also be viewed on-line or printed for a fee from the NRC's Public Document Room (PDR) at 11555 Rockville Pike, Rockville, MD; the mailing address is USNRC PDR, Washington, DC 20555; telephone 301-415-4737 or (800) 397-4209; fax (301) 415-3548; and e-mail PDR.Resource@nrc.gov.

[2] Copies of the non-NRC documents included in these references may be obtained directly from the publishing organization.

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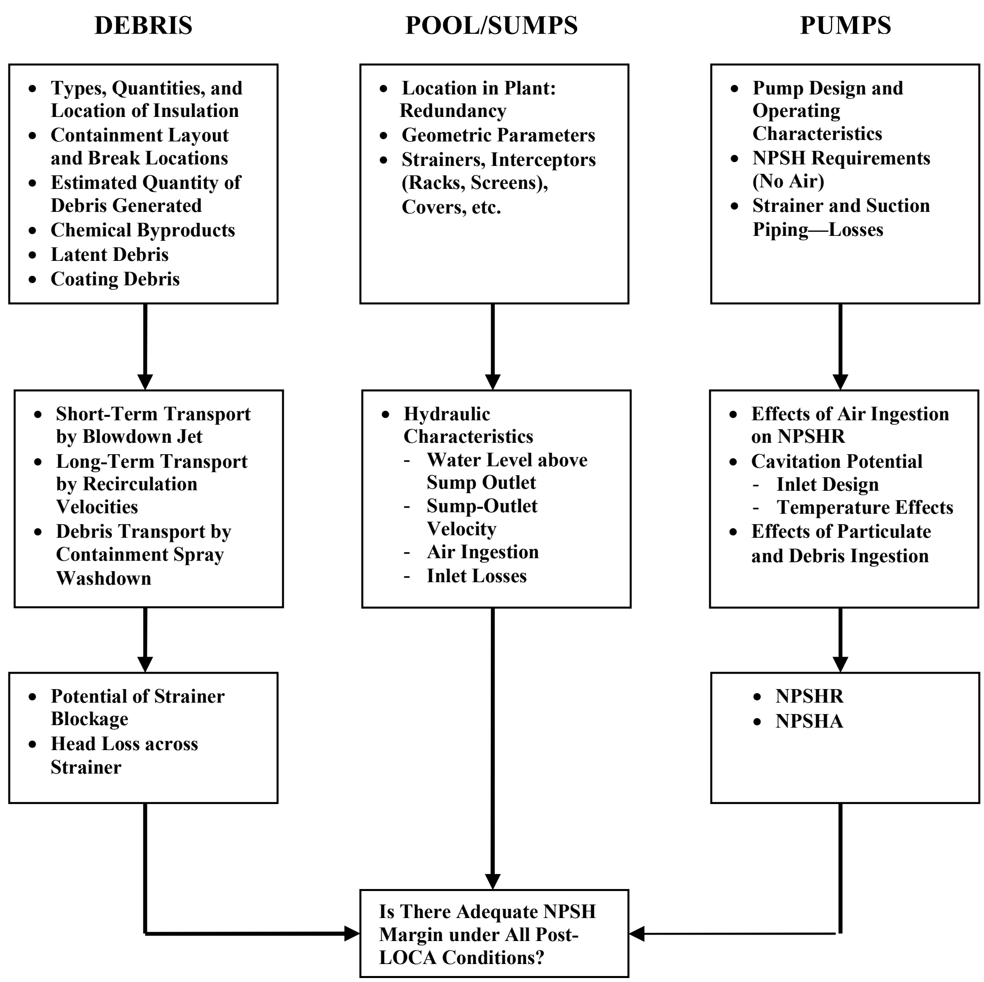
# APPENDIX A

# ADDITIONAL GUIDELINES FOR THE REVIEW OF HYDRAULIC PERFORMANCE OF WATER SOURCES FOR EMERGENCY CORE COOLING SYSTEMS

Water sources for long-term recirculation should be evaluated under possible conditions after a loss-of-coolant accident (LOCA) to determine the adequacy of their design for providing long-term recirculation. Technical evaluations can be subdivided into (1) emergency core cooling system (ECCS) strainer hydraulic performance, (2) pump suction inlet hydraulic performance, (3) LOCA-induced debris effects, and (4) impacts of ingested air on pump performance. Figure A-1 identifies the specific considerations within these categories and the combination thereof. The primary acceptance criterion is that adequate net positive suction head (NPSH) margin exists at the pump inlet under all postulated post-LOCA conditions such that the required coolant flow is delivered to the reactor. However, other potential failure modes, such as structural failure, flashing or deaeration as coolant flows through the strainer, and insufficient flow (for partially submerged or vented strainers), should also be considered as applicable, as discussed in the regulatory positions.

**Figure A-1. Technical considerations relevant to ECCS suction strainer performance**



## A-1. Emergency Core Cooling System Strainer Hydraulic Performance

ECCS strainer hydraulic performance is primarily concerned with the potential for air ingestion and for flashing or deaeration of the recirculating coolant at, or across, an ECCS strainer surface, including the debris bed, or internal flow restriction. Air ingestion could occur in several ways, including (1) through vortex formation, (2) through the release of gas dissolved in the recirculating coolant via deaeration after undergoing a pressure drop, and (3) through entrainment with water drainage that splashes down onto, or in the direct vicinity of, the strainer. Flashing could occur if the strainer pressure drop is sufficiently large that the recirculating coolant undergoes a transition to the vapor phase anywhere in the system. Deaeration may occur if the differential pressure across the strainer is great enough to liberate entrained gasses from the fluid. These phenomena may be evaluated on the basis of factors such as the strainer submergence, the strainer approach velocity, the strainer debris bed head loss, the temperature of the recirculating coolant, and the properties of the containment atmosphere.

Licensees should perform prototypical testing to ensure that an ECCS strainer is not subject to vortex formation. Consistent with the range of possible plant-specific values, the testing should consider conservatively low submergence levels and conservatively high flow rates. If the potential exists for a nonuniform flow distribution among the various modules in a strainer array, a conservatively high flow rate should be used to account for this nonuniformity to ensure that vortexing does not occur. Some work has been performed to determine analytically whether vortex formation will occur under various hydraulic conditions for specific types of strainers. NUREG/CR-2758, "A Parametric Study of Containment Emergency Sump Performance," provides details of the testing (Ref. A-1). The evaluations have been based on empirical data and are not generically applicable. Therefore, licensees should conduct properly scaled testing to determine the strainer potential for vortex formation under plant-specific conditions. In some plant designs, the flowpath upstream of the strainers may result in significant vorticity in the flow approaching the strainers. Computational fluid dynamics simulations may be useful in identifying this situation. If significant, then the strainer vortex tests should include consideration of vorticity in the flow upstream of strainer.

Licensees should conduct an analysis to ensure that deaeration (or offgassing) caused by the pressure drop at the strainer surface or internal flow restrictions does not lead to air void formation within or downstream of the strainer that could adversely impact safety pump performance. The accumulation and transport behavior of air voids inside a strainer is not well understood and demonstrating that gas voids generated at or inside the strainer surface through deaeration do not eventually reach the pump suction inlet is complex. Furthermore, excessive deaeration could lead to increases in differential pressure across the strainer because of the presence of two-phase flow. Therefore, licensees should ensure that strainer submergence is sufficient relative to the strainer head loss and other parameters of interest to prevent deaeration across the strainer debris bed or internal flow restrictions. If the strainer submergence is not sufficient to ensure zero deaeration under the potential post-LOCA conditions, then licensees should follow the guidance below for increasing the required NPSH caused by gas voids. Air ingestion larger than 2 percent by volume (or 1 percent by volume if the ratio of the flow rate to the best efficiency flow rate is greater than 120 percent or less than 40 percent) should be avoided to ensure that the pumps are performing adequately and to ensure that a significant increase in pressure drop across the strainer does not occur.

Strainers should be designed such that water drainage does not splash down directly onto their surfaces or in their direct vicinity. Drainage splashing down onto a water surface above or directly adjacent to the strainer can result in entrained air being generated and subsequently being drawn downstream of the ECCS strainer by the recirculation flow. As discussed above, this entrained air could adversely impact the performance of the pumps taking suction from the strainer. For designs in which water drainage in the vicinity of the strainer cannot be avoided, a solid cover plate should be provided to prevent entrained air from being drawn into the strainer.

Licensees should conduct an analysis to ensure that flashing of the recirculating coolant does not occur as a result of the pressure drop at the strainer surface or internal flow restrictions that could result in unacceptable head loss increases.  Head loss tests are typically not conducted at the highest potential plant fluid temperatures; therefore, the strainer tests would not model a head loss increase caused by two-phase flow.  Therefore, licensees should perform an analysis to ensure that flashing resulting from a pressure drop at the strainer surface or internal flow restrictions is prevented or the effects conservatively analyzed.

## A-2. Pump Suction Inlet Hydraulic Performance

In addition to evaluating ECCS strainer hydraulic performance, licensees should also consider the pump suction inlet hydraulic performance.  Evaluation of the pump suction inlet hydraulic performance may be particularly important for partially submerged strainer configurations, vented strainer designs with a free surface above the pump suction inlets, or strainers that could potentially have an interior free surface formed by gas voids caused by accumulated gas from vortexing at the strainer surface or from deaeration. (see NUREG/CR-6762, "GSI-191 Technical Assessment:  Parametric Evaluations for Pressurized Water Reactor Recirculation Sump Performance," (Ref. A-2)).

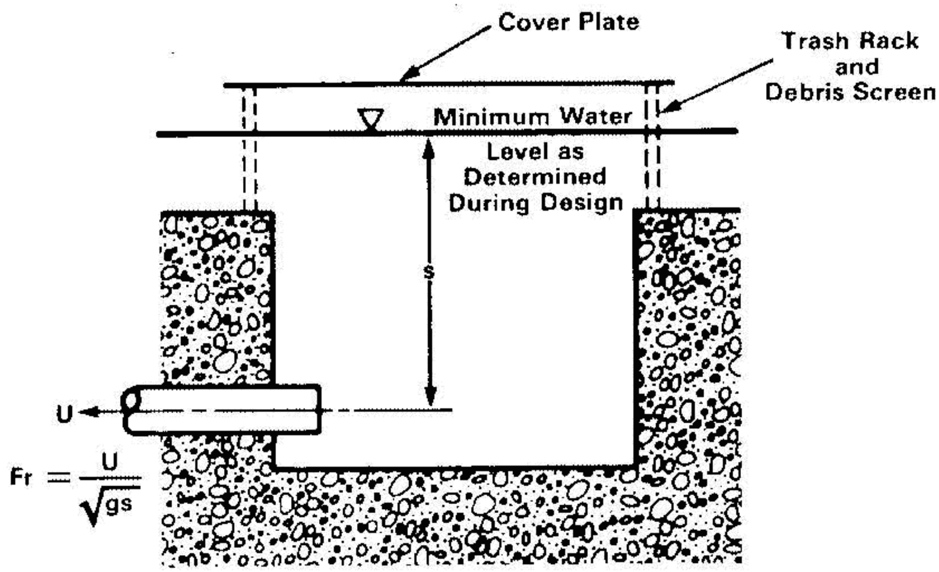
Pump suction inlet hydraulic performance (with respect to air ingestion potential) can be evaluated on the basis of submergence level ((s) water depth above the pump suction inlet piping) and necessary pumping capacity (or pump inlet velocity).  The ratio of the water depth above the pipe centerline and the inlet pipe velocity based on the effective pipe flow area, *U,* can be expressed nondimensionally as the Froude number (see Figure A-2):

$$\text{Froude number} = \frac{U}{\sqrt{gs}},$$

where *g* is the acceleration due to gravity.

Extensive experimental results have shown that the hydraulic performance of pump suction inlets (particularly the potential for air ingestion resulting from vortex formation) is a strong function of the Froude number.  Perturbations in the geometry of the flow approach path, such as a sharp turn just before reaching the sump can also influence vortex formation.  Where these sharp turns exist, quiescent flume test may not be able to accurately predict vortex formation or behavior.  Other nondimensional parameters (e.g., the Reynolds number and the Weber number) are of secondary importance.

**Figure A-2. Submergence level**




Pump suction inlet hydraulic performance can be divided into the following performance categories.

a. zero air ingestion (α) caused by vortexing at the pump suction inlets, for which vortex suppressors or increases in the required NPSH above that from the pump manufacturer's curves are not needed;

b. air ingestion (α) of 2 percent or 1 percent, depending upon flow rate, or less caused by vortexing at the pump suction inlets, which is a conservative level at which degradation of pumping capability is not expected, provided that an increase to the required NPSH is accounted for as noted below; and

c. vortex suppressors to reduce air ingestion caused by vortexing at the pump suction inlets to zero.

d. For pressurized-water reactors (PWRs), determination of those pump suction inlet designs having ingestion levels of 2 percent or less can be obtained using the correlations given in Table A-1, which is only applicable to PWR sump screens without a complete water seal (e.g., screens are not fully submerged) and the appropriate sump geometry that accompanies the table. However, it should be noted that most strainers have the potential to generate and accumulate air in the long term, which could lead to the formation of a free surface inside the strainer volume. If long-term generation and accumulation of air cannot be ruled out, licensees should continue to consider the design guidance in Table A-1, even if fully submerged. Some plant designs have open or vented sumps downstream of the strainers. For these cases, Table A-1 also applies. If the PWR pump suction inlet design deviates significantly from the bounding values of design parameters noted, similar performance data should be obtained for verification of adequate hydraulic performance.

e. For boiling-water reactors (BWRs), full-scale tests of pump suction inlet designs for safety pumps have shown that air ingestion is zero for Froude numbers less than 0.8, with a minimum submergence of 6 feet, and operation up to a Froude number of 1.0 with the same minimum submergence may be possible before air ingestion levels of 2 percent occur (NUREG-0897, Revision 1, "Containment Emergency Sump Performance (Technical Findings Related to Unresolved Safety Issue A-43)," issued October 1985 (Ref. A-3), and NUREG/CR-2772, "Hydraulic Performance of Pump Suction Inlets for Emergency Core Cooling Systems in Boiling Water Reactors," issued June 1982 (Ref. A-4)).[12]

[12] The present interim Froude numbers used for addressing transient and steady-state issues relative to Generic Letter 2008-01, "Managing Gas Accumulation in Emergency Core Cooling, Decay Heat Removal, and Containment Spray Systems," are no gas transport in pipes for ≤ 0.31, all gas is cleared from a pipe if ≥ 2.0, and time to clear gas from a pipe between 0.31 and 2.0 is a function of flow rate and pipe geometry. The values associated with submergence values are for assessing whether gas enters the pipes from the sump under steady-state conditions.

**Table A-1. PWR Hydraulic Design Guidelines for Air Ingestion**
(Tables 5.1 and 5.2 in NUREG-0897, Revision 1 (Ref. A-3))

**Zero Air Ingestion**

| Item | Horizontal Outlets | Vertical Outlets |
|---|---|---|
| Minimum Submergence, s (ft) | 9 | 9 |
| (m) | 2.7 | 2.7 |
| Maximum Froude Number, Fr | 0.25 | 0.25 |
| Maximum Pipe Velocity, U (ft/s) | 4 | 4 |
| (m/s) | 1.2 | 1.2 |

NOTE: These guidelines were established using experimental results from NUREG/CR-2758, et. al., and are based on sumps having a right rectangular shape.

**Air Ingestion Less Than 2 Percent**

| | **HORIZONTAL OUTLETS** | | **VERTICAL OUTLETS** | |
|---|---|---|---|---|
| **ITEM** | **DUAL** | **SINGLE** | **DUAL** | **SINGLE** |
| Coefficient $\alpha_0$ | -2.47 | -4.75 | -4.75 | -9.14 |
| Coefficient $\alpha_1$ | 9.38 | 18.04 | 18.69 | 35.95 |
| Minimum submergence, s (ft) | 7.5 | 8.0 | 7.5 | 10.0 |
| (m) | 2.3 | 2.4 | 2.3 | 3.1 |
| Maximum Froude number, Fr | 0.5 | 0.4 | 0.4 | 0.3 |
| Maximum pipe velocity, U (ft/s) | 7.0 | 6.5 | 6.0 | 5.5 |
| (m/s) | 2.1 | 2.0 | 1.8 | 1.7 |
| Maximum screen face velocity (blocked and minimum submergence) (ft/s) | 3.0 | 3.0 | 3.0 | 3.0 |
| (m/s) | 0.9 | 0.9 | 0.9 | 0.9 |
| Maximum approach flow velocity (ft/s) | 0.36 | 0.36 | 0.3 | 0.36 |
| (m/s) | 0.11 | 0.11 | 0.11 | 0.11 |
| Maximum sump outlet coefficient, $C_L$ | 1.2 | 1.2 | 1.2 | 1.2 |

* Air ingestion ($\alpha$) is empirically calculated as $\alpha = \alpha_0 + (\alpha_1 \times Fr)$, where $\alpha_0$ and $\alpha_1$ are coefficients derived from test results as given in the table.

This table applies to pump suction inlet geometry. See guidance developed for resolution of GL 2008-01 (Ref. A-5) for gas accumulation downstream of the inlet; Interim Staff Guidance, DC/COL-ISG-019, "Proposed Interim Staff Guidance Review of Evaluation to Address Gas Accumulation Issues in Safety Related Systems" (Ref. A-6) ; and the 11$^{th}$ revision of NRC's "Guidance to NRC/NRR/DSS/SRXB Reviewers for Writing Temporary Instruction Suggestions for the Region Inspections," dated May 23, 2011 (Ref. A-7).

## A-3. Impacts of Ingested Air on Pump Performance

Table A-2 presents the recommended limits on allowed air ingestion for steady-state conditions. Higher levels than what are listed have been shown to initiate degradation of pumping capacity. Air ingestion from vortex formation, deaeration, and entrainment from splashdown are included in the limits and the calculation for adjustment of required NPSH.

The limit on sump air ingestion and the NPSH criteria are applied independently. However, steady-state air ingestion levels less than 2 percent can also affect NPSH margin (Ref. A-4). If air ingestion is indicated, then the following relationship can be used to correct the required NPSH from the pump curves for steady-state operating conditions:

$$NPSH_{required(\alpha p < 2\%)} = NPSH_{required(liquid)} \times \beta,$$

where $\beta = 1 + 0.50\alpha_p$ and $\alpha_p$ is the volumetric percentage of air in the fluid at the pump inlet flange.

For transient conditions, the effect of gas on NPSH does not have to be considered if the Table A-2 transient conditions are met because the short term effects are adequately covered by the conservatism associated with the void fraction, Φ.

**Table A-2. Impact of Ingested Air on Pump Performance**
(Taken from Reference A-7)

| Condition | $\% \frac{Q}{Q_{BEP}}$ | Φ for BWR Typical Pumps | Φ for PWR Typical Pumps | | |
|---|---|---|---|---|---|
| | | | Single Stage | Multistage Stiff Shaft | Multistage Flexible Shaft |
| Steady-State Operation | 40–120% | 0.02 | 0.02 | 0.02 | 0.02 |
| Steady State Operation | <40% or >120% | 0.01 | 0.01 | 0.01 | 0.01 |
| Transient Operation | 70–120% | 0.10 for ≤5 s | 0.05 for ≤20 s | 0.20 for ≤20 s | 0.10 for ≤5 s |
| Transient Operation | <70% or >120% | 0.05 for ≤5 s | 0.05 for ≤20 s | 0.05 for ≤20 s | 0.05 for ≤5 s |

where: Q = water volumetric flow rate
BEP = best efficiency point
Transient Φ is averaged over the specified time span
Instantaneous Φ < 1.7 times the listed value[13]

[13] The value of 1.7 represents mutual judgment of industry and Office of Nuclear Reactor Regulation staff representatives (See section 1.4 of Reference A-7 for additional information and qualification).

## A-4. Criteria for Evaluating Emergency Core Cooling System Strainer Failure

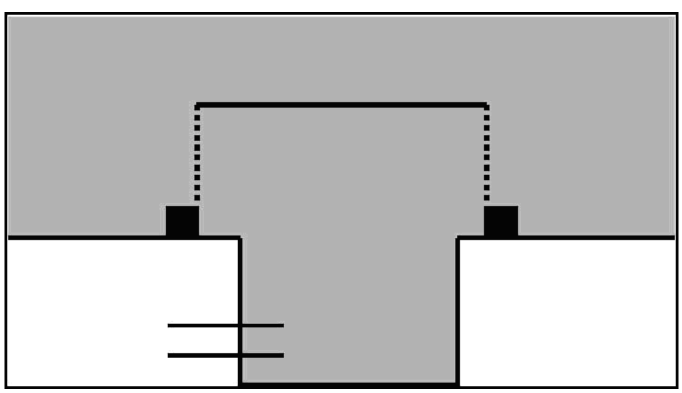
The applicable ECCS strainer failure criteria depend on a number of factors, including submergence and structural strength, and may be pump or system dependent. Figures A-3(a), A-3(b), and A-3(c) illustrate the three basic strainer configurations of fully submerged, partially submerged, and vented strainers. Although only vertical strainers with configurations that appear more consistent with PWR plants are shown here, the same designations are generally applicable to other strainer designs, including those used for BWRs. The key distinction between the fully and partially submerged configurations is that partially submerged or vented strainers allow equal pressure above the water surface on both sides of the strainer. Fully submerged strainers have a complete seal of water between the pump inlet and the containment atmosphere along all water paths passing through the sump screen. The following sections describe the effect of this difference on evaluating the sump failure criterion (Ref. A-2, Volume 1, Section 1.4).

### A-4.1 Fully Submerged Sump Strainers

Figure A-3a presents a schematic of a fully submerged strainer. Potential failure modes considered for systems with this strainer configuration include (1) structural failure of the strainers caused by excessive differential pressure and (2) cavitation within the safety pump housings when head loss caused by debris accumulation exceeds the pump $NPSH_{Margin}$. (Note that if a hypothetical system failure caused by excessive head loss were to occur in a fully submerged configuration, a strainer structural failure, rather than cavitation, may likely be the cause of the failure because the presence of containment accident pressure would deter pump cavitation and ensure that the flow demanded by the pump would continue to pass through the strainer regardless of the increasing head loss until a structural failure would occur.) For this set of plants in which ECCS strainers are fully submerged at the time of switchover, the onset of cavitation is determined by comparing the $NPSH_{Margin}$, which is part of the plant's licensing basis, with the screen head loss calculated in the plant evaluations performed in accordance with Section C.1.3 in this regulatory guide. For this case, therefore, the ECCS strainer failure criterion is assumed to be reached when one of the following occurs:

- Head loss across the debris bed results in loss of $NPSH_{Margin}$.
- Head loss across the debris bed is greater than or equal to the structural limit.

**Figure A-3a. Strainer schematic**



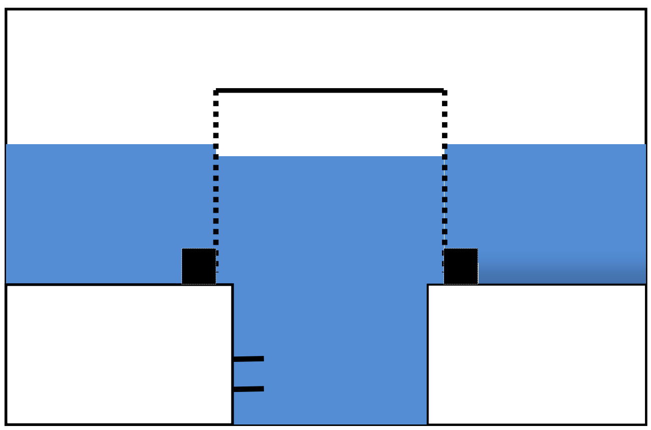
(a) Fully submerged strainer configuration showing solid water from the pump inlet to the containment atmosphere

Note that cavitation could occur in one pump housing, whereas a different pump with a different NPSH margin may not have cavitation. Only in certain conditions (see Section C.1.3.1.3) may credit be taken for continued operation under cavitating conditions, which could relax the above failure criterion for a brief period and provide an opportunity for recovery action.

### A-4.2 Partially Submerged Sump Screens

Figure A-3b presents a schematic of a partially submerged strainer. Failure modes for systems with this strainer configuration include (1) pump cavitation, (2) structural failure, or (3) when head loss caused by debris buildup prevents sufficient water from entering the strainer (i.e., flow starvation). This failure mode, caused by a lack of adequate flow, occurs when water infiltration through a debris bed on the strainer can no longer satisfy the volumetric demands of the pump or pumps taking suction from the strainer. Because the volumes inside and outside the strainer are at equal atmospheric pressures, the only force available to move water through the debris bed is the static pressure head of the water in the pool.

**Figure A-3b. Strainer schematic**



(b) Partially submerged strainer configuration with containment atmosphere over both the external pool and the strainer internal water surface

Numeric simulations confirm that an effective head loss across a debris bed approximately equal to one-half the submerged strainer height can be sufficient to prevent adequate water flow (i.e., the pressure available to move water through the debris bed is approximately the average between the gravitational head at the existing depth of the pool and zero head at the pool surface). For complex geometry strainers, the calculation of the pressure available for moving water through the debris bed may require more complicated evaluations and additional testing. For all partially submerged strainers, failure is assumed to be reached when one of the following occurs:

- Head loss across the debris bed is greater than or equal to $NPSH_{Margin}$.
- Head loss across the debris bed is greater than or equal to one-half of the submerged screen height.
- Head loss across the debris bed is greater than or equal to the structural limit.

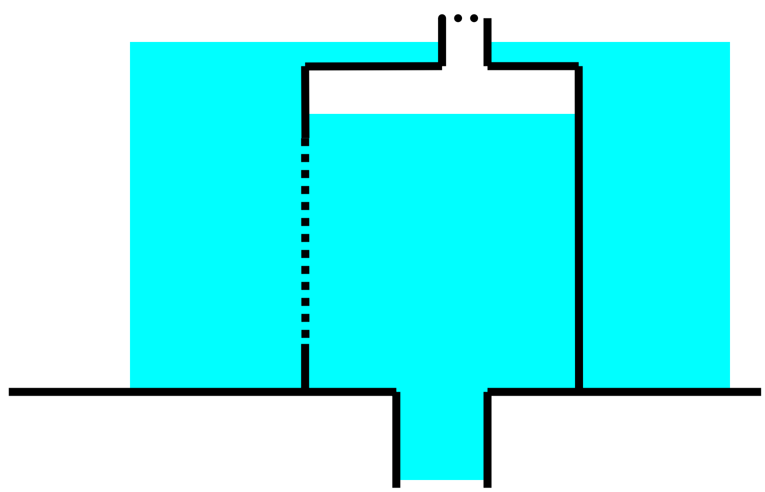
When the flow starvation failure criterion is met, the water level on the downstream side of the screen would drop rapidly, and all pumps taking suction from the sump would have insufficient flow for continued operation.

After switchover to ECCS recirculation, the configuration may change from partially submerged to fully submerged. This can occur for a number of reasons, including the accumulation of containment spray water, the continued melting of ice condenser reservoirs, and the continued addition of the refueling water storage tank inventory to the containment pool. As the containment pool depth changes during recirculation, the "wetted area" (or submerged area) of the strainers can also change. The wetted area determines the average approach velocity of water that may carry debris and the amount of debris that may accumulate per unit of strainer area. Both of these variables effect head loss. The gravitational head of the containment pool across the strainer also varies with the water level. The containment pool water level should be calculated as a function of time, and a conservative assessment should be made of debris transport and the accumulation of debris on the strainer. For plants that have systems that initiate recirculation for containment spray and ECCS at different times, evaluations should consider the containment pool water level and strainer debris loading appropriately, considering this timing.

### A-4.3 Vented Submerged Strainers

A flow starvation failure mode may occur with submerged, but vented, strainers, as illustrated in Figure A-3(c). The potential for this to occur and the subsequent impact on pump performance should be evaluated in the same manner as for a partially submerged strainer, above.

**Figure A-3c. Strainer schematic**

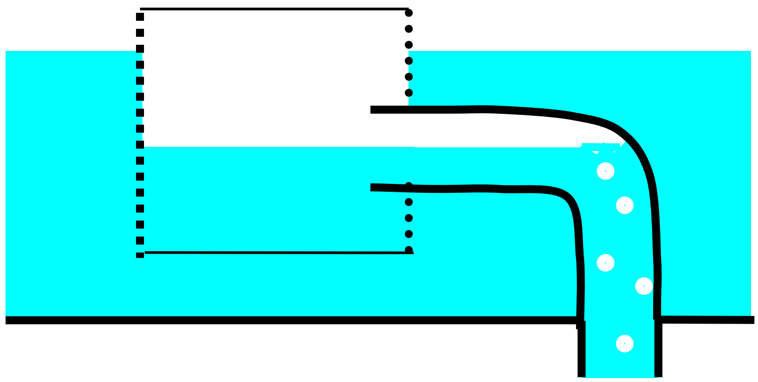


(c) Vented submerged strainer

### A-4.4 Partial Suction Line Uncovery

The new generation of suction strainer designs that are composed of a series of modules connected by piping may be susceptible to the uncovery of piping internal to the strainer that would not occur with earlier strainer designs. For such a strainer design, if a complete water seal does not exist over all strainer surfaces, uncovery of any of these internal connecting pipes is possible and represents an additional failure criterion that must be analyzed. Figure A-3d illustrates the partial uncovery of suction piping for a partially submerged strainer. This is a special case of partially submerged strainers. Failure could occur if the internal suction pipes connecting different strainer modules become uncovered, which can severely impact the head loss and can lead to gas ingestion.  This type of design should be totally avoided.

**Figure A-3d.  Strainer schematic**



(d) Internal suction line uncovery

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