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DRAFT REGULATORY GUIDE

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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 to implement 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 pressurized-water reactor (PWR) and boiling-water reactor (BWR) types of light-water reactors.

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* (CFR), Part 50, "Domestic Licensing of Production and Utilization Facilities" (Ref. 1), requires that systems important to safety be designed to accommodate LOCAs. GDC 35, "Emergency Core Cooling," GDC 38, "Containment Heat Removal," and GDC 41, "Containment Atmosphere Cleanup," 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). Pursuant to 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. Pursuant to 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. Licensees of domestic nuclear power plants are

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This regulatory guide is being issued in draft form to involve the public in the early stages of the development of a regulatory position in this area. It has not received final staff review or approval and does not represent an official NRC final staff position.

Public comments are being solicited on this draft guide (including any implementation schedule) and its associated regulatory analysis or value/impact statement. Comments should be accompanied by appropriate supporting data. Written comments may be submitted to the Rules, Announcements, and Directives Branch, Office of Administration, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001; e-mailed to nrcrep.resource@nrc.gov; submitted through the NRC's interactive rulemaking Web page at http://www.nrc.gov; or faxed to (301) 492-3446. Copies of comments received may be examined at the NRC's Public Document Room, 11555 Rockville Pike, Rockville, MD. Comments will be most helpful if received by September 10, 2010.

Electronic copies of this draft regulatory guide are available through the NRC's interactive rulemaking Web page (see above); the NRC's public Web site under Draft Regulatory Guides in the Regulatory Guides document collection of the NRC's Electronic Reading Room at http://www.nrc.gov/reading-rm/doc-collections/; and the NRC's Agencywide Documents Access and Management System (ADAMS) at http://www.nrc.gov/reading-rm/adams.html, under Accession No. ML092850003. The regulatory analysis may be found in ADAMS under Accession No. ML101610267.

also required to 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, 10 CFR Part 50 Appendix B "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants "criteria apply to all aspects of suction strainer design, fabrication, testing and operation. Criterion XI "Test Control" is particularly important to the 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).

The NRC issues regulatory guides to describe to the public methods that the staff considers acceptable for use in implementing specific parts of the agency's regulations, to explain techniques that the staff uses in evaluating specific problems or postulated accidents, and to provide guidance to applicants. Regulatory guides are not substitutes for regulations and compliance with them is not required.

This regulatory guide contains information collection requirements covered by 10 CFR Part 50 that the Office of Management and Budget (OMB) approved under OMB control number 3150-0011. 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.

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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 emergency core cooling system (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 both, (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 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 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 information appears

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[1] Gas may exist in system piping downstream of the strainers that is of concern when recirculation is initiated. This is addressed by activities in response to Generic Letter 2008-01 ("Managing Gas Accumulation in Emergency Core Cooling, Decay Heat Removal, and Containment Spray Systems," NRC Generic Letter 2008-01, ML072910759, January 11, 2008), and will be addressed in a planned regulatory guide.

in NUREG/CR-6808, "Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance," (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), "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,'" (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. In order for a centrifugal pump to perform its safety function, there must be adequate margin between the available and the required NPSH[2]. 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 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 (ANSI)/Hydraulic Institute (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. However, for some 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.

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

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[2] The term 'required NPSH' is not an NRC regulatory requirement. American National Standards Institute (ANSI)/Hydraulic Institute (HI) 1.3-2009, "American National Standard for Rotodynamic (Centrifugal) Pumps for Design and Application,", defines NPSH parameters, including required NPSH (see Appendix A to this guide).

prudent to not take 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 debris head loss from the NPSH margin excluding debris head loss. The total head loss caused by debris blockage, 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 Generic Letter (GL) 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors," (Ref. 7). Section C of this guide and "NRC Staff Review Guidance regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing," (Ref. 8), discuss this in more detail.

The analyses 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 analyzed 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; the 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 bypasses a strainer is also dependent upon the strainer area and the velocity of the fluid approaching the strainer.

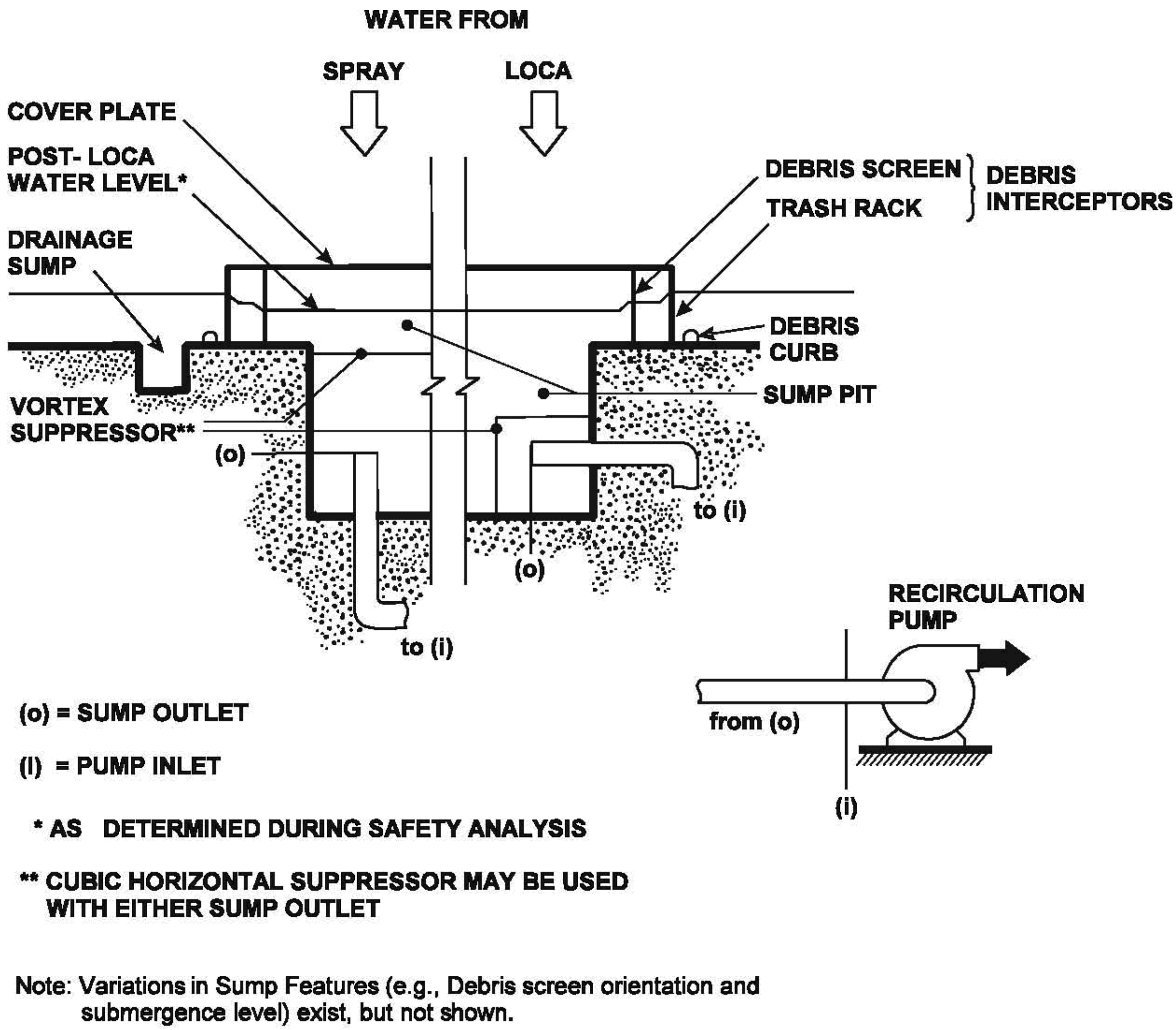
As noted above, a number of factors, including plant design and layout, can cause degraded pump performance. In particular, debris blockage effects on ECCS strainers, sump outlet configurations, and post-LOCA hydraulic conditions (e.g., air ingestion) should be considered in an integrated manner. Small amounts of ingested gas, typically 2 percent by volume when the ratio of flow rate to best efficiency flow rate is between 40 percent 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, "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 and therefore redesign of one or more of the recirculation loop components may be necessary.

This regulatory guide was developed with insights from operating PWRs and BWRs and provides common regulatory positions applicable to both PWRs and BWRs. In certain areas, this regulatory guide provides separate guidance for PWR and BWR plants based on the design features of currently operating reactors. Advanced PWR or BWR designs may employ design features that are different from the operating reactors that formed the basis for 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 advanced reactor designs, this document provides guidance for both PWRs and BWRs, with the recognition that some sections may need to be adjusted 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. Figure 1 shows the features and relationships of the ECCS sumps pertinent to this guide.

Figure 1. Conceptual Features of a PWR ECCS Recirculation Sump



The design of PWR sumps and their outlets considers the avoidance of air ingestion, gas void intrusion, flashing, 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. 11), provide additional technical information relevant to sump ECCS hydraulic performance and original design guidelines. The hydraulic design guidelines provided in Table A-2 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. Excessive deaeration through a debris bed or internal flow restriction could result in two-phase flow and 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. Licensees should evaluate and address deaeration, flashing, and other air entrainment mechanisms, as discussed in Appendix A.

Placement of the ECCS sumps at the lowest level practical ensures maximum use of available recirculation coolant. Areas within the containment in which coolant could accumulate during the containment spray period are provided, as necessary, with drains or flowpaths to the sumps to prevent coolant holdup. Also, debris may block these 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 sump 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 ECCS sumps. Containment drainage sumps are used to collect and monitor normal equipment leakage flow for leakage detection systems within containments. They are typically separated from the ECCS sumps and are located at an elevation lower than the ECCS sumps to minimize inadvertent spillover into the ECCS sumps from minor leaks or spills within containment. The floor adjacent to the ECCS sumps would normally slope downward, away from the ECCS sumps, toward the drainage collection sumps. This downward slope away from the ECCS sumps will minimize the transport and collection of debris against the ECCS strainers. 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 will 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, the demonstration of the effectiveness of such interceptors in capturing fine debris is significantly more 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 are to be designed with 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 sumps from high-energy pipelines is an important consideration in protection against 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 sumps and sump outlets should be separated to the extent practical to reduce the possibility that a single event could render both sumps 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 sumps become operational. 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 and 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 under water at the time of recirculation, either because of unique sump designs or because of uncertainties in water-level estimates. ECCS and CSS systems 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.

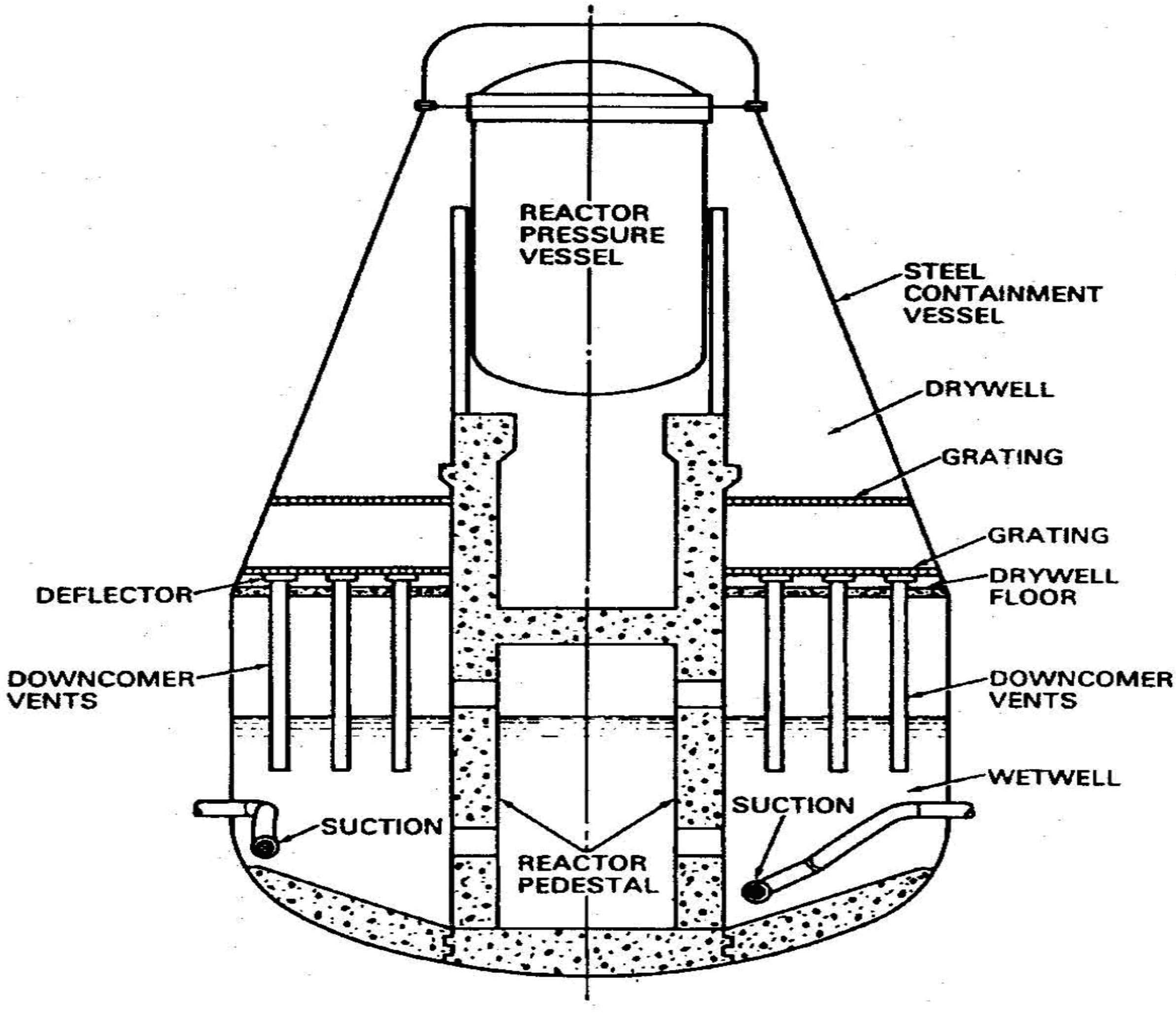
A strainer with a complex geometry design that is located on the containment floor level would minimize the deposition or settling of debris on strainer surfaces and thus help to ensure the greatest possible free flow through the strainer. Elevating the sump strainers slightly above the containment floor level, preferably on a pedestal, minimizes the potential for debris buildup. NUREG/CR-6772, "GSI-191: Separate-Effects Characterization of Debris Transport in Water," (Ref. 12), 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(s) of curbs. NUREG/CR-6916, "Hydraulic Transport of Coating Debris," (Ref. 13), provides test results for the transport of protective coating debris.

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 2 shows the features and relationships of the suppression pool or wetwell pertinent to this guide.

Figure 2. 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. BWR strainer designs should additionally consider subsequent guidance developed during the resolution of GSI-191 and GL 2004-02 on chemical and downstream effects, and strainer head loss and vortexing. For details, refer to the recent NUREG-series publications, several industrial topical reports (TRs) and their accompanying safety evaluations (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," (Ref. 14); IN 95-06, "Potential Blockage of Safety-Related Strainers by Material Brought inside Containment," (Ref. 15); and IN 95-47, "Unexpected Opening of a Safety/Relief Valve and Complications Involving Suppression Pool Cooling Strainer Blockage," (Ref. 16)). 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. 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.

C. REGULATORY POSITION

1. General

This section gives regulatory positions on design criteria, performance standards, and analysis methods that relate to all water-cooled reactor types (Section C.1.1) and also 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. The guidance is generic.

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. The adequacy of the combinations of the features and capabilities should be evaluated using the criteria and assumptions in Section C.1.3.

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 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 flow conditions. 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 blockage 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). Suction strainer features that should be taken into consideration include relative flow velocities and uniform flow throughout the surface area.

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 sump or suppression pool. The potential for long, thin slivers passing axially through the suction strainer and then reorienting and clogging at any flow restriction downstream should be considered.

1.1.1.10 Consideration should be given to 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. WCAP-16406-P-A, "Evaluation of Downstream Sump Debris Effects in Support of GSI-191," (Ref. 17), and its SE (Ref. 18) 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.

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. The staff has provided guidance on prototypical head loss testing in Section C.1.3.12.

1.1.2 Minimizing Debris

The debris and chemical reaction products (see Section 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 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, 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.

1.1.2.3 Licensees should adequately assess any new/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 postaccident sump/pool analysis. Additionally, licensees should assess tags and labels, which can fail and be transported to the sump, 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 sump screen, in place of insulation types (e.g., fibrous and microporous) that can become debris that can more readily transport to the sump screen 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 minimize 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., coatings or jacketing).

1.1.3 Instrumentation/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 conduct an evaluation to ensure that 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 (each refueling outage), licensees should inspect, including by visual examination, strainers, trash racks, vortex suppressors, and pump suction piping inlets for evidence of structural degradation, potential for debris bypass, and the presence of corrosion or debris blockage. Similar inspections should also be conducted 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 nonsafety 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 that will 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. Structural adequacy of any interceptors or trash racks used to prevent debris blockage of these flowpaths should also be assessed. This is 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 ECC and containment heat removal systems should be designed so that sufficient available NPSH is provided to the system pumps assuming the maximum expected temperature of the pumped fluid and with no increase in containment pressure from that present before the postulated LOCA.

For containment pools with temperature less than 212 degrees F, 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. For PWR subatmospheric containments, this guidance should apply after termination of the injection phase. For these subatmospheric containments, prior to 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, no additional containment pressure should be included in the determination of available NPSH than 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 post-test examination of the pump to demonstrate that pump performance will not be degraded and that the pump continues to meet all 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, 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 residual heat should be calculated with margin.

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

1.3.1.6 The calculation of available NPSH should minimize the 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, and the volume of empty system piping). Nonleak-tight structures such as ducting for heating, ventilation, and air conditioning should not be credited 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. Volume shrinkage of the reactor coolant inventory as it cools should be considered 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. The limiting small-break LOCA water level should be explicitly considered because elevated break locations may be possible and certain sources of inventory (e.g., PWR accumulators) may not inject.

1.3.1.7 The pipe and fitting resistance and the nominal strainer resistance without blockage by debris should be calculated in a recognized, defensible method or determined 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) should be calculated with consideration of the potential worst case distribution of flow through the strainer. For some curvilinear type strainer designs, this occurs with a filtering debris bed near the strainer outlet and a clean strainer where the unobstructed flow path 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 Section Cs 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 Available NPSH should be calculated 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 breaks in each high-pressure system that relies on 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 most challenging break location and size that results in debris generation that produces the maximum head loss across the sump screen. All aspects of the accident scenario must be considered 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 staff expects that testing will simulate the debris from the break location that transports the maximum amount of debris or the worst combination of debris to the sump screen and produces the maximum head loss. At a minimum, the following postulated break locations and pipe break characteristics should be considered:

1.3.2.1 Large breaks with two or more different types of debris, including the breaks with the largest quantity and greatest variety of debris within the expected zone of influence (ZOI), should be considered.

1.3.2.2 Breaks where debris is most easily transported to the sump should be considered (e.g., breaks in areas with the most direct path to the sump or suppression pool).

1.3.2.3 Licensees should consider medium and large breaks that have the largest 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 This evaluation should disregard break exclusion zones (i.e., pipe breaks must be postulated in break exclusion zones).

1.3.2.5 NRC Branch Technical Position (BTP) 3-4, "Postulated Rupture Locations in Fluid System Piping inside and outside Containment" (Ref. 19), should be excluded 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 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, licensees should consider breaks that produce the greatest contribution of latent debris sources, which may produce the limiting debris loading condition for sump screen blockage concerns.

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 the selection criteria for break locations should be the same 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. The volume of material contained within the ZOI should be used 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.

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

d. Debris generation testing for determination of the ZOI should be performed in a manner that is prototypical of the plant condition. Test scaling may be challenging 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 that it is being applied to (e.g., insulation jacketing seam, jacketing thickness, and banding/latching strength).

e. If the evaluation uses simplified ZOI models, sufficient conservatism should be applied 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 nonuniform blowdown that could create damage in a particular direction at much greater distances from the break. Therefore, such a spherical model would likely be nonconservative 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. Applicable test data should be the basis for predicting the size of the postulated debris. For breaks postulated in the vicinity of the containment penetrations, the potential for debris generation from the packing materials used in the penetrations should also be considered. Breaks that could destroy the insulation installed on the pressure vessel should be considered. 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 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 prior to 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 (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.

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 sump or suppression pool. Consideration of containment sump or suppression pool debris transport should address (1) debris transport during the fillup 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.

1.3.4.2 Transport analyses within the sump or suppression 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 or suppression pool flow (i.e., debris suspended within the flow) because of neutral buoyancy or turbulence (e.g., individual fibers and fine particulates), (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 fillup is to use acceptably verified computational fluid dynamics simulations in combination with experimental debris transport data. NEI 04-07, "PWR Sump Performance Evaluation Methodology," (Ref. 20) and Appendix III to the SE on NEI Guidance Report 04-07, "PWR Sump Performance Evaluation Methodology," (Ref. 21), provides 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 sump or suppression pool strainer.

1.3.4.5 Curbs can be credited 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 fillup phase (see NUREG/CR-6772 (Ref. 12) for limitations).

1.3.4.6 If transported to the sump or suppression 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 fillup, adequate theoretical and experimental basis should be provided to demonstrate that such settling is prototypical of plant conditions.

1.3.4.7 In lieu of performing detailed blowdown and washdown debris transport analyses, licensees can conservatively assume that all debris will be transported to the containment sump or suppression pool.

In lieu of performing detailed pool fillup (as applicable) and recirculation 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 minimize head loss caused by floating or buoyant debris.

1.3.4.9 Credit

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 Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Coatings Evaluation," (Ref. 22), 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." (Ref. 30 provides a general approach to conduct 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.

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 The debris characteristics (e.g., size, shape, density) of failed coatings should be determined separately for each coating within containment.

1.3.5.4 Coating chip debris transportability in flowing water may be determined by using the results in NUREG/CR-6916 (Ref. 13) 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, "PWR Sump Performance Evaluation Methodology," Revision 0, issued December 2004 (Ref. 20), and its accompanying SE (Ref. 21) provide general considerations for latent debris in terms of its potential impact on strainer blockage and some variables that should be addressed on a plant-specific basis. 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," (Ref. 23), 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, conservative analyses that are based on latent debris measurements made for operating plants may be performed for 10 CFR Part 52 applicants.

1.3.7 Upstream Effects

a. The staff's SE on NEI 04-07 (Ref.21) 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. WCAP-16406-P-A, (Ref. 17), 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, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and Chemical Debris in the Recirculating Fluid," (Ref. 24), for review.[3] 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 limitations to be specified in the NRC SE being prepared for WCAP-16793-NP Rev 1. 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, (2) geometry concerns (i.e., mesh and frame versus perforated plate), (3) ECCS strainer material selection for the postaccident environment (i.e., corrosion-resistant materials that can withstand the post-LOCA environment), and (4) the addition of hydrodynamic loads.

1.3.9.2 Structural loads on a strainer should be computed using the maximum pressure drop across the strainer. The limiting conditions corresponding to the break location and debris source term that induce the maximum total head loss at the ECCS strainer should be evaluated.

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

[3] WCAP-16793-NP, Revision 1, is currently under staff review and had not yet received NRC approval when the staff developed this guide.

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. 26), when analyzing the seismic loading conditions during the structural analyses of the strainers.

1.3.9.5 The licensee 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. This evaluation should be done in 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, 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 TR WCAP-16530-NP-A, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids To Support GSI-191," (Ref. 27), and "NRC Staff Review Guidance regarding Generic Letter 2004-02 Closure in the Area of Plant-Specific Chemical Effect Evaluations" (Ref. 8), 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 sump or suppression 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) 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), the NRC provides 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.

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., minimum bed of fibers supporting a layer of 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 sump 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, the potential for vortex formation internal to the strainer should be evaluated. 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 The adequacy of ECCS strainer designs should be validated 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.

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 (Ref. 20) and its associated SE (Ref. 21). Additionally, “NRC Staff Review Guidance regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing” (Ref. 8), provides a general approach to conduct plant-specific prototype head loss testing. If the test facility is scaled properly and the testing procedures are conservative, it is expected that the measured head loss is also conservative. To ensure adequate strainer function, licensees should design the test facility properly and conduct the test following conservative testing procedures.

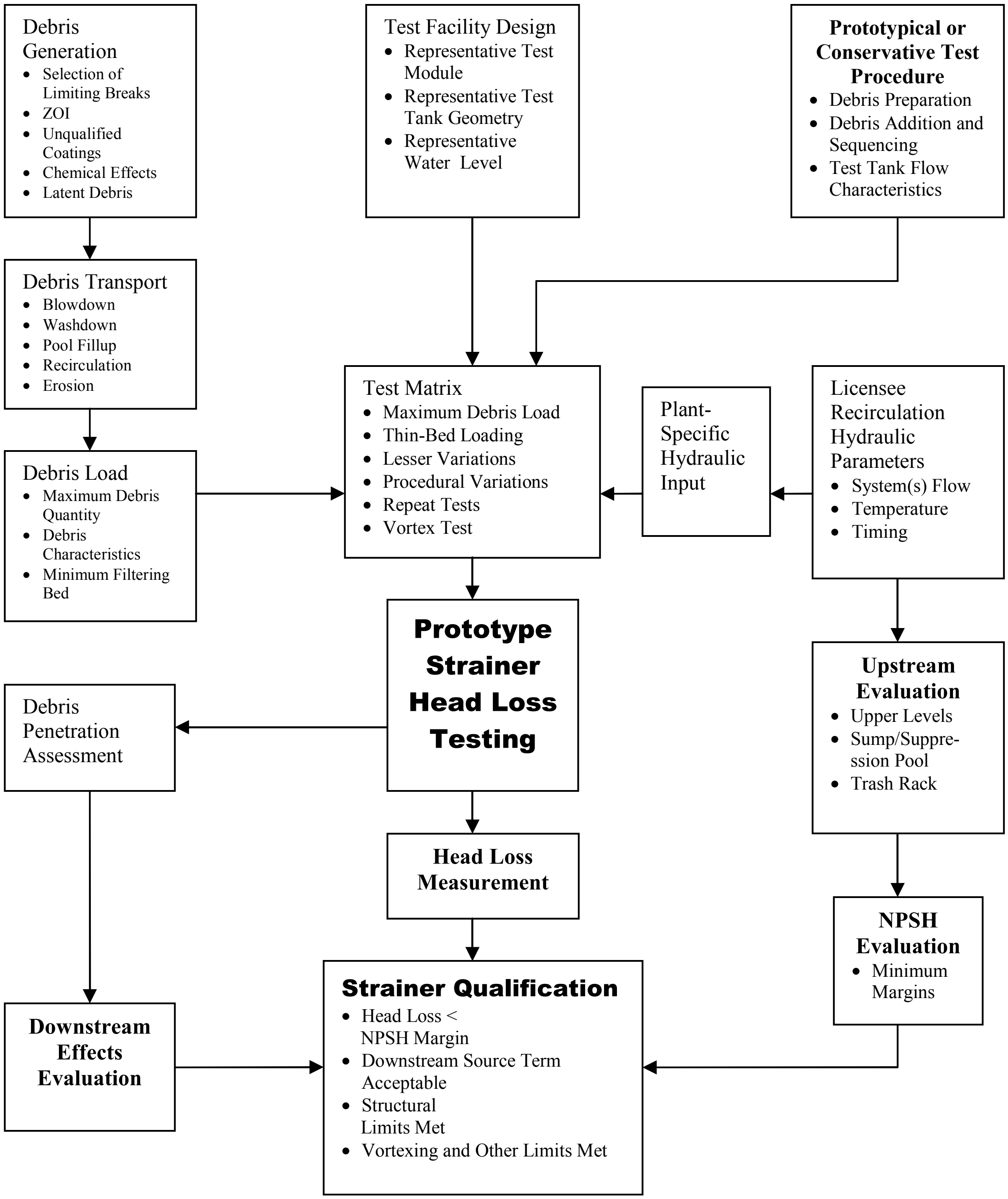
b. The objective of prototypical head loss testing is to determine the potential peak or bounding head loss that could occur across a suction strainer debris bed during a postulated LOCA scenario. The conditions within the test tank should be prototypical or conservative with respect to the plant sump or suppression pool, including the postulated limiting debris loading, the recirculation system hydraulics, and key aspects of various accident scenarios. The testing matrix box shown in Figure 3 (see page 28) illustrates the input logic and information for the head loss test.

c. The test specifications should be designed to determine the worst case head loss from all the possible types of debris beds that could accumulate given the bounding quantities of debris (i.e., thin-bed versus maximum debris accumulations and beds with stratified debris).

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 sump or suppression pool 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 nonconservative effect when the temperature is scaled. The scaling of head loss results to alternate approach velocities or debris loadings can be very challenging because of a lack of understanding of theoretical debris bed head loss behavior and because of variations in the results of experiments that have examined these parameters.

e. The results of head loss testing may need to be extrapolated for a time period matching the mission time of the ECCS. A linear extrapolation of the test data is considered to be conservative.

Figure 3. Conceptual Schematic of the Process Used for Strainer Qualification



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 complete transport. If desired, testing to credit reductions in debris transport to the strainer can be conducted separately under conditions that are conservatively or prototypically scaled to the plant condition. However, if a licensee performs strainer head loss testing that credits debris settlement within the test tank, it 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. Scaling of the debris areal density on the test tank floor should be considered relative to the plant condition. Special consideration should also be given to the adequacy of 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 sump pool. 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.

g. The flows downstream of the test strainer may be sampled to determine the amount of debris passing through the strainer. This debris could potentially damage or clog components such as pumps, throttling valves, or components within the reactor core. The downstream debris characteristics may be used 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 be different than 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. Licensees should 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.

h. Worst case single failures should be considered in the analyses and testing. 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 should consider one LPSI train failure to stop. This assumption leads to a conservatively calculated maximum flow rate to and through the screen. In addition, the sump pool subcooling is assumed to be at a minimum at the beginning of the recirculation phase, thus resulting in a minimum NPSH margin.

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.

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 4 (see page 31).

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 floor elevation in the containment exclusive of the reactor vessel cavity and the drainage sump to maximize the pool depth relative to the strainers. Appropriately designed ECCS strainers and debris interceptors should protect the sump inlets. A curb could be provided upstream of the strainers to prevent high-density debris from being swept along the floor into the sump. 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. 12) and NUREG/CR-6916 (Ref. 13) have demonstrated that substantial quantities of settled debris could transport across the sump pool floor to the sump screen by sliding or tumbling.

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 sump 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 4. PWR LLOCA Accident Progression in a Large, Dry Containment (See 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 • RCS blowdown as quasi-steady jet • Flow quality < 0.05; increase with time	• Impulse load on insulation • Peeled covers • Insulation destroyed • Pieces wetted	• Pressurization • Recirculating vapor flows • 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 • Accumulator inject
10	• Two-phase jet • Flow quality > 0.1 (increasing) • RCS pressure < 1,000 psia	• Destruction under steady loads • Erosion of solid insulation • Concrete spallation and paint dust/chips	• Cont spray actuat. pressure > CS setpoint • NaOH additive for iodine, high pH • Pressure and temp reach peak values		• Fully mixed conditions • Debris break up	• HPSI inject • RPV pressure > LPSI shutoff head
End Blowdown	• ECCS injection from RWST commences	• Termination of debris generation by jet impingement		• Pool starts forming • Thin sheets of fast moving water		• LPSI inject • Ramps to design flow
100	• Flooded R-X core • Design injection flow from break		• Depressurization and cooldown of cont. • Vapor flow velocity btwn compartments minimal • Sprays form a thin liquid film on struct.	• Turbulent pool dynamics, gradually decreasing turbulent intensity • Increasing height	• Washroom of insulation • Start of sedimentation	• Design flow out the break • Borated water (2,000 ppm)
1,000 End Injection	• Switchover to sump (t < 1800 s)	• Generation by erosion/corrosion • Paint chips and delaminating • Spray erosion	• Cont. sprays terminated in large dry (@ 2 hrs) • Fan coolers operate	• Flow through sump • Recirculation flow patterns • Steady pool height	• Transport to sump screen • Accumulation/DH	• Suction from sump • RHR H-X
10,000	• Cooldown of cont. • Licensing issues			• Several pool turnovers • Low turbulence		• Hot-leg injection

2.2 Chemical Reaction Effects

a. The Westinghouse report WCAP-16530-NP-A, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," and the limitations discussed in the SE for WCAP-16530-NP-A (Ref. 27) provide an acceptable approach for PWRs to evaluate chemical effects that may occur in a postaccident containment sump pool.

b. Plant-specific information should be used to determine chemical precipitant 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. 7) provides a general approach for PWR licensees to conduct plant-specific chemical effect evaluations.

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 5 and 6 (see pages 32 and 33, respectively), and take into consideration the BWR Owners Group document NEDO-32686-A, "Utility Resolution Guide for ECCS Suction Strainer Blockage (Ref 28).

3.1 Suppression Pools and Debris Interceptors

3.2.1 For the purposes of evaluating strainer performance, the level of water in the suppression pools or wetwell should be assumed to be the minimum value given in the technical specifications reduced by the drawdown caused by suppression pool water in the drywell and the sprays.

3.2.2 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.

3.2.2 Credit should not be taken 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.1.3.4.7 is 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 5. Debris Blockage Considerations for BWR LOCA Sequences

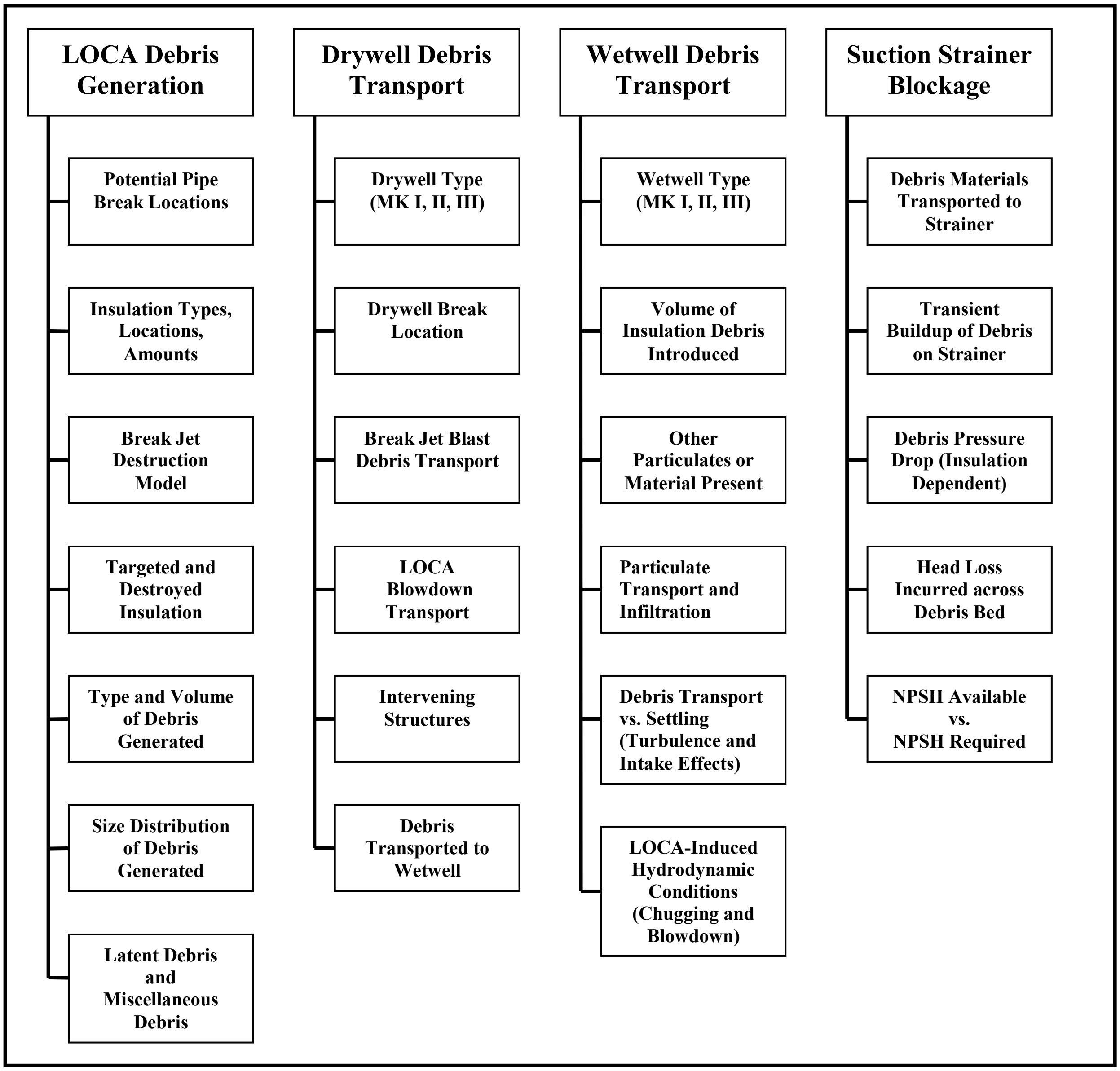
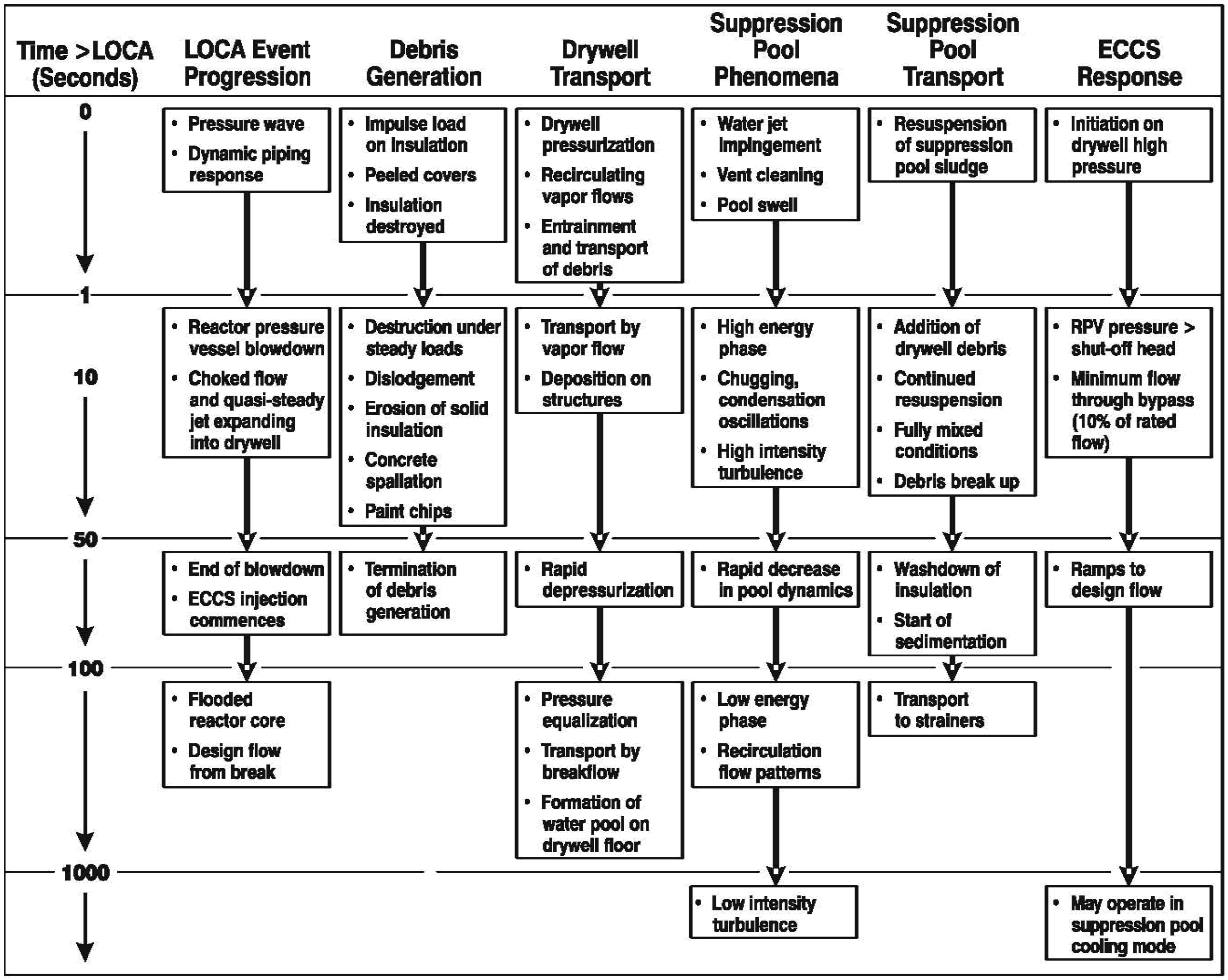


Figure 6. Events that May Affect Debris Blockage for BWR LOCA Sequences



D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC's plans for using this draft regulatory guide. The NRC does not intend or approve any imposition or backfit in connection with its issuance.

The NRC has issued this draft guide to encourage public participation in its development. The NRC will consider all public comments received in development of the final guidance document. In some cases, applicants or licensees may propose an alternative or use a previously established acceptable alternative method for complying with specified portions of the NRC's regulations. Otherwise, the methods described in this guide will be used in evaluating compliance with the applicable regulations for license applications, license amendment applications, and amendment requests.

REFERENCES[1]

1. 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," U.S. Nuclear Regulatory Commission, Washington, DC.

2. 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, Washington, DC.

3. NUREG/CR-6808, "Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance," prepared for the U.S. Nuclear Regulatory Commission by Los Alamos National Laboratory, Los Alamos, NM.

4. Letter to NEI from the NRC, "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,'" U.S. Nuclear Regulatory Commission, Washington, DC. (Agencywide Documents Access and Management System (ADAMS) Accession No. ML080230112)

5. ANSI/HI 1.3-2009, "American National Standard for Rotodynamic (Centrifugal) Pumps for Design and Application," American National Standards Institute, Washington, DC, and Hydraulic Institute, Parsippany, NJ.[2]

6. GSI-191, "Assessment of Debris Accumulation on PWR Sump Performance," U.S. Nuclear Regulatory Commission, Washington, DC.

7. GL 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors," U.S. Nuclear Regulatory Commission, Washington, DC.

8. "NRC Staff Review Guidance regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing," U.S. Nuclear Regulatory Commission, Washington, DC. (ADAMS Accession No. ML080230038)

9. NUREG-0897, "Containment Emergency Sump Performance (Technical Findings Related to Unresolved Safety Issue A-43)," Revision 1, Washington, DC.

10. NUREG/CR-2792, "An Assessment of Residual Heat Removal and Containment Spray System Pump Performance under Air and Debris Ingesting Conditions," prepared for the U.S. Nuclear Regulatory Commission by Creare, Inc., Hanover, NH.

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[1] Publicly available NRC published documents such as Regulations, Regulatory Guides, NUREGs, and Generic Letters listed herein are available electronically through the Electronic Reading room on the NRC's public Web site at: http://www.nrc.gov/reading-rm/doc-collections/. Copies are also available for inspection or copying 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.

11. NUREG/CR-2758, “A Parametric Study of Containment Emergency Sump Performance,” SAND-82-0624, prepared for the U.S. Nuclear Regulatory Commission by Sandia National Laboratories, Albuquerque, NM.

12. NUREG/CR-6772, “GSI-191: Separate-Effects Characterization of Debris Transport in Water,” prepared for the U.S. Nuclear Regulatory Commission by Los Alamos National Laboratory, Los Alamos, NM.

13. NUREG/CR-6916, “Hydraulic Transport of Coating Debris,” prepared for the U.S. Nuclear Regulatory Commission by the Naval Surface Warfare Center, West Bethesda, MD, and Pacific Northwest National Laboratory, Richland, WA.

14. IN 94-57, “Debris in Containment and the Residual Heat Removal System,” U.S. Nuclear Regulatory Commission, Washington, DC.

15. IN 95-06, “Potential Blockage of Safety-Related Strainers by Material Brought Inside Containment,” U.S. Nuclear Regulatory Commission, Washington, DC.

16. IN 95-47, “Unexpected Opening of a Safety/Relief Valve and Complications Involving Suppression Pool Cooling Strainer Blockage,” U.S. Nuclear Regulatory Commission, Washington, DC.

17. WCAP-16406-P-A, “Evaluation of Downstream Sump Debris Effects in Support of GSI-191,” Revision 1, Westinghouse Electric Company, LLC, Pittsburg, PA. (ADAMS Accession No. ML081000027)

18. “Safety Evaluation by the Office of Nuclear Reactor Regulation, Topical Report (TR) WCAP-16406-P-A, Revision 1, ‘Evaluation of Downstream Sump Debris Effects in Support of GSI-191,’” U.S. Nuclear Regulatory Commission, Washington, DC. (ADAMS Accession No. ML073520295)

19. NRC Standard Review Plan, NUREG-0800, Branch Technical Position (BTP) 3-4 “Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping,” U.S. Nuclear Regulatory Commission, Washington, DC.

20. NEI 04-07, “PWR Sump Performance Evaluation Methodology,” Nuclear Energy Institute, Washington, DC. (ADAMS Accession No. ML050550138)

21. Safety Evaluation for NEI Guidance Report 04-07, “PWR Sump Performance Evaluation Methodology,” U.S. Nuclear Regulatory Commission, Washington, DC. (ADAMS Accession No. ML050550156)

22. “NRC Staff Review Guidance regarding Generic Letter 2004-02 Closure in the Area of Coatings Evaluation,” U.S. Nuclear Regulatory Commission, Washington, DC, (ADAMS Accession No. ML080230462)

23. NEI 02-01, Revision 1, “Condition Assessment Guidelines: Debris Sources inside PWR Containments,” Nuclear Energy Institute, Washington, DC. (ADAMS Accession No. ML030420318)

24. WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," Revision 1, Westinghouse Electric Company, LLC, Pittsburg, PA, April 2009. (ADAMS Accession No. ML091190484) (Revision 1 is currently under staff review and was not yet approved when this guide was developed.)

25. " Safety Evaluation for Pressurized Water Reactor (PWR) Owners Group (PWROG) Topical Report (TR) WCAP-16793-NP, Revision 1, 'Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and Chemical Debris in the Recirculating Fluid,'" U.S. Nuclear Regulatory Commission, Washington, DC, Later

26. Regulatory Guide 1.92, "Combining Modal Responses and Spatial Components in Seismic Response Analysis," U.S. Nuclear Regulatory Commission, Washington, DC.

27. "Final Safety Evaluation by the Office of Nuclear Reactor Regulation, Topical Report WCAP-16530-NP-A 'Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids To Support GSI-191," U.S. Nuclear Regulatory Commission, Washington, DC, and Topical Report WCAP-16530-NP-A. (ADAMS Accession Nos. ML081150379, ML073520891)

28. NEDO-32686-A, "Utility Resolution Guide for ECCS Suction Strainer Blockage," Volumes 1-4, BWR Owners Group, (ADAMS Accession Nos. ML092530482, ML092530500, ML092530505, ML092530507)

29. SECY-85-349, "Resolution of Unresolved Safety Issue A-43, "Containment Emergency Sump Performance,"" U.S. Nuclear Regulatory Commission, Washington, DC, (ADAMS Accession No. ML033520145)

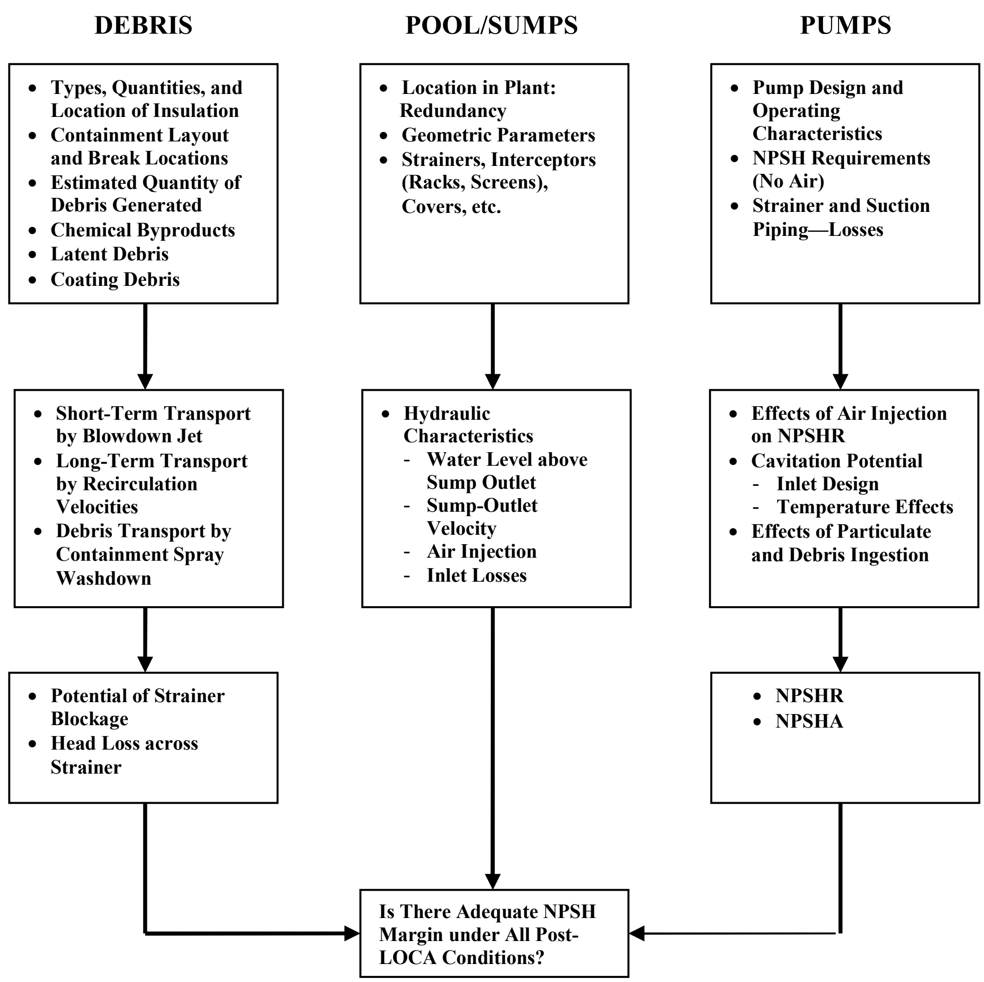
30. "Revised Guidance Regarding Coatings Zone of Influence For Review of Final Licensee Responses To Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents At Pressurized-Water Reactors." April 6, 2010, U.S. Nuclear Regulatory Commission, Washington, DC, (ADAMS Accession No. ML100960495)

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 shows 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. However, other potential failure modes, such as structural failure, flashing of coolant 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 Sump 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 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. 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.

Prototypical testing should be performed to ensure that an ECCS strainer is not subject to vortex formation. Consistent with the range of possible plant-specific values, conservatively low submergence levels and conservatively high flow rates should be considered in the testing. 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," issued July 1982, provides details of the testing (Ref. A-1). The evaluations have been based on empirical data and are not generically applicable. Therefore, testing should be conducted to determine the strainer potential for vortex formation under plant-specific conditions.

An analysis should be conducted to ensure that deaeration 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 may be challenging. 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 there is sufficient strainer submergence 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 the guidance below for increasing the required NPSH caused by gas voids should be followed. 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.

An analysis should be conducted 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

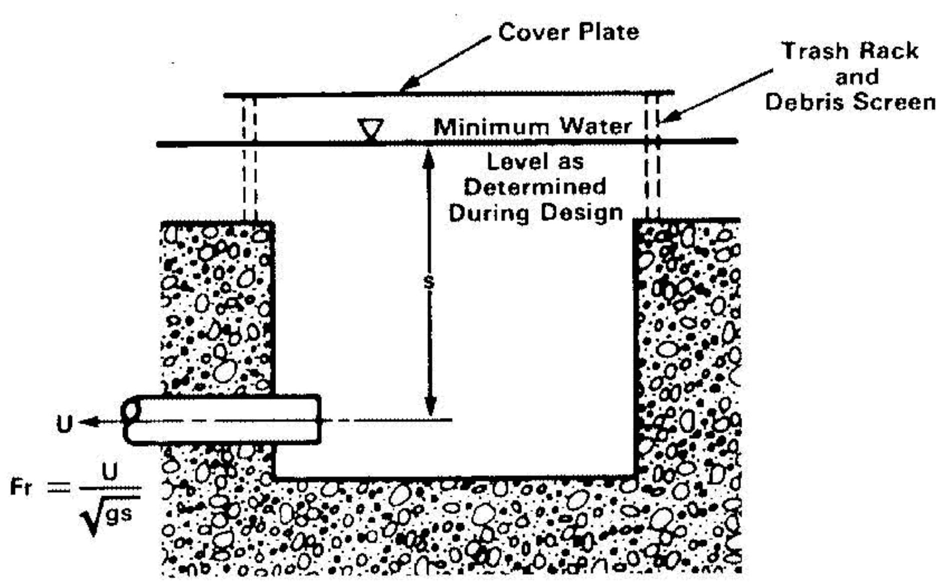
In addition to evaluating ECCS strainer hydraulic performance, licensees should also consider the pump suction inlet hydraulic performance. Evaluation of the pump suction inlet hydraulic performance may be particularly important for partially submerged strainer configurations, vented strainer designs 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.

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:

$$\text{Froude number} = \frac{U}{\sqrt{gs}}, \quad \text{(see Fig. A-1a)}$$

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 and the submergence level. 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.

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 and the appropriate sump geometry that accompanies the table. 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.

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 1.0 with the same minimum submergence may be possible before air ingestion levels of 2 percent occur (Ref. A-2 and A-3)).[5]

A-3. Impacts of Ingested Air on Pump Performance

The pump industry historically has determined required NPSH for pumps on the basis of percentage degradation in pumping capacity. The percentage has at times been arbitrary but is generally in the range of 1 to 3 percent. A 2-percent limit on allowed air ingestion is recommended for steady state conditions that have been existing for ≥ 20 seconds because higher levels have been shown to initiate degradation of pumping capacity. Air ingestion from vortex formation, deaeration, and entrainment from splashdown are included in the 2-percent limit and the calculation for adjustment of required NPSH.

The limit on sump air ingestion of 2 percent by volume and the NPSH criteria are applied independently. However, air ingestion levels less than 2 percent can also affect NPSH margin (Ref. A-4). If air ingestion is indicated, licensees can use the following relationship 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 α_p is the air ingestion rate (in percent by volume) at the pump inlet flange. For transient conditions, the effect of gas on NPSH does not have to be considered if the following conditions

[5] The present interim Froude numbers used for addressing transient and steady state GL 2008-01 issues are no gas transport in pipes for ≤ 0.31, all gas is cleared from a pipe if ≥ 2.5, some gas may be transported at ≤ 0.65, and time to clear gas from a pipe between 0.65 and 2.5 is a function of flow rate. The values associated with submergence values are for assessing whether gas enters the pipes from the sump under steady state conditions.

are met because the short term effects are adequately covered by the conservatism associated with the void fraction, Φ:

Table A-1 Impact of Ingested Air on Pump Performance

Condition	Typical BWR Pumps Allowable Φ, %	Typical PWR Pumps Allowable Φ, %		
		Single Stage	Multi-Stage Stiff Shaft	Multi-Stage Flexible Shaft
Transient ≤ 5 seconds, 70% ≤ Q/Q_{BEP} ≤ 120%	10	7	20	10
Transient ≤ 5 seconds, Q/Q_{BEP} < 70% or >120%	5	5	5	5
Transient ≤ 20 seconds, 70% ≤ Q/Q_{BEP} ≤ 120%	4	4	20	5
Transient ≤ 20 seconds, Q/Q_{BEP} < 70% or >120%	3	3	5	5

where: Q = water volumetric flow rate
BEP = best efficiency point
Transient Φ is averaged over the specified time span
Instantaneous Φ < 1.5 times the listed value

A-4. Combined Effects

As shown in Figure A-l, three interdependent effects (i.e., ECCS strainer hydraulic performance, , debris generation and transport, and pump operation under adverse conditions) warrant evaluation for determining long-term recirculation capability (e.g., loss of NPSH margin).

A-5. 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 effect of this difference in evaluation of the sump failure criterion is described below (Ref. A-5)

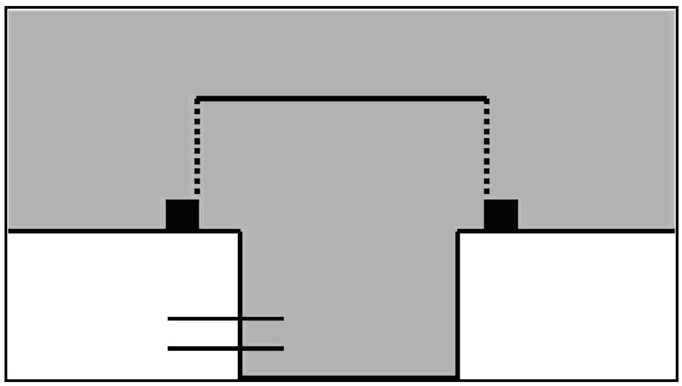
A-5.1 Fully Submerged Sump Strainers

Figure A-3(a) presents a schematic of a fully submerged strainer. Potential failure modes for systems with this strainer configuration include (1) structural failure of the strainers caused by excessive differential pressure, (2) flow starvation caused by excessive debris on the strainer, and (3) 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. Sump Screen Schematic



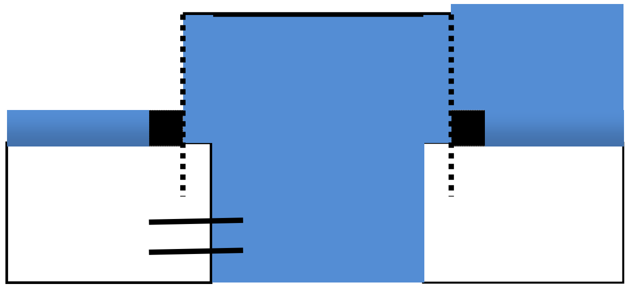
(a) Fully submerged strainer configuration showing solid water from the pump inlet to the containment atmosphere.

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 in the regulatory guide) 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-5.2 Partially Submerged Sump Screens

Figure A-3(b) 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. Sump Screen Schematic



(b) Partially submerged strainer configuration showing containment atmosphere over both the external pool and the internal sump pit with water on the lower portion of the strainer.

Numeric simulations confirm that an effective head loss across a debris bed approximately equal to one-half the submerged strainer height is 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 such as additional testing. For all partially submerged sump screens, the sump failure criterion 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 is greater than or equal to one-half of the submerged screen height.

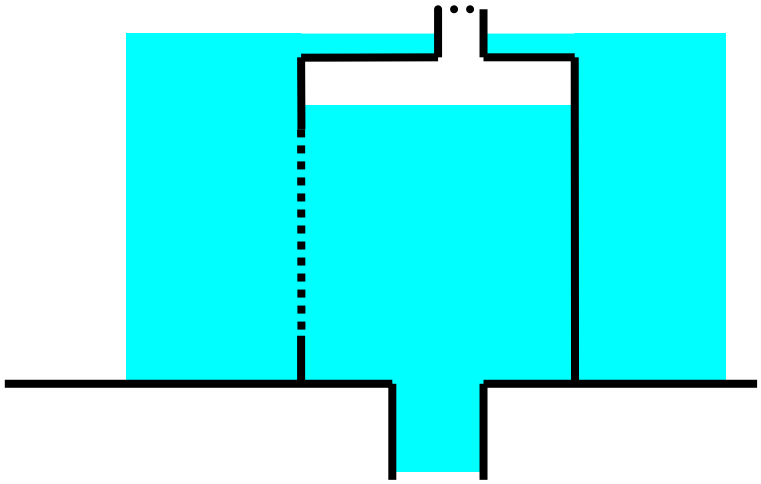
When the flow starvation failure criterion is met, the water level on the downstream side of the screen would drop rapidly, and all pumps taking suction from the sump would have insufficient flow for continued operation.

After switchover to ECCS recirculation, the sump 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 pool depth changes during recirculation, the "wetted area" (or submerged area) of the sump screens can also change. The wetted area of the screen determines the average approach velocity of water that may carry debris, the accumulation of debris on the screen and subsequent head loss, and the gravitational head of the pool across the screen. The sump 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 sump screen. For systems, such as the recirculation containment spray system, that could initiate suction from the recirculation sumps before ECCS switchover, the sump water level and debris loading on strainers applicable at that time should be calculated.

A-5.3 <u>Vented Submerged Strainers</u>

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

Figure A-3c. Sump Screen Schematic



(c) Vented submerged sump screen

A-5.4 Partial Suction Line Uncovery

The new generation of sump strainer designs that are composed of chains 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-4 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 severely limits the head loss. This type of design should be totally avoided.

Figure A-4. Internal Suction Line Uncovery

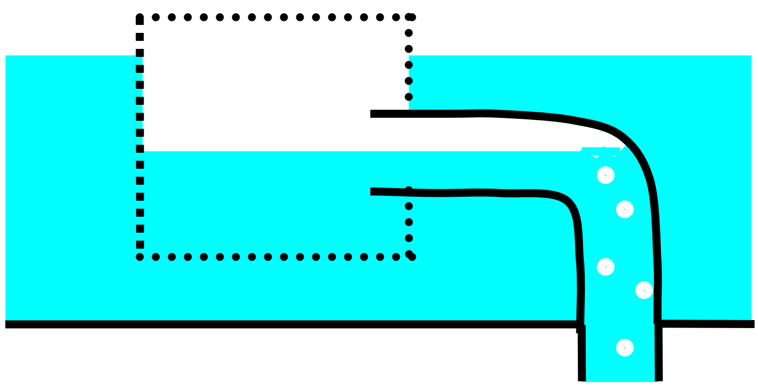


Table A-2.

PWR Hydraulic Design Guidelines for Air Ingestion
(Table 5.1 & 5.2 in NUREG-0897 Revision 1)

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 α_0	-2.47	-4.75	-4.75	-9.14
Coefficient α_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 (α) is empirically calculated as $\alpha = \alpha_0 + (\alpha_1 \times Fr)$, where α_0 and α_1 are coefficients derived from test results as given in the table.

APPENDIX A REFERENCE

A-1. NUREG/CR-2758, "A Parametric Study of Containment Emergency Sump Performance," SAND-82-0624, prepared for the U.S. Nuclear Regulatory Commission by Sandia National Laboratories, Albuquerque, NM, July 1982.

A-2. NUREG-0897, "Containment Emergency Sump Performance (Technical Findings Related to Unresolved Safety Issue A-43)," Revision 1, October 1985.

A-3. NUREG/CR-2772, "Hydraulic Performance of Pump Suction Inlets for Emergency Core Cooling Systems in Boiling Water Reactors,"ARL-398A, prepared for the U.S. Nuclear Regulatory Commission by Sandia National Laboratories, Albuquerque, NM, June 1982.

A-4 NEI 04-07, "PWR Sump Performance Evaluation Methodology," Nuclear Energy Institute, Washington, DC, December 2004. (Agencywide Documents Access and Management System Accession No. ML050550138)

A-5. NUREG/CR-6762, "GSI-191 Technical Assessment: Parametric Evaluations for Pressurized Water Reactor Recirculation Sump Performance," Revision 1, Volumes 1–4, LA-UR-01-4083, prepared for the U.S. Nuclear Regulatory Commission by Los Alamos National Laboratory, Los Alamos, NM, August 2002.