U.S. NUCLEAR REGULATORY COMMISSION

Revision 2
May 1996

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 1.82
(Draft was issued as DG-1038)

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

A. INTRODUCTION

General Design Criteria 35, "Emergency Core Cooling"; 36, "Inspection of Emergency Core Cooling System"; 37, "Testing of Emergency Core Cooling System"; 38, "Containment Heat Removal"; 39, "Inspection of Containment Heat Removal System"; and 40, "Testing of Containment Heat Removal System," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," require that systems be provided to perform specific functions, e.g., emergency core cooling, containment heat removal, and containment atmosphere clean up following a postulated design basis accident. These systems must be designed to permit appropriate periodic inspection and testing to ensure their integrity and operability. General Design Criterion 1, "Quality Standards and Records," of Appendix A to 10 CFR Part 50 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.

This guide describes methods acceptable to the NRC staff for implementing these requirements with respect to the sumps and suppression pools performing the functions of water sources for emergency core cooling, containment heat removal, or containment atmosphere cleanup. The guide also provides guidelines for evaluating the adequacy of the sump and suppression pool for long-term recirculation cooling * following a loss-of-coolant accident (LOCA). This guide applies to light-water-cooled reactors. Additional information is provided in NRC Bulletin 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling Water Reactors" (Ref. 1); NRC Bulletin 95-02, "Unexpected Clogging of a Residual Heat Removal Pump Strainer While Operating in Suppression Pool Cooling Mode" (Ref. 2); NRC Bulletin 93-02, "Debris Plugging of Emergency Core Cooling Suction Strainers" (Ref. 3); Supplement 1 to NRC Bulletin 93-02, "Debris Plugging of Emergency Core Cooling Suction Strainers" (Ref. 4); and Generic Letter 85-22, "Potential for Loss of Post-LOCA Recirculation Capability due to Insulation Debris Blockage" (Ref. 5).

This regulatory guide has been revised to alter the debris blockage evaluation guidance for boiling water reactors (BWRs) because operational events, analyses,

* Lines indicate substantive changes from Revision 1.

and research work after the issuance of Revision 1 indicated that the previous guidance was not comprehensive enough to adequately evaluate a BWR plant's susceptibility to the detrimental effects caused by debris blockage of the suction strainers. Only the sections concerning BWRs have been changed from Revision 1.

The information collections mentioned in this regulatory guide are covered by the requirements in 10 CFR Part 50, which were approved by the Office of Management and Budget, approval number 3150-0011.

B. DISCUSSION

GENERAL

The primary safety concerns regarding long-term recirculation cooling following a LOCA are (1) LOCA-generated and pre-LOCA debris materials transported to the debris interceptors, resulting in adverse blockage effects, (2) post-LOCA hydraulic effects, particularly air ingestion, 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).

Debris resulting from a LOCA with debris that exists before a LOCA could block the emergency core cooling (ECC) debris interceptors (i.e., trash racks, debris screens, suction strainers) and result in degradation or loss of NPSH margin. Such debris can be divided into the following categories: (1) debris generated by the LOCA and transported by blowdown forces (e.g., insulation, paint), (2) debris generated or transported by washdown, and (3) other debris that existed before a LOCA (e.g., corrosion material, foreign material, sludge in a BWR suppression pool). Debris can be further subdivided into (1) debris that has a high density and could sink but is still subject to fluid transport if local recirculation flow velocities are high enough, (2) debris that has an effective specific gravity of 1.0 and tends to be suspended or sink slowly but will nonetheless be transported by very low velocities or local fluid turbulence phenomena, and (3) debris that will float indefinitely by virtue of low density and will be transported to and possibly through the debris interceptors.

Debris generation, early debris transport, long-term post-LOCA transport, and attendant blockage of debris interceptors must be evaluated to ensure that the ability of the emergency core cooling systems (ECCS) to provide long-term post-LOCA core cooling is not jeopardized. All potential debris sources should be evaluated, including but not limited to insulation materials (e.g., fibrous, ceramic, and metallic), filters, corrosion material, foreign materials, and paints or coatings. Relevant information for such evaluations is provided in the Regulatory Position and in Appendix A to this guide. References 6 through 18 provide additional information relevant to the above concerns.

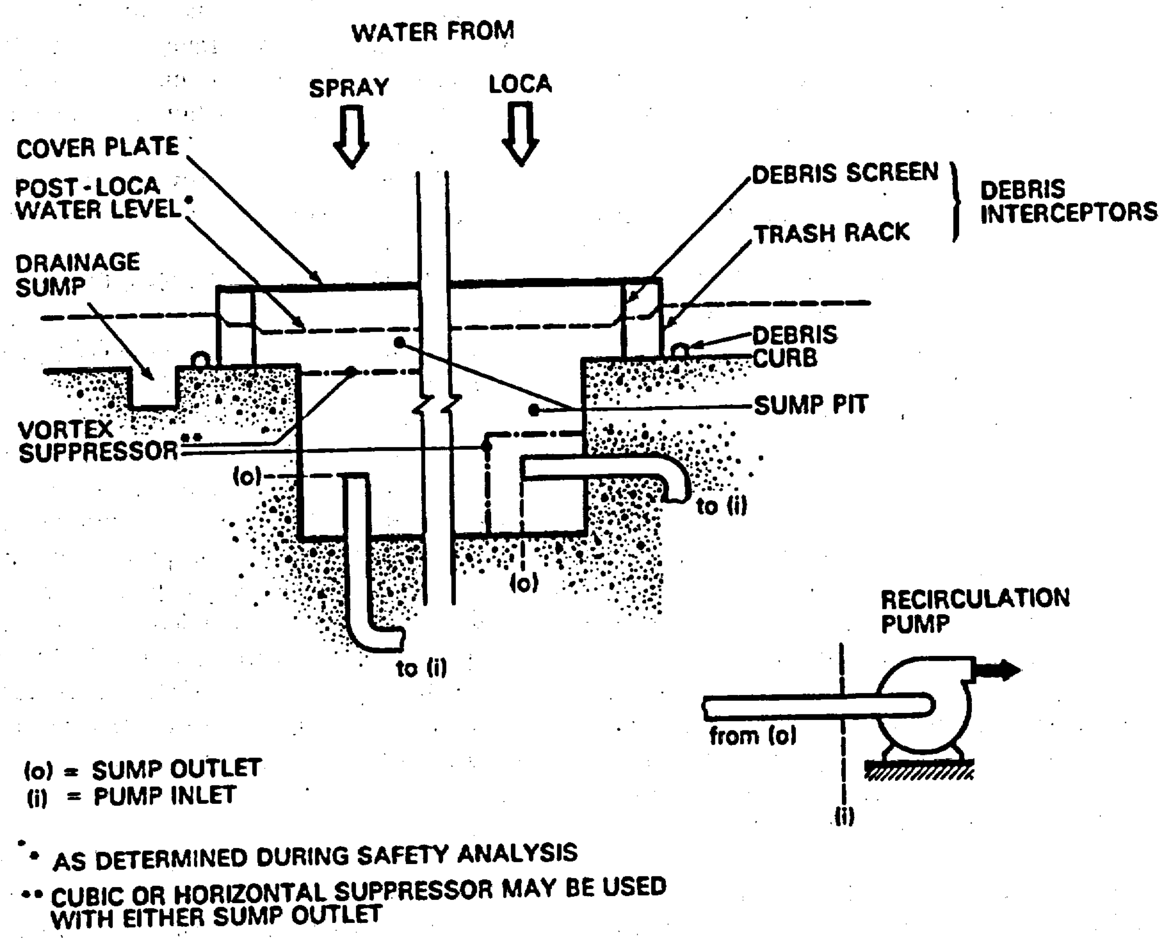
PRESSURIZED WATER REACTORS

In pressurized water reactors (PWRs), the containment emergency sumps provide for the collection of reactor coolant and chemically reactive spray solutions following a LOCA; thus, the sumps serve as water sources to effect long-term recirculation for the functions of residual heat removal, emergency core cooling, and containment atmosphere cleanup. These water sources, the related pump inlets, and the piping between the sources and inlets are important safety components. The sumps servicing the ECCS and the containment spray systems (CSS) are referred to in this guide as ECC sumps. Features and relationships of the ECC sumps pertinent to this guide are shown in Figure 1.

The design of PWR sumps and their outlets includes consideration of the avoidance of air ingestion and other undesirable hydraulic effects (e.g., circulatory flow patterns, outlets leading to high head losses). The location and size of the sump outlets within ECC sumps is important in order to minimize air ingestion since ingestion is a function of submergence level and velocity in the outlet piping. It has been experimentally determined for PWRs that air ingestion can be minimized or eliminated if the sump hydraulic design considerations provided in Appendix A to this guide are followed. References 6, 8, 11, and 13 provide additional technical information relevant to sump ECC hydraulic performance and design guidelines.

Placement of the ECC sumps at the lowest level practical ensures maximum use of available recirculation coolant. Since there may be places within the containment where coolant could accumulate during the containment spray period, these areas can be provided with drains or flow paths to the sumps to prevent coolant holdup. This guide does not address the design of such drains or paths. Because debris can migrate to the sump via 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 ECC sumps.

Figure 1. PWR



Containment drainage sumps are used to collect and monitor normal leakage flow for leakage detection systems within containments. They are separated from the ECC sumps and are located at an elevation lower than the ECC sumps to minimize inadvertent spillover into the ECC sumps from minor leaks or spills within containment. The floor adjacent to the ECC sumps would normally slope downward, away from the ECC sumps, toward the drainage collection sumps. This downward slope away from the ECC sumps will minimize the transport and collection of debris against the debris interceptors. High-density debris may be swept along the floor by the flow toward the trash rack. A debris curb upstream of and in close proximity to the rack will decrease the amount of such debris reaching the rack.

It is necessary to protect sump outlets with debris interceptors of sufficient strength to withstand the vibratory motion of seismic events, to resist jet loads and impact loads that could be imposed by missiles that may be generated by the initial LOCA, and to withstand the differential pressure loads imposed by the accumulation of debris. Considerations for selecting materials for the debris interceptors 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 ECC sumps from high-energy pipelines is an important consideration in protection against missiles, and it is necessary to shield the screens and racks adequately from impacts of ruptured high-energy piping and associated jet loads from the break. When the screen and rack structures are oriented vertically, the adverse effects from debris collecting on them will be reduced. Redundant ECC sumps and sump outlets are separated to the extent practical to reduce the possibility that an event causing the interceptors or outlets of one sump to either be damaged by missiles or partially clogged could adversely affect other pump circuits.

It is expected that the water surface will be above the top of the debris interceptor structure after completion of the safety injection. However, the uncertainties about the extent of water coverage on the structure, the amount of floating debris that may accumulate, and the potential for early clogging do not favor the use of a horizontal top interceptor. Therefore, in the computation of available interceptor surface area, no credit may be taken for any horizontal interceptor surface; preferably, the top of the interceptor structure is a solid cover plate that will provide additional protection from LOCA-generated loads and is designed to provide for the venting of any trapped air.

Debris that is small enough to pass through the trash rack and that could clog or block the debris screens or outlets needs to be analyzed for head loss effects. Screen and sump outlet blockage will be a function of the types and quantities of insulation debris that can be transported to these components. A vertical inner debris screen would impede the deposition or settling of debris on screen surfaces and thus help to ensure the greatest possible free flow through the fine inner debris screen. Slowly settling debris that is small enough to pass through the trash rack openings could block the debris screens if the coolant flow velocity is too great to permit the bulk of the debris to sink to the floor level during transport. If the coolant flow velocity ahead of the screen is at or below approximately 5 cm/sec (0.2 ft/sec), debris with a specific gravity of 1.05 or more is likely to settle before reaching the screen surface and thus will help to prevent blockage of the screen.

The size of openings in the screens is dependent on the physical restrictions that may exist in the systems that are supplied with coolant from the ECC sump. The size of the mesh of the fine debris screen is determined by considering a number of factors, including the size of the openings in the containment spray nozzles, coolant channel openings in the core fuel assemblies, and such pump design characteristics as seals, bearings, and impeller running clearances.

As noted above, degraded pumping can be caused by a number of factors, including plant design and layout. In particular, debris blockage effects on debris interceptor and sump outlet configurations and post-LOCA hydraulic conditions (e.g., air ingestion) must be considered in a combined manner. Small amounts of air ingestion, i.e., 2% or less, will not lead to severe pumping degradation if the "required" NPSH from the pump manufacturer's curves 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 as calculated for the pump inlet. Appendix A to this guide provides information for estimating NPSH margins in PWR sump designs where estimated levels of air ingestion are low (2% or less). References 6 and 13 provide additional technical findings relevant to NPSH effects on pumps performing the functions of residual heat removal, emergency core cooling, and containment atmosphere cleanup. When air ingestion is 2% 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. If air ingestion is not small, redesign of one or more of the recirculation loop components may be required to achieve satisfactory design.

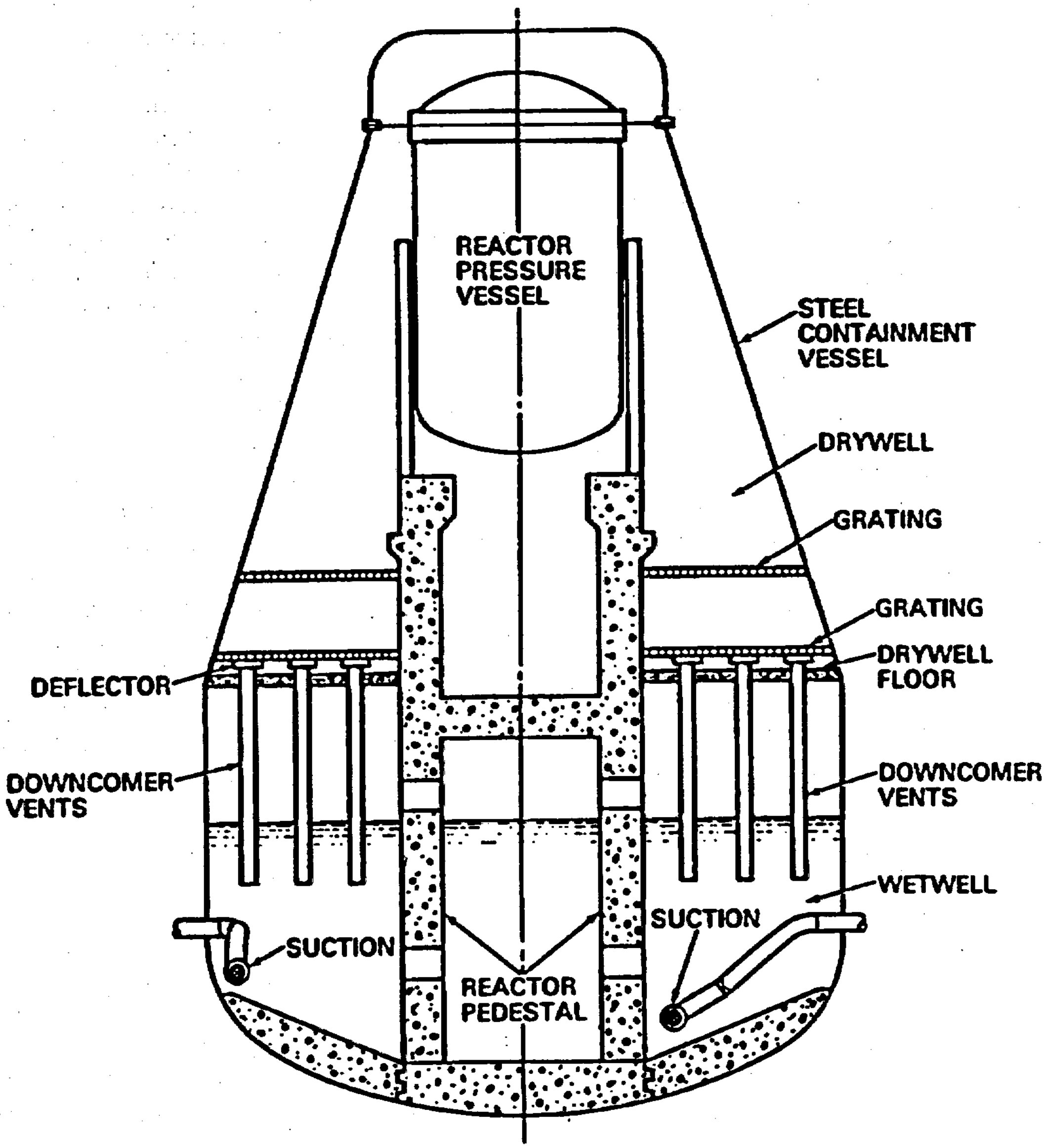
To ensure the operability and structural integrity of the racks and screens, access openings are necessary to permit inspection of the ECC sump structures and outlets. Inservice inspection of racks, screens, vortex suppressors, and sump outlets, including visual examination for evidence of structural degradation or corrosion, should be performed on a regular basis at every refueling period downtime. Inspection of the ECC sump components late in the refueling period will ensure the absence of construction trash in the ECC sump area.

BOILING WATER REACTORS

In boiling water reactors (BWRs), the suppression pool, in conjunction with the primary containment, downcomers, and vents, 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. Features and relationships of the suppression pool pertinent to this guide are shown in Figure 2. Concerns with the performance of the suppression pool hydraulics and ECC 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 ECC pumps (e.g., the impact on NPSH available at the pump inlets). References 6 and 12 provide data on the performance and air ingestion characteristics of BWR suction strainer configurations.

It is desirable to consider the use of debris interceptors (i.e., suction strainers) in BWR designs to protect the pump inlets and NPSH margins. The debris interceptor can be a passive suction strainer or an active suction strainer or active strainer system. A passive suction strainer is a device that prevents debris, which may block restrictions in the systems served by the ECC pumps or damage components, from entering

Figure 2. BWR with a Mark II Containment



the ECC pump suction line by accumulating debris on a porous surface. An example of a passive suction strainer is a truncated cone-shaped, perforated plate strainer. An active suction strainer or an active strainer system is a device or system that will take some action to prevent debris, that may block restrictions in the systems served by the ECC pumps or damage components from entering the ECC pump suction lines, remove debris from the flow stream upstream of the ECC pumps, or mitigate any detrimental effects of debris accumulation. Examples of active mitigation systems are listed in Appendix B.

Suppression pool debris transport analysis should include the effects of LOCA progression because LOCAs of different sizes will affect the duration of LOCA-related hydrodynamic phenomena (e.g., condensation oscillation, chugging). 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 prior to a LOCA (Refs. 19, 20, and 21), could block or damage the suction strainers and needs to be analyzed for head loss effects. This head loss analysis should include filtering of particulate 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.

C. REGULATORY POSITION

1. PRESSURIZED WATER REACTORS

Reactor building sumps that are designed to be a source of water for the functions of emergency core cooling, containment heat removal, or containment atmosphere cleanup following a LOCA should meet the following guidelines.

1.1. A minimum of two sumps should be provided, each with sufficient capacity to service one of the redundant halves of the ECCS and CSS.

1.2. To the extent practical, the redundant sumps should be physically separated by structural barriers from each other and from high-energy piping systems to preclude damage to the sump components (e.g., racks, screens, and sump outlets) by whipping pipes or high-velocity jets of water or steam.

1.3. The sumps should be located on the lowest floor elevation in the containment exclusive of the reactor vessel cavity. The sump outlets should be protected by at least two vertical debris interceptors: (1) a fine inner debris screen and (2) a coarse outer trash rack to prevent large debris from reaching the debris screen. A curb should be provided upstream of the trash racks to prevent high-density debris from being swept along the floor into the sump.

1.4. The floor in the vicinity of the ECC sump should slope gradually downward away from the sump.

1.5. All drains from the upper regions of the reactor building should terminate in such a manner that direct streams of water, which may contain entrained debris, will not impinge on the debris interceptors.

1.6. The strength of the trash racks should be adequate to protect the debris screens from missiles and other large debris. Debris interceptors should be capable of withstanding the loads imposed by missiles, by the accumulation of debris, and by pressure differentials caused by post-LOCA blockage.

1.7. The available interceptor surface area used in determining the design coolant velocity should be calculated to conservatively account for blockage that may result. Only the vertical interceptor area that is below the design basis water level should be considered in determining available surface area. Fibrous insulation debris should be considered as uniformly distributed over the available debris screen area. Blockage should be calculated based on estimated levels of destruction (References 6 and 17).

1.8. Evaluation or confirmation of (1) sump hydraulic performance (e.g., geometric effects and air ingestion), (2) debris effects (e.g., debris transport, interceptor blockage, and head loss), and (3) the combined impact on NPSH available at the pump inlet should be performed to ensure that long-term recirculation cooling can be accomplished. Such an evaluation should arrive at a determination of NPSH margin calculated at the pump inlet. An assessment of the susceptibility of the recirculation pump seal and bearing assembly design to failure from particulate ingestion and abrasive effects should be made to protect against degradation of long-term recirculation pumping capacity.

1.9. The top of the debris interceptor structures should be a solid cover plate that is designed to be fully submerged after a LOCA and completion of the ECC injection. It should be designed to ensure the venting of air trapped underneath the cover.

1.10. The debris interceptors should be designed to withstand the vibratory motion of seismic events without loss of structural integrity.

1.11. The size of openings in the debris screens should be based on the minimum restriction found in systems served by the pumps performing the recirculation function. The minimum restriction should take into account the requirements of the systems served.

1.12. Sump outlets should be designed to prevent degradation of pump performance by air ingestion and other adverse hydraulic effects (e.g., circulatory flow patterns, high intake-head losses).

1.13. Materials for debris interceptors should be selected to avoid degradation during periods of inactivity and operation and should have a low sensitivity to such adverse effects as stress-assisted corrosion that may be induced by the chemically reactive spray during LOCA conditions.

1.14. The debris interceptor structures should include access openings to facilitate inspection of these structures, any vortex suppressors, and the sump outlets.

1.15. Inservice inspection requirements for ECC sump components (i.e., debris interceptors, any vortex suppressors, and sump outlets) should include (1) inspection during every refueling period downtime and (2) a visual examination for evidence of structural distress or corrosion.

2. BOILING WATER REACTORS

2.1 Features Needed To Minimize the Potential for Loss of NPSH

The suppression pool, which is the source of water for such functions as emergency core cooling and containment heat removal following a LOCA, in conjunction with the vents and downcomers between the drywell and the wetwell, should contain an appropriate combination of the following features and actions to ensure the availability of the suppression pool for long-term cooling. Implementation of all the features and actions listed below is not required to ensure BWRs are not susceptible to the detrimental effects of debris blockage. A plant may discover through evaluation that only one of the features and actions listed below is required to ensure availability of the suppression pool for long-term cooling. Also, a licensee is not limited to the features and actions listed below. The adequacy of the combinations of the features and actions taken should be evaluated using the criteria and assumptions in Regulatory Position 2.2.

2.1.1 Passive Strainers

The inlet of pumps performing the above functions should be protected by a suction strainer placed upstream of the pumps; this is to prevent the ingestion of debris that may block restrictions in the systems served by the ECC pumps or damage components. The following items should be considered in the design and implementation of a passive strainer.

2.1.1.1. A suction strainer design (i.e., size and shape) should be chosen that will avoid the loss of NPSH from debris blockage during the period that the ECCS is required to operate in order to maintain long-term cooling or maximize the time before loss of NPSH caused by debris blockage when used with an active mitigation system (see Regulatory Position 2.1.4).

2.1.1.2. The size of openings in the suppression pool suction strainers should be based on the minimum restrictions found in systems served by the suppression pool. The minimum restriction should take into account the operability of the systems served. For example, spray nozzle clearances, coolant channel openings in the core fuel assemblies, and such pump design characteristics as seals, bearings, and impeller running clearances will need to be considered in the design to ensure long-term pump operability. An assessment should be performed to determine the ECCS pumps' susceptibility to degradation from debris ingestion and abrasive effects, and actions should be taken to minimize the potential for degradation of long-term recirculation pumping capacity.

2.1.1.3. ECC pump suction inlets should be designed to prevent degradation of pump performance through air ingestion and other adverse hydraulic effects (e.g., circulatory flow patterns, high intake head losses).

2.1.1.4. All drains from the upper regions of the reactor building should terminate in such a manner that direct streams of water, which may contain entrained debris, will not impinge on the suppression pool suction strainers.

2.1.1.5. The strength of the suction strainers should be adequate to protect the debris screen from missiles and other large debris. Each suction strainer should be capable of withstanding the loads imposed by missiles, debris accumulation, and LOCA-induced hydrodynamic loads.

2.1.1.6. The suction strainers should be designed to withstand the vibratory motion of seismic events without loss of structural integrity.

2.1.1.7. Material for suction strainers should be selected to avoid degradation during periods of inactivity and normal operations.

2.1.2 Minimizing Debris

The amount of potential debris (see Regulatory Position 2.3.1) that could block the ECC suction strainers should be minimized. This may be accomplished by:

2.1.2.1. Containment cleanliness programs should be designed to clean the suppression pool on a regular basis and plant procedures should be designed for control and removal of foreign materials from containment, or

2.1.2.2. Debris interceptors in the drywell in the vicinity of the downcomers or vents may serve effectively in reducing debris transport to the suppression pool. In addition to meeting Regulatory Position 2.1.1, debris interceptors between the drywell and wetwell should not reduce the suppression capability of the containment.

2.1.3 Instrumentation

If relying on operator actions to prevent the accumulation of debris on suction strainers or to mitigate the consequences of the accumulation of debris on the suction strainers, safety-related instrumentation that provides operators with an indication and audible warning of impending loss of NPSH for ECCS pumps should be available in the control room.

2.1.4 Active Strainers

An active component or system (see Appendix B) should be provided to prevent the accumulation of debris on a suction strainer or mitigate the consequences of accumulation of debris on a suction strainer. An active system should be able to prevent debris that may block restrictions found in the systems served by the ECC pumps from entering the system. The operation of the active component or system should not adversely affect the operation of other ECC components or systems.

2.1.5 Inservice Inspections

Inservice inspections should be established that include (1) inspection during every refueling outage to ensure the cleanliness of the suppression pool (Ref. 2), (2) a visual examination for evidence of structural degradation or corrosion of the suction strainers and strainer system, and (3) an inspection of the wetwell and the drywell, including the vents, downcomers, and deflectors, for the identification and removal of debris or trash that could contribute to the blockage of suppression pool suction strainers.

2.2 Evaluation and Alternate Water Sources

In order to demonstrate that a combination of the features and actions listed above are adequate to ensure long-term cooling and that the five criteria of 10 CFR 50.46(b) will be met following a LOCA, an evaluation using the criteria and assumptions in Regulatory Position 2.3 should be conducted. If a licensee is relying on operator actions to prevent the accumulation of debris on suction strainers or to mitigate the consequences of the accumulation of debris on the suction strainers, an evaluation should be performed to ensure that the operator has adequate indications, time, and system capabilities to perform the actions required.

In addition to a combination of the features and actions described above, procedures may be established to use existing systems and sources of water other than the suppression pool to provide injection and long-term cooling to the core. Establishing procedures to use alternate water sources will provide a diverse means of providing injection and long-term cooling to the core. Procedures to align alternate water sources may already be contained in emergency operating procedures. Because of the importance of the ECCS cooling function, consideration should be given to including the valves and piping needed to align alternate water sources in a plants' maintenance program.

2.3 Evaluation of Long-Term Recirculation Capability

During any evaluation of the susceptibility of a BWR to debris blockage, the considerations and events shown in Figures 3 and 4 should be addressed. The following techniques, assumptions, and criteria should be used in a deterministic, plant-specific evaluation to ensure that any implementation of a combination of the features and actions listed in Regulatory Position 2.1 are adequate to ensure a reliable water source for long-term recirculation after a LOCA. Unless otherwise noted, the techniques, assumptions, and criteria listed below are applicable to an evaluation of passive and active strainers. The assumptions and criteria listed below can also be used to develop test conditions for suction strainers or strainer systems.

2.3.1 Debris Generation and Sources

2.3.1.1. Consistent with the requirements of 10 CFR 50.46, debris generation should be calculated for a number of postulated LOCAs of different sizes, locations, and other properties sufficient to provide assurance that the most severe postulated LOCAs are calculated.

2.3.1.2. An acceptable method for determining the shape of the zone of influence of a break is described in NUREG/CR-6224 (Ref. 18). The volume contained within the zone of influence should be used to estimate the amount of debris generated by a postulated break. The distance of the zone of influence from the break should be supported by analysis or experiments for the

Figure 3. Debris Blockage Considerations

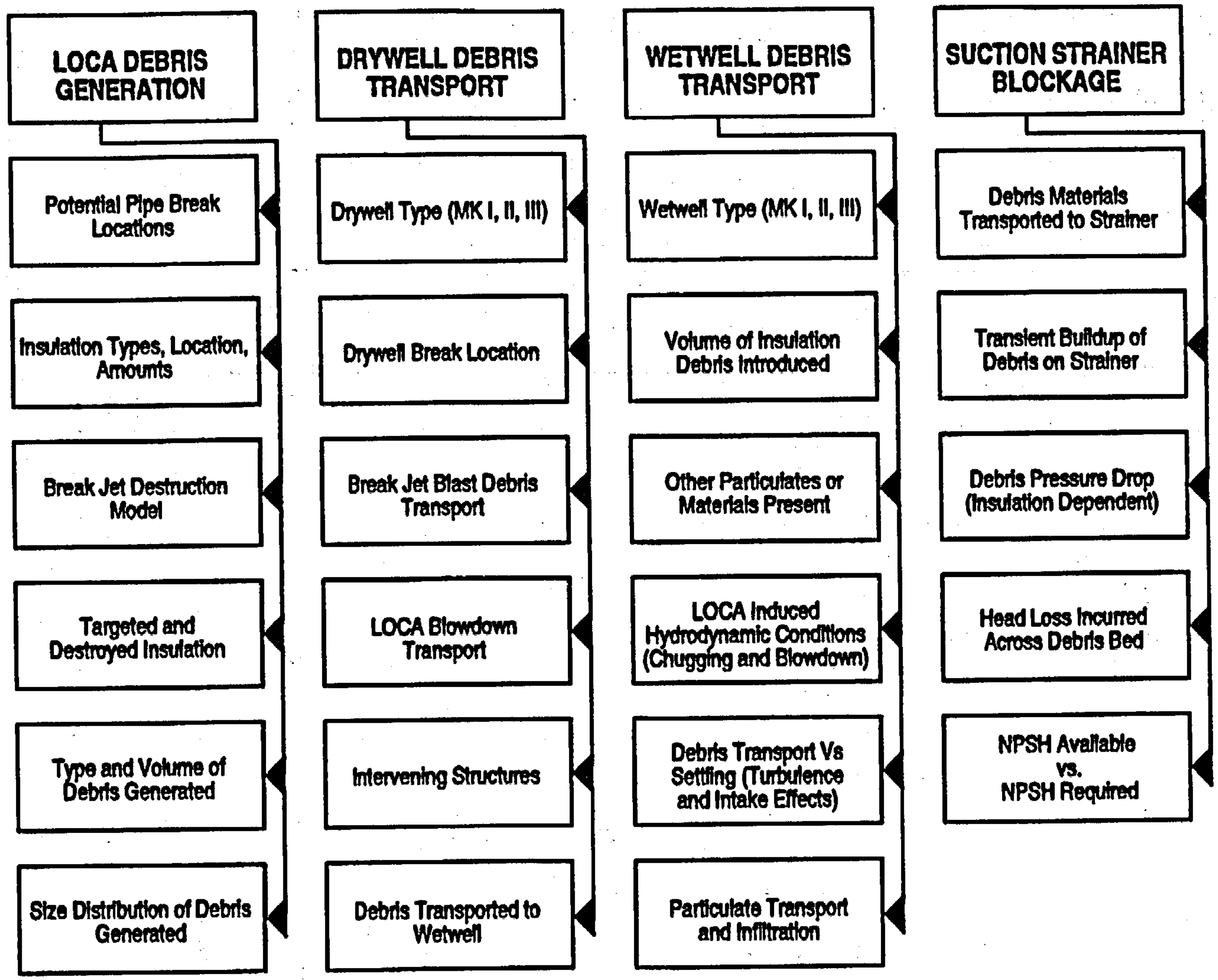
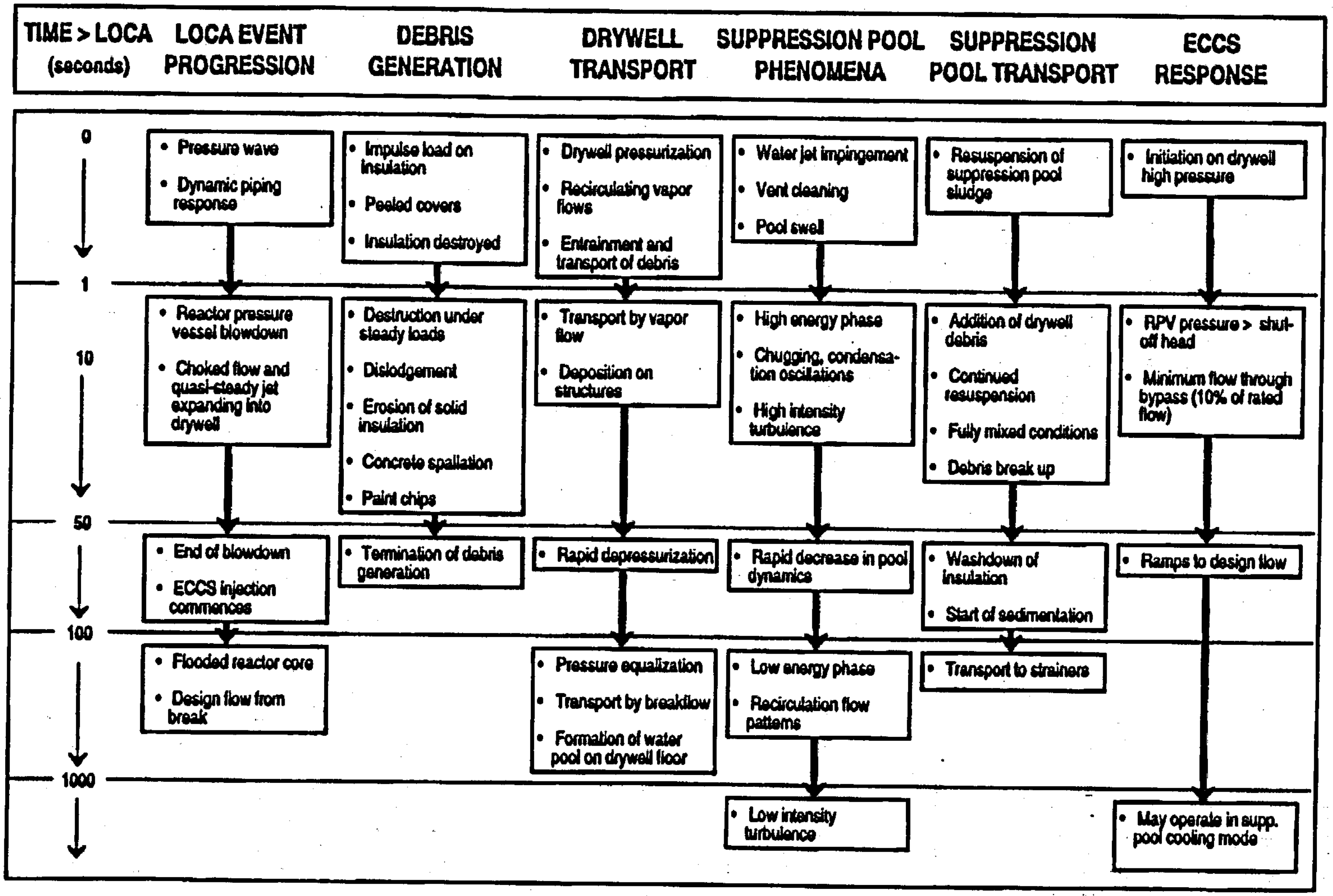


Figure 4. Events that May Effect Debris Blockage



break and potential debris. The shock wave generated during postulated pipe break and the subsequent jet should be the basis for estimating the amount of debris generated and the size or size distribution of the debris generated within the zone of influence.

2.3.1.3. Identify all sources of fibrous materials in the containment such as fire protection materials, thermal insulation, or filters that are present during operation.

2.3.1.4. All insulation, painted surfaces, and fibrous, cloth, plastic, or particulate materials within the zone of influence should be considered debris sources. Analytical models or experiments should be used to predict the size of the postulated debris.

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

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

2.3.1.6. The cleanliness of the suppression pool and containment during plant operation should be considered when estimating the amount and type of debris available to block the suction strainers. The potential for such material (e.g., corrosion products) and foreign materials (e.g., tape, wire ties, wire, paper, plastic) to impact head loss across the suction strainer should also be considered.

2.3.1.7. The amount of particulates estimated to be in the pool prior to a LOCA should be considered 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.

2.3.2 Debris Transport

2.3.2.1. It should be assumed that all the postulated debris will be transported to the suppression pool. If debris interceptors (see Regulatory Position 2.1.2.2) have been installed in the drywell, the amount of debris transported to the suppression pool can be less than 100%. The amount of the reduction of the transport of debris to the suppression pool should be quantified experimentally or analytically.

2.3.2.2. It should be assumed that LOCA-induced phenomena (i.e., pool swell, chugging, condensation oscillations) will suspend all the debris assumed to be in the suppression pool at the onset of the LOCA.

2.3.2.3. The amount or concentration of debris in the suppression pool should be calculated based on the amount of debris estimated to reach the suppression pool from the drywell and the amount of debris and foreign materials estimated to be in the suppression pool prior to a postulated break.

2.3.2.4. Credit should not be taken for debris settling until LOCA-induced turbulence in the suppression pool has ceased. The debris settling rate for the postulated debris should be validated analytically or experimentally.

2.3.2.5. Bulk suppression pool velocity from recirculation operations, LOCA-related hydrodynamic phenomena, and other hydrodynamic forces (e.g., local turbulence effects or pool mixing) should be considered for both debris transport, including settling, and suction strainer velocity computations.

2.3.3 Strainer Blockage and Head Loss

2.3.3.1. Strainer blockage should be based on the amount of debris estimated using the assumptions and criteria described in Regulatory Position 2.3.1 and on the debris transported to the wetwell (Regulatory Position 2.3.2). This volume of debris, as well as other materials that could be present in the suppression pool prior to a LOCA, should be used to estimate the rate of accumulation of debris on the strainer surface.

2.3.3.2. The flow rate through the strainer and the concentration of debris in the suppression pool should be used to estimate the rate of accumulation of debris on the strainer surface.

2.3.3.2. The suppression pool suction strainer area should be used in determining the approach velocity and should conservatively account for blockage that may result. Unless otherwise shown analytically or experimentally, debris should be assumed to be uniformly distributed over the available suction strainer surface (See Refs. 6, 17, and 18).

2.3.3.4. The NPSH available to the ECC pumps should be determined using the conditions specified in the plant's licensing basis (e.g., Regulatory Guide 1.1 (Ref. 22)).

2.3.3.5. Estimates of head loss caused by debris blockage should be developed from empirical data based on the strainer design (e.g., surface area and geometry), postulated debris (i.e., amount, size distribution, type), and approach velocity. Any head loss correlation should conservatively account for filtration of particulates by the debris bed.

2.3.3.6. The performance characteristics of a passive or an active strainer for the debris types and amounts postulated should be supported by appropriate test data.

D. IMPLEMENTATION

The purpose of this section is to provide information to licensees and applicants regarding the NRC staff's plans for using this regulatory guide.

Except in those cases in which an applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the methods described in this guide, which reflects public comments, will be used in the evaluation of all:

1. Applications for final design approval of standardized designs that are intended for referencing in future construction permit or combined license applications and have not received approval by April 1996.

2. Plant modifications that may affect the availability of water sources for long-term recirculation (e.g., altering potential sources of debris or strainer/sump designs).

3. Licensees' implementation of the requested actions in NRC Bulletin 96-03 (see Ref. 1).

REFERENCES

1. NRC Bulletin 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling Water Reactors," USNRC, May 6, 1996.[1]

2. NRC Bulletin No. 95-02, "Unexpected Clogging of a Residual Heat Removal Pump Strainer While Operating in Suppression Pool Cooling Mode," USNRC, October 17, 1995.[1]

3. NRC Bulletin No. 93-02, "Debris Plugging of Emergency Core Cooling Suction Strainers," USNRC, May 11, 1993.[1]

4. NRC Bulletin No. 93-02, Supplement 1, "Debris Plugging of Emergency Core Cooling Suction Strainers," USNRC, February 18, 1994.[1]

5. Generic Letter 85-22, "Potential for Loss of Post-LOCA Recirculation Capability due to Insulation Debris Blockage," USNRC, December 3, 1985.[1]

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

7. J. Wysocki and R. Kolbe, "Methodology for Evaluation of Insulation Debris Effects," NUREG/CR-2791 (SAND82-7067), USNRC, September 1982.[2]

---

[1]Copies of these documents are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202) 634-3273; fax (202) 634-3343.

[2]Copies of these documents are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202) 634-3273; fax (202) 634-3343. Copies of NUREG-series documents may be purchased at current rates from the U.S. Government Printing Office, P.O. Box 37082, 0402-9328 (telephone (202) 512-1800); or from the National Technical Information Service by writing NTIS at 5282 Port Royal Road, Springfield, VA 22161.

8. G.G. Weigand et al., "A Parametric Study of Containment Emergency Sump Performance," NUREG/CR-2758 (SAND82-0624), USNRC, July 1982.[2]

9. M.S. Krein et al., "A Parametric Study of Containment Emergency Sump Performance: Results of Vertical Outlet Sump Tests," NUREG/CR-2759 (SAND82-7062), USNRC, October 1982.[2]

10. M. Padmanabhan and G.E. Hecker, "Assessment of Scale Effects on Vortexing, Swirl, and Inlet Losses in Large Scale Sump Models," NUREG/CR-2760 (ARL-48-82), USNRC, June 1982.[2]

11. M. Padmanabhan, "Results of Vortex Suppressor Tests, Single Outlet Sump Tests, and Miscellaneous Sensitivity Tests," NUREG/CR-2761 (SAND82-7065), USNRC, September 1982.[2]

12. M. Padmanabhan, "Hydraulic Performance of Pump Suction Inlets for Emergency Core Cooling Systems in Boiling Water Reactors," NUREG/ CR-2772 (ARL-398A), USNRC, June 1982.[2]

13. P.S. Kammath, T.J. Tantillo, W.L. Swift, "An Assessment of Residual Heat Removal and Containment Spray Pump Performance Under Air and Debris Ingesting Conditions," NUREG/CR-2792 (CREARE TM-825), USNRC, September 1982.[2]

14. D.N. Brocard, "Buoyancy, Transport, and Head Loss of Fibrous Reactor Insulation," NUREG/CR-2982 (SAND82-7205), Revision 1, USNRC, July 1983.[2]

15. W.W. Durgin and J. Noreika, "The Susceptibility of Fibrous Insulation Pillows to Debris Formation Under Exposure to Energetic Jet Flows," NUREG/CR-3170 (SAND83-7008), USNRC, March 1983.[2]

16. J.J. Wysocki, "Probabilistic Assessment of Recirculation Sump Blockage Due to Loss-of-Coolant Accidents," NUREG/CR-3394, Volumes 1 and 2 (SAND83-7116), USNRC, July 1983.[2]

17. D.N. Brocard, "Transport and Screen Blockage Characteristics of Reflective Metallic Insulation Materials," NUREG/CR-3616 (SAND83-7471), USNRC, January 1984.[2]

18. G. Zigler et al., "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris," NUREG/CR-6224 (SEA No. 93-554-06-A:1), USNRC, October 1995.[2]

19. NRC Information Notice 95-47, "Unexpected Opening of a Safety/Relief Valve and Complications Involving Suppression Pool Cooling Strainer Blockage," USNRC, October 4, 1995.[1]

20. NRC Information Notice 95-06, "Potential Blockage of Safety-Related Strainers by Material Brought Inside Containment," USNRC, January 25, 1995.[1]

21. NRC Information Notice 94-57, "Debris in Containment and the Residual Heat Removal System," USNRC, August 12, 1994.[1]

22. Regulatory Guide 1.1, "Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal System Pumps," USNRC, November 2, 1970.[3]

---

[3]Requests for single copies should be made in writing to the U.S. Nuclear Regulatory Commission, Washington, DC 20555, Attention: Distribution and Mail Services Section; requests may also be faxed to (301) 415-2260. Copies of NRC documents are also available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC 20555; telephone (202) 634-3273; fax (202) 634-3343.

APPENDIX A

GUIDELINES FOR REVIEW OF WATER SOURCES FOR EMERGENCY CORE COOLING

Water sources for long-term recirculation should be evaluated under possible post-LOCA conditions to determine the adequacy of their design for providing long-term recirculation. Technical evaluations can be subdivided into (1) sump hydraulic performance, (2) LOCA-induced debris effects, and (3) pump performance under adverse conditions. Specific considerations within these categories, and the combination thereof, is shown in Figure A-1. Determination that adequate NPSH margin exists at the pump inlet under all postulated post-LOCA conditions is the final criterion.

SUMP HYDRAULIC PERFORMANCE

Sump hydraulic performance (with respect to air ingestion potential) can be evaluated on the basis of submergence level (or water depth above the PWR sump or BWR suction strainer outlets) and required pumping capacity (or pump inlet velocity). The water depth above the pipe centerline (s) and the inlet pipe velocity (U) can be expressed nondimensionally as the Froude number:

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

where g is the acceleration due to gravity. Extensive experimental results have shown that the hydraulic performance of ECC sumps (particularly the potential for air ingestion) is a strong function of the Froude number. Other nondimensional parameters (e.g., Reynolds number and Weber number) are of secondary importance.

Sump hydraulic performance can be divided into three performance categories:

1. Zero air ingestion, which requires no vortex suppressors or increase of the "required" NPSH above that from the pump manufacturer's curves.

2. Air ingestion of 2% or less, a conservative level at which degradation of pumping capability is not expected based on an increase of the "required" NPSH (see Figure A-2).

3. Use of vortex suppressors to reduce air ingestion effects to zero.

For PWRs, zero air ingestion can be ensured by use of the design guidance set forth in Table A-1. Determination of those designs having ingestion levels of 2% or less can be obtained using correlations given in Table A-2 and the attendant sump geometric envelope. Geometric and screen guidelines for PWRs are contained in Tables A-3.1, A-3.2, A-4, and A-5. Table A-6 presents design guidelines for vortex suppressors that have shown the capability to reduce air ingestion to zero. These guidelines (Tables A-1 through A-6) were developed from extensive hydraulic tests on full-scale sumps and provide a rapid means of assessing sump hydraulic performance. If the PWR sump design deviates significantly from the design boundaries noted, similar performance data should be obtained for verification of adequate sump hydraulic performance.

For BWRs, full-scale tests of suppression pool suction strainer screen outlet designs for recirculation 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% may occur (Refs. A-1 and A-2).

LOCA-INDUCED DEBRIS EFFECTS

Assessment of LOCA debris generation and the determination of possible debris interceptor blockage is complex. The evaluation of this safety question is dependent on the types and quantities of insulation employed, the location of such insulation materials within containment and with respect to the sump or suppression pool strainer location, the estimation of quantities of debris generated by a pipe break, and the migration of such debris to the interceptors. Thus blockage estimates (i.e., generation, transport, and head loss) are specific to the insulation material, piping layout, and the plant design.

Since break jet forces are the dominant debris generator, the predicted jet envelope will determine the quantities and types of insulation debris. Figure A-2 provides a three-region model that has been developed from analytical and experimental considerations as identified in References A-1 and A-3. The destructive results (e.g., volume of insulation and other debris generated, size of debris) of the break jet forces will be considerably different for different types of insulation, different types of installation methods, and distance from the break. Region I represents a total destruction zone; Region II represents a region where high levels of damage are possible depending on insulation type, whether encapsulation is employed, methods of attachment, etc.; and Region III represents a region where dislodgement of insulation in whole, or as-fabricated, segments is likely occur. References A-1 and A-3 provide a more detailed discussion of these considerations. References A-1 and A-3 through A-7 provide more detailed information relevant to assessing debris generation and transport.

PUMP PERFORMANCE UNDER ADVERSE CONDITIONS

The pump industry historically has determined NPSH requirements for pumps on the basis of a percentage degradation in pumping capacity. The percentage has at times been arbitrary, but generally is in the range of 1% to 3%. A 2% limit on allowed air ingestion is recommended since higher levels have been shown to initiate degradation of pumping capacity.

The 2% by volume limit on sump air ingestion and the NPSH requirements act independently. However, air ingestion levels less than 2% can also affect NPSH requirements. If air ingestion is indicated, correct the NPSH requirement from the pump curves by the relationship:

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

where $\beta = 1 + 0.50\alpha_p$ and α_p is the air ingestion rate (in percent by volume) at the pump inlet flange.

COMBINED EFFECTS

As shown in Figure A-1, three interdependent effects (i.e., sump or suction strainer performance, debris generation and transport, and pump operation under adverse conditions) require evaluation for determining long-term recirculation capability (i.e., loss of NPSH margin).

FIGURE A-1. Technical Considerations Relevant to PWR ECC Sump Performance

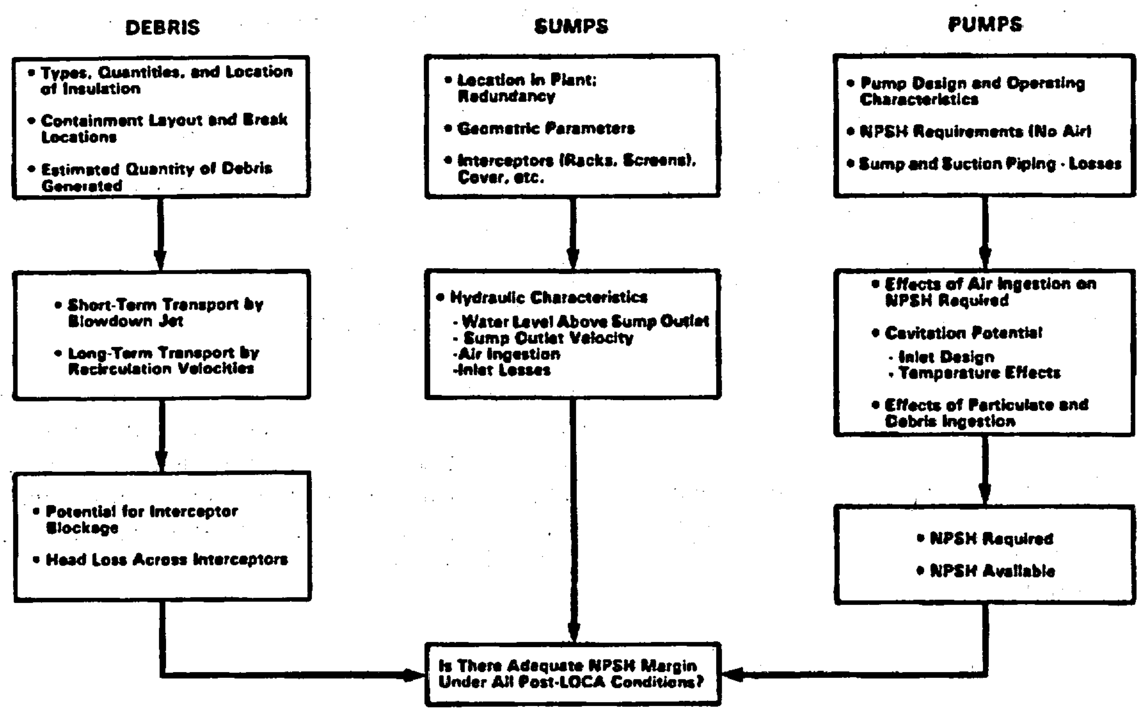


FIGURE A-2. Multiple Region Insulation Debris Model for PWRs

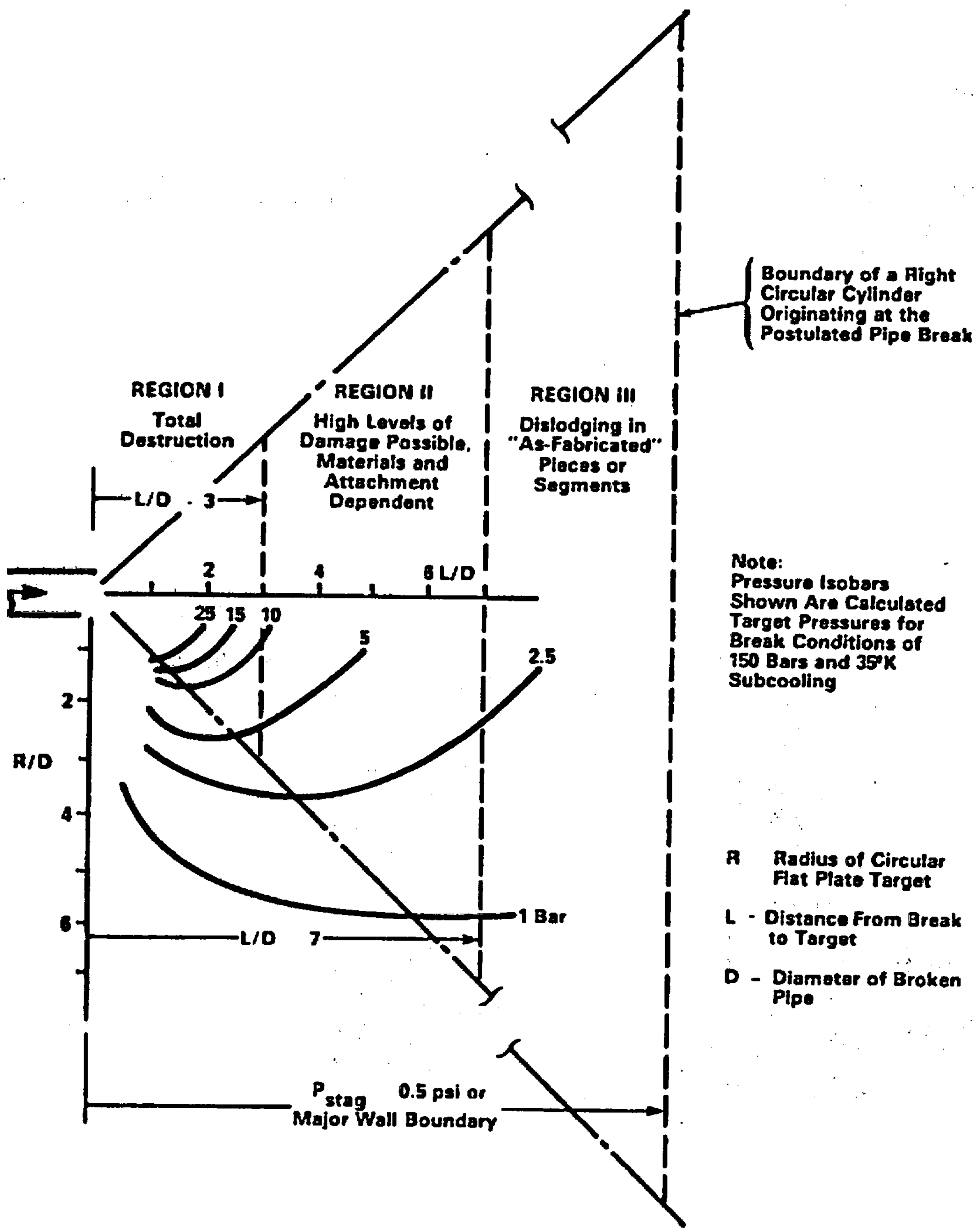


TABLE A-1

PWR HYDRAULIC DESIGN GUIDELINES FOR 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 References A-8, A-9, and A-10 and are based on sumps having a right rectangular shape.

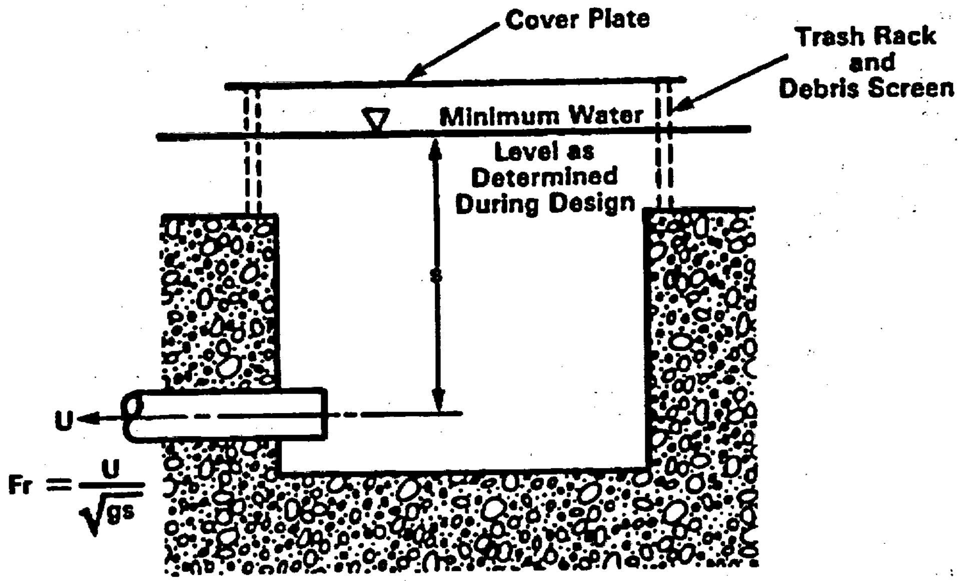


TABLE A-2

PWR HYDRAULIC DESIGN GUIDELINES FOR AIR INGESTION <2%

Air ingestion (α) is empirically calculated as
$\alpha = \alpha_o + (\alpha_1 \times Fr)$
where α_o and α_1 are coefficients derived from test results as given in the table below

Item		Horizontal Outlets Dual	Horizontal Outlets Single	Vertical Outlets Dual	Vertical Outlets Single
Coefficient α_o		-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	0.36	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

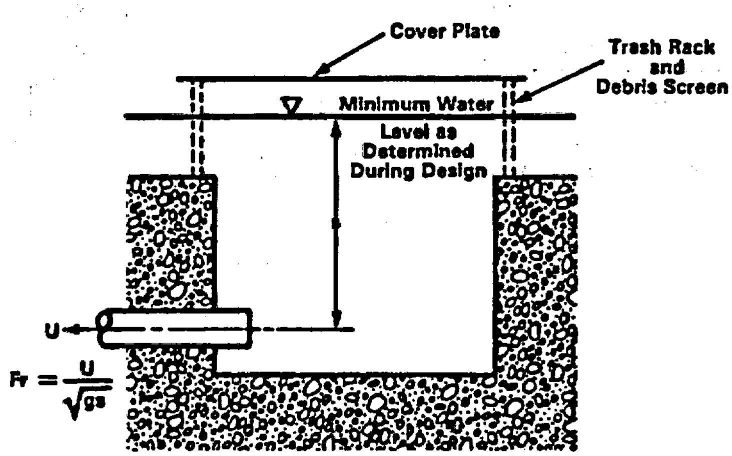


TABLE A-3.1

PWR GEOMETRIC DESIGN ENVELOPE GUIDELINES FOR HORIZONTAL SUCTION OUTLETS

Sump Outlet	Size			Sump Outlet Position*						Screen	
	Aspect Ratio	Min. Perimeter (ft)	Min. Perimeter (m)	e_y/d	$(B-e_y)/d$	c/d	b/d	f/d	e_x/d	Min. Area (ft^2)	Min. Area (m^2)
Dual	1 to 5	36	11	>1	>3	>1.5	>1	>4	>1.5	75	7
Single	1 to 5	16	4.9	>1	>3	>1.5	>1	-	>1.5	35	3.3

NOTE: Dimensions are always measured to pipe centerline.

* Preferred location.

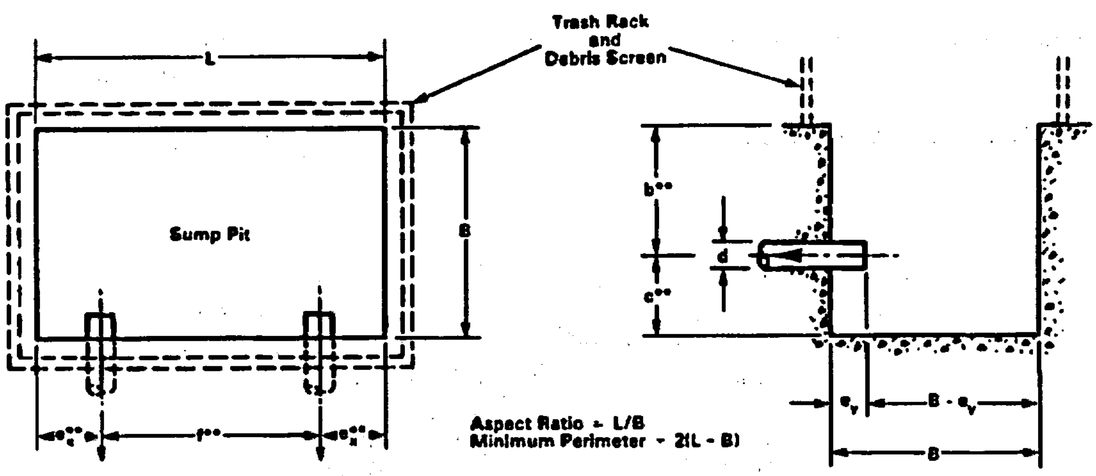


TABLE A-3.2

PWR GEOMETRIC DESIGN ENVELOPE GUIDELINES FOR VERTICAL SUCTION OUTLETS

<table>
<tr><th rowspan="2">Sump Outlet</th><th colspan="3">Size</th><th colspan="6">Sump Outlet Position*</th><th colspan="2">Screen</th></tr>
<tr><th>Aspect Ratio</th><th>Min. Perimeter (ft)</th><th>(m)</th><th>e_y/d</th><th>$(B-e_y)/d$</th><th>c/d</th><th>b/d</th><th>f/d</th><th>e_x/d</th><th>Min. Area (ft^2)</th><th>(m^2)</th></tr>
<tr><td>Dual</td><td>1 to 5</td><td>36</td><td>11</td><td rowspan="2">>1</td><td rowspan="2">>1</td><td>>0</td><td rowspan="2">>1</td><td>>4</td><td rowspan="2">>1.5</td><td>75</td><td>7</td></tr>
<tr><td>Single</td><td>1 to 5</td><td>16</td><td>4.9</td><td><1.5</td><td>-</td><td>35</td><td>3.3</td></tr>
</table>

NOTE: Dimensions are always measured to pipe centerline.

* Preferred location.

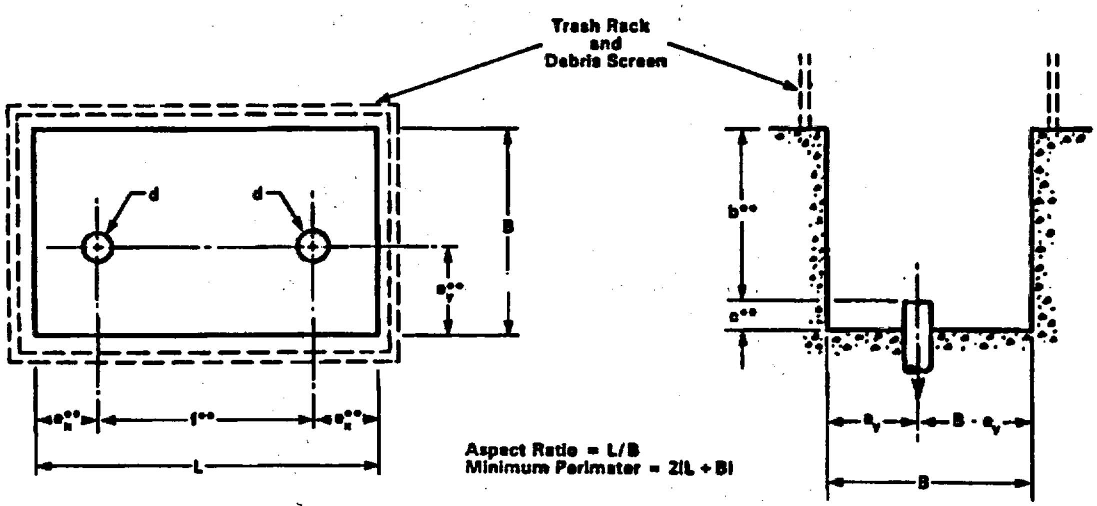


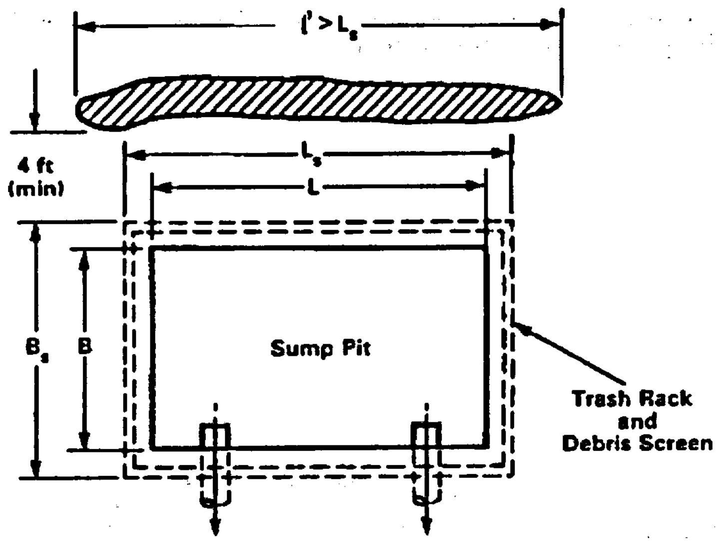
TABLE A-4

ADDITIONAL GUIDELINES RELATED TO SUMP SIZE AND PLACEMENT

1. The clearance between the trash rack and any wall or obstruction of length ℓ equal to or greater than the length of the adjacent screen/grate (B_s or L_s) should be at least 4 feet (1.2 meters).

2. A solid wall or large obstruction may form the boundary of the sump on one side only, i.e., the sump must have three sides open to the approach flow.

3. These additional guidelines should be followed to ensure the validity of the data in Tables A-1, A-2, A-3.1, and A-3.2.



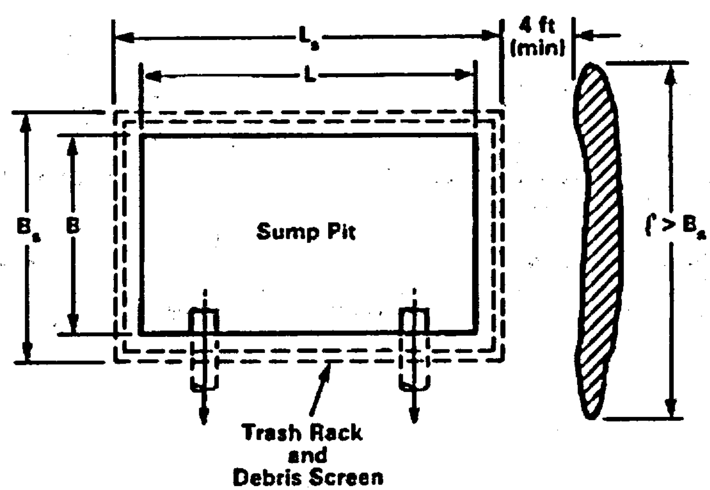


TABLE A-5

PWR DESIGN GUIDELINES FOR INTERCEPTORS AND COVER PLATE

1. Screen area should be obtained from Tables A-3.1 and A-3.2.
2. Minimum height of interceptors should be 2 feet (0.61 meter).
3. Distance from sump side to screens, g_s, may be any reasonable value.
4. Screen mesh should be ¼ inch (6.4 mm) or finer.
5. Trash racks should be vertically oriented 1- to 1½-inch (25- to 38-mm) standard floor grate or equivalent.
6. The distance between the debris screens and trash racks should be 6 inches (15.2 cm) or less.
7. A solid cover plate should be mounted above the sump and should fully cover the trash rack. The cover plate should be designed to ensure the release of air trapped below the plate (a plate located below the minimum water level is preferable).

NOTE: See Reference A-1.

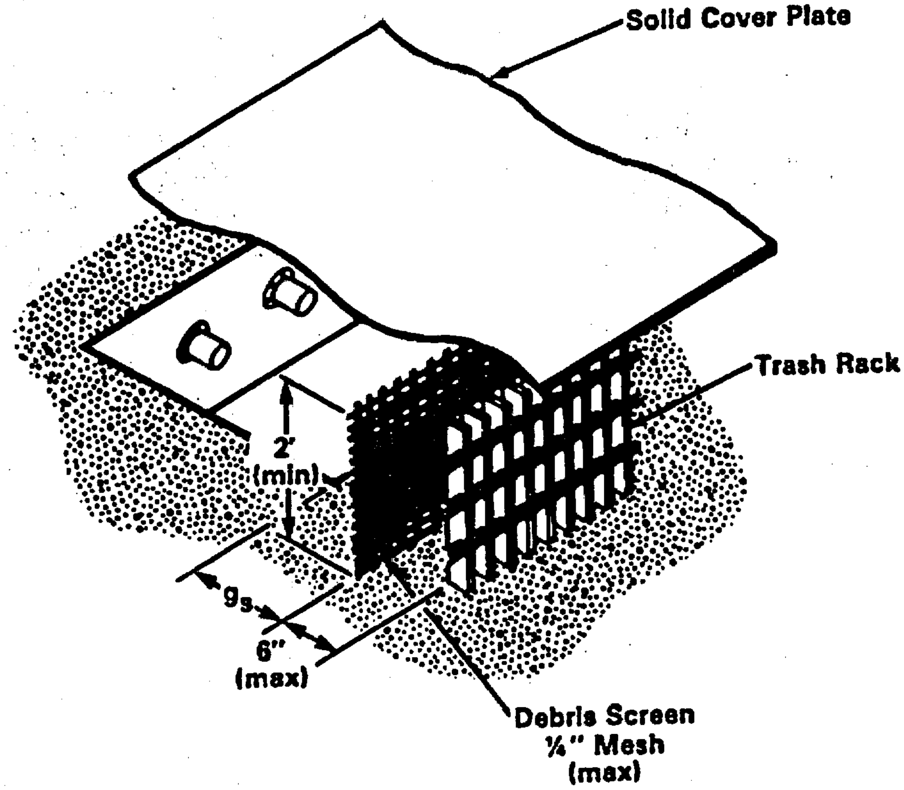


TABLE A-6

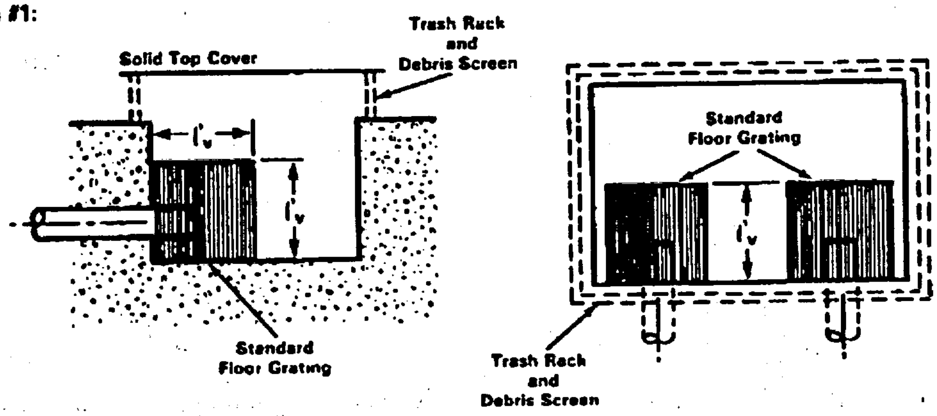
PWR GUIDELINES FOR SELECTED VORTEX SUPPRESSORS

1. Cubic arrangement of standard 1½-inch (30-mm) deep or deeper floor grating (or its equivalent) with a characteristic length, ℓ_v, that is at least 3 pipe diameters and with the top of the cube submerged at least 6 inches (15.2 cm) below the minimum water level. Noncubic designs with $\ell_v > 3$ pipe diameters for the horizontal upper grate and satisfying the depth and distances to the minimum water level given for cubic designs are acceptable.

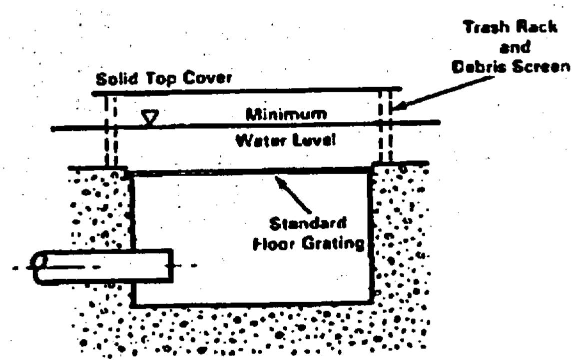
2. Standard 1½-inch (38-mm) or deeper floor grating (or its equivalent) located horizontally over the entire sump and containment floor inside the screens and located below the lip of the sump pit.

NOTE: Tests on these types of vortex suppressors at Alden Research Laboratory have demonstrated their capability to reduce air ingestion to zero even under the most adverse conditions simulated.

Design #1:



Design #2:



APPENDIX A REFERENCES

A-1 A.W. Serkiz, "Containment Emergency Sump Performance (Technical Findings Related to Unresolved Safety Issue A-43)," NUREG-0897, Revision 1, USNRC, October 1985.[4]

A-2 M. Padmanabhan, "Hydraulic Performance of Pump Suction Inlets for Emergency Core Cooling Systems in Boiling Water Reactors," NUREG/CR-2772 (SAND82-7064), USNRC, June 1982.[1]

A-3 G. Zigler et al., "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris," NUREG/CR-6224 (SEA No. 93-554-06-A:1), USNRC, October 1995.[1]

A-4 D.N. Brocard, "Buoyancy, Transport, and Head Loss of Fibrous Reactor Insulation," NUREG/-CR-2982 (SAND82-7205), Revision 1, USNRC, July 1983.[1]

[4]Copies of these documents are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington DC 20555; telephone (202) 634-3273; fax (202) 634-3343. Copies of NUREG-series documents may be purchased at current rates from the U.S. Government Printing Office, P.O. Box 37082, 0402-9328 (telephone (202) 512-1800); or from the National Technical Information Service by writing NTIS at 5282 Port Royal Road, Springfield, VA 22161.

A-5 W.W. Durgin and J.Noreika, "The Susceptibility of Fibrous Insulation Pillows to Debris Formation Under Exposure to Energetic Jet Flows," NUREG/CR-3170 (SAND83-7008), USNRC, March 1983.[1]

A-6 J.J. Wysocki, "Probabilistic Assessment of Recirculation Sump Blockage Due to Loss-of-Coolant Accidents," NUREG/CR-3394, Volumes 1 and 2 (SAND83-7116), USNRC, July 1983.[1]

A-7 D.N. Brocard, "Transport and Screen Blockage Characteristics of Reflective Metallic Insulation Materials," NUREG/CR-3616 (SAND83-7471), USNRC, January 1984.[1]

A-8 G.G. Weigand et al., "A Parametric Study of Containment Emergency Sump Performance," NUREG/CR-2758 (SAND82-0624), USNRC, July 1982.[1]

A-9 M.S. Krein et al., "A Parametric Study of Containment Emergency Sump Performance: Results of Vertical Outlet Sump Tests," NUREG/-CR-2759 (SAND82-7062), USNRC, October 1982.[1]

A-10 M. Padmanabhan and G.E. Hecker, "Assessment of Scale Effects on Vortexing, Swirl, and Inlet Losses in Large Scale Sump Models," NUREG/CR-2760 (SAND82-7063), USNRC, June 1982.[1]

APPENDIX B

EXAMPLES OF ACTIVE MITIGATION SYSTEMS

In-Line (or Pipeline) Strainer

A strainer installed in the piping system, upstream of equipment, that will remove harmful objects and particulates from the fluid stream by a backwashing action.

Self-Cleaning Strainer

A strainer that is used upstream of equipment to filter out harmful objects and particulates and is designed to clean itself without external help.

Strainer Backwashing System

A system designed to dislodge objects and particulates from the surface of a strainer by directing a fluid stream in the opposite direction of the flow through the strainer.

REGULATORY ANALYSIS

A separate regulatory analysis was not prepared for this Revision 2 to Regulatory Guide 1.82 since the guidance for pressurized water reactors has not been changed; the guide is being revised to clarify the type of analysis applicable to boiling water reactors. Therefore a new regulatory analysis is not needed. The regulatory analysis (NUREG-0869, Revision 1, "USI A-43 Regulatory Analysis," October 1985) that was prepared for the resolution of USI A-43, "Containment Emergency Sump Performance," is available for inspection or copying for a fee in the Commission's Public Document Room at 2120 L Street NW., Washington, DC 20555 (telephone (202)634-3273, fax (202)634-3343).