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Historical Perspectives and Insights on ACRS Activities and Recommendations with Respect to PWR Sump Performance

Prepared By
Hossein P. Nourbakhsh
Senior Technical Advisor

Christopher Mehrvarzi
Summer Intern

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Advisory Committee on Reactor Safeguards
U.S. Nuclear Regulatory Commission
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ABSTRACT

This report has been prepared for use by the NRC Advisory Committee on Reactor Safeguards (ACRS) in its ongoing review activities with respect to the resolution of Generic Safety Issue (GSI) 191, “Assessment of Debris Accumulation on PWR Sump Performance,” The current regulations and guidance documents related to ECCS capability and sump performance for PWRs have been discussed. The Committee’s observations and recommendations with respect to PWR sump performance have been summarized to provide insights and historical perspectives on Committee’s views on this subject. An overview of international perspectives on PWR sump performance has also been presented.

The views expressed in this paper are solely those of the authors and do not necessarily represent the views of the ACRS.

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ABBREVIATIONS

ACRS	Advisory Committee on Reactor Safeguards
AEC	Atomic Energy Commission
ATWS	Anticipated Transient without Scram
BWR	Boiling Water Reactor
CFR	Code of Federal Regulations
CSS	Containment Spray System
DBA	Design Basis Accident
ECCS	Emergency Core-Cooling Systems
EDO	Executive Director for Operations
ESF	Engineered Safety Feature
GL	Generic Letter
IAEA	International Atomic Energy Agency
LOCA	Loss-of-Coolant Accident
LWR	Light Water Reactor
NEI	Nuclear Energy Institute
NRC	Nuclear Regulatory Commission
PRA	Probabilistic Risk assessment
PWR	Pressurized Water Reactor
RCS	Reactor Coolant System
RES	Office of Nuclear regulatory Research
RG	Regulatory Guide
RPV	Reactor pressure Vessel
SER	Safety Evaluation Report
SRM	Staff Requirements Memorandum
SRP	Standard Review Plan

1 INTRODUCTION

The subject of loss-of-coolant accidents (LOCAs) and emergency core-cooling systems (ECCS) has been a major topic of interest to light water reactor safety. It is perhaps the subject which has received the most attention in licensing reviews. The containment sump in a pressurized water reactor (PWR) is part of the ECCS. Debris blockage during loss-of-coolant accidents that require recirculation operation has been identified as a potential vulnerability to PWR recirculation sump screens and associated flow paths. Such debris blockage could impede the long-term operation of the ECCS or containment spray system. Debris can also pass through sump screens and have adverse effects on the downstream components including pumps and fuel assemblies.

The issue of PWR sump performance has a long history, dating back to 1979 when it was affirmed as a part of the Unresolved Safety Issue A-43 (USI A-43). The technical concerns evaluated under USI A-43 included the possible transport of large quantities of LOCA-generated insulation debris to the sump screen(s), and the potential for sump screen blockage to reduce NPSH margin below that required for the recirculation pumps to maintain long-term cooling. With the state of knowledge and understanding of the issue at the time, the NRC concluded in 1985 that that no regulatory action was warranted for operating nuclear power plants, but that new nuclear power plants would need to satisfy the guidance in the newly issued revision 1 to Regulatory Guide (RG) 1.82," Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident." The NRC also concluded that operating nuclear power plants should consider the guidance in the revised RG 1.82 when making plant modifications, namely changing thermal insulation.

The 1992 clogging of intake strainers for containment spray water in Barsebäck-2, a BWR in Sweden, renewed the interest on safety questions associated with strainer blockage. Although the Barsebäck incident in itself was not very serious, it revealed a weakness in the implementation of defense-in-depth concept in the design, which under other circumstances could have led to the failure of the ECCS and containment spray system. The Barsebäck-2 event also demonstrated that larger quantities of fibrous debris could reach the strainers than had been predicted by models and analysis methods developed for the resolution of the strainer blockage issue. The NRC initiated new research programs on the accumulation of debris on BWR suction strainers. Results of research on BWR ECCS suction strainer blockage identified new phenomena and failure modes that were not considered in the resolution of Issue A-43. Based on the results of these studies, the NRC concluded that additional regulatory action was warranted for operating BWRs and asked BWRs to conduct plant-specific evaluations of their suction strainer performance and, if necessary, modify their plant design and/or operation.

In light of insights gained during the assessment of BWR suction strainers and oversight of BWR plant-specific evaluations and modifications, the NRC sponsored a new research effort to study the accumulation of debris on PWR containment sump. NRC concluded that GSI-191, "Assessment of Debris Accumulation on PWR Sump Performance," was a credible concern for the population of domestic PWRs. The NRC also concluded that detailed plant-specific evaluations were needed to determine the

susceptibility of each U.S.-licensed PWR to ECCS sump blockage and that appropriate corrective actions should be taken if necessary.

The ACRS has played an important role toward resolution of GSI-191. In particular the Committee raised the issues such as chemical and downstream effects that were not originally considered.

This report has been prepared for use by the Committee in its ongoing review of staff's progress toward resolution of GSI-191. A number of reference materials, including regulations related to ECCS capability and sump performance for PWRs [1], PWR Sump Performance section of the NRC Public Website [2], and the ACRS reports on the past reviews of PWR sump performance issue were reviewed for the preparation of this report.

The report begins with an overview of regulations and guidance documents related to ECCS capability and sump performance for PWRs as well as the role of ACRS in resolution of safety issues. It then summarizes the past Committee's observations and recommendations regarding sump performance issue. The report also presents an overview of international perspectives on PWR sump performance issue.

2 REGULATIONS AND GUIDANCE DOCUMENTS RELATED TO PWR SUMP PERFORMANCE REQUIREMENTS

The containment sump in a PWR is part of the ECCS. According to Section 50.46 of Title 10 of the Code of Federal Regulations (10 CFR 50.46), “Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors,” each nuclear power plant is required to have an ECCS to mitigate postulated LOCAs. Section 50.46(b)(5) specifically requires that ECCS be designed so that after its successful initial operation, the core temperature be maintained at an acceptably low value and decay heat be removed for the extended period of time required by the long-lived radioactivity remaining in the core. For a number of postulated LOCAs, the ECCS pumps take suction from the containment sump (also known as emergency or recirculation sump), and the debris in the containment could subsequently accumulate on the sump screen or be transported into the ECCS.

Containment sump also serves as the water source to support long-term recirculation for the functions of heat removal and atmospheric cleanup of the containment spray system (CSS). The regulatory objectives of the CSS design is contained in Appendix A, “General Design Criteria for Nuclear Power Plants,” to 10 CFR Part 50. General Design Criterion 38 requires that systems to remove heat from reactor containment be provided to reduce rapidly, consistent with the functioning for other associated systems, the pressure and temperature following any LOCA and maintain them at acceptably low levels. The systems provided for containment heat removal include the fan cooler and spray systems.

General Design Criterion 41 of Appendix A to 10 CFR Part 50 requires the containment atmosphere cleanup systems be provided as necessary to reduce fission product released to the environment following postulated accidents. Containment spray as a fission product cleanup system is discussed in the Section 6.5.2 of the Standard Review Plan (SRP) [3]. Section 6.5.2 of the SRP currently requires that the spray system be designed in accordance with the requirement of the ANSI/ANS Standard 56.6-1979, “PWR and BWR Spray System Design Criteria,” except that the containment sump solution be maintained at values at or above PH levels of 7, commencing with spray recirculation, to minimize the re-volatilization of iodine in the sump water.

In response to the concerns regarding the potential for coatings in containment to form debris and block sump screens, the NRC issued Generic Letter 98-04, "Potential for Degradation of the Emergency Core Cooling System and the Containment Spray System After a Loss-of-Coolant Accident Because of Construction and Protective Coating Deficiencies and Foreign Material in Containment," to obtain information in order to evaluate how the licensees maintain and monitor these coatings. Also, the NRC revised Regulatory Guide 1.54, "Service Level I, II, and III Protective Coatings Applied to Nuclear Power Plants," to use current American Society for Testing and Materials (ASTM) standards for the selection, qualification, application, and maintenance of protective coatings.

In November 2003, in light of insights gained from more recent assessment of debris accumulation on PWR sump performance, the NRC issued revision 3 to Regulatory Guide 1.82, "Water Sources for Long-Term Recirculation Cooling following a Loss of Coolant Accident." In September 2004, the NRC also issued GL 2004-02, “Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactor,” asking the PWR licensees to perform a plant specific mechanistic evaluation of the recirculation functions and, as appropriate, to take additional actions (e.g., plant modifications) to ensure system functionality [4]. Since that time, the need to address additional issues (e.g., chemical effects and in-vessel downstream effects) associated with sump performance has been emerged whose scope were not fully known at the time GL 2004-02 was issued. These issues have required additional testing and plant modifications for many licensees.

In May 2004, the Nuclear Energy Institute (NEI) submitted a report [5], “Pressurized Water Reactor Sump Performance Evaluation Methodology,” to NRC for review. In the staff’s review of the NEI submission, portions of the proposed guidance were found to be acceptable as is; other portions needed additional justification and/or modification.
The NEI submission, as approved in accordance with the staff safety evaluation, provides an acceptable overall guidance methodology for the plant-specific evaluation of ECCS or core spray system CSS sump performance following any postulated accident for which ECCS or CSS recirculation is required, with specific attention given to the potential for debris accumulation that could impede or prevent the ECCS or CSS from performing its intended safety functions. GL 2004-02 refers to this safety evaluation as an acceptable approach for demonstrating compliance with the regulations.

3 THE ROLE OF ACRS IN RESOLVING GENERIC SAFETY ISSUES

For over 50 years the ACRS has had a continuing statutory responsibility for providing independent reviews of, and advising on, the safety of proposed or existing reactor facilities. According to 1957 amendment to the *Atomic Energy Act* of 1954, which establishes the ACRS as a Statutory Committee advising the Atomic energy Commission (AEC), "The Committee shall review safety studies and facility license applications referred to it and shall make reports thereon, shall advise the Commission with regard to the hazards of proposed or existing reactor facilities and the adequacy of proposed reactor safety standards and shall perform other such duties as the Commission may request." The *Energy Reorganization Act* of 1974 transferred the AEC's licensing functions to the U. S. NRC, and assigned the ACRS to NRC with its statutory requirements intact.

Section 210 of 1974 *Energy Reorganization Act* (Public Law 95-209) requires that NRC maintain a Generic Issues (GIs) Program for the specification and analysis of unresolved safety issues relating to nuclear reactors and take such action as may be necessary to implement corrective measures with respect to such issues. The tracking and progress reports on the status and resolutions of GIs should be included in the annual report of the Commission to the Congress.

Management Directive (MD) 6.4, "Generic Issues Program," delineates the NRC's program for addressing reactor and non-reactor generic issues (GIs). Figure 1 illustrates the processes for resolving GIs related to areas of review by ACRS. The Office of Nuclear Regulatory Research (RES) staff is responsible for screening all new GIs associated with nuclear reactor power plants, and performing the technical assessments of those GSIs that the screening identifies as warranting further processing. The Office of Nuclear Reactor Regulation (NRR) is responsible for developing and issuing regulations or guidance that may be recommended in the technical assessments, and subsequently verifies the implementation of the resultant regulation or guidance by licensees and/or certificate holders. The staff also conducts an "adequate protection evaluation" for each newly identified GSI to determine whether plants should continue operating while the issue is being resolved. The ACRS has the authority and responsibility of reviewing staff analyses of GIs and advising the Commission and the staff on the processes and methodologies for addressing all GIs except those related to areas of Advisory Committee on Medical Uses of Isotopes (ACMUI) responsibility.

ACRS review of GSIs generally begins with in-depth reviews by the appropriate Subcommittee of ACRS. With input from Subcommittee members, Subcommittee Chairman develops proposed ACRS position. Briefings by the external stakeholders and the NRC staff are provided to both the Subcommittee and Full Committee. ACRS positions are developed after extensive deliberations by the full Committee. When the Committee has completed its review, its report is submitted to the Commission. At times, ACRS also issues letters to Executive Director of Operations (EDO) identifying issues of concern and items for which additional information, discussions, and clarifications are needed.

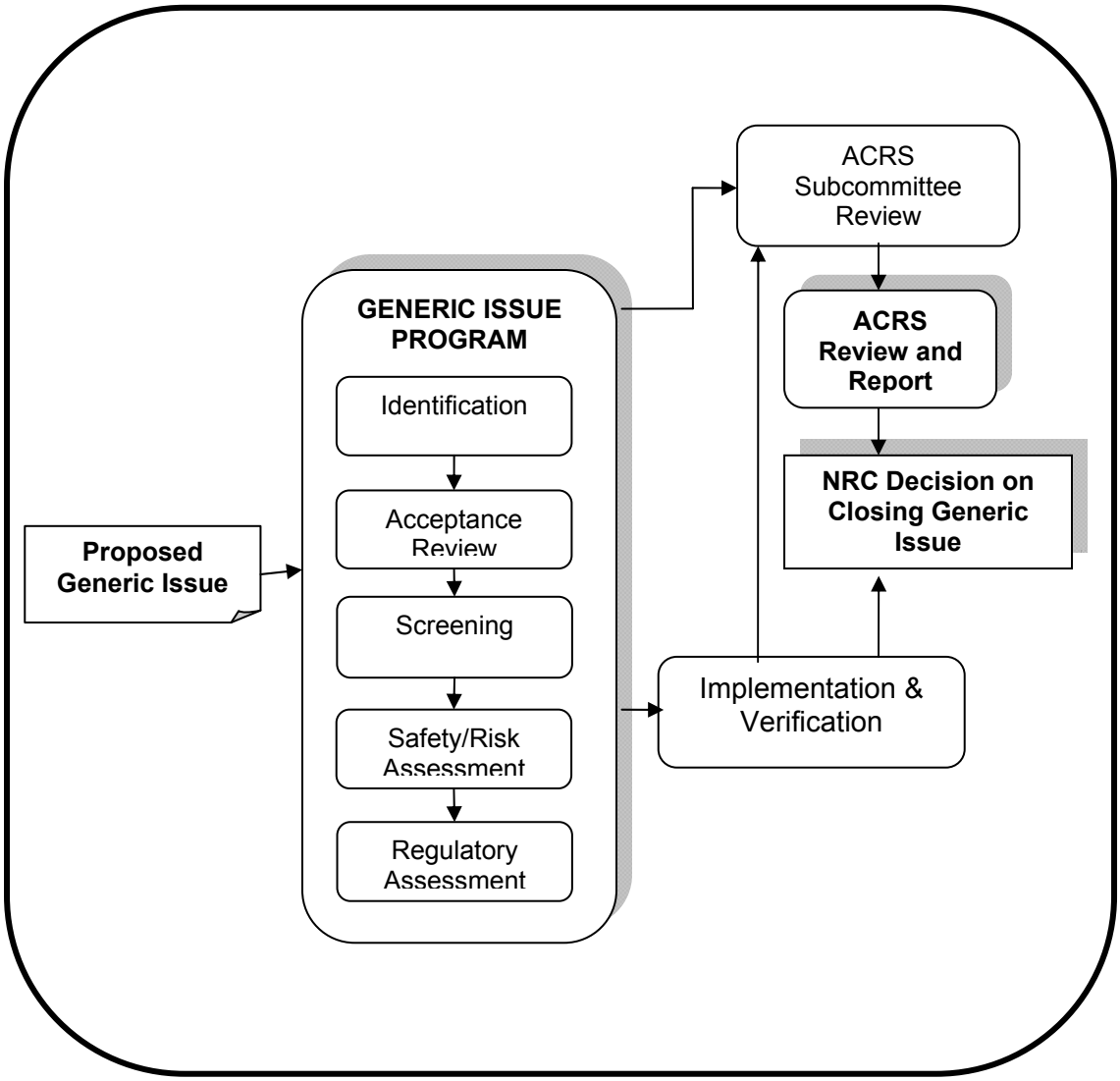

Figure 1: The Processes for Resolution of Generic Issues
Related to Areas of Review by ACRS

In a December 20, 2005 Staff Requirements Memorandum (SRM) [6], resulting from the December 8, 2005 meeting with ACRS, the Commission directed the Committee to "make among its highest priorities its role in the resolution of GSI-191." The Commission also directed the staff to "expedite efforts to provide the ACRS with information necessary to make its assessment and recommendations." The Commission further noted that it "continues to value the independent technical views of the ACRS on significant matters under consideration by the agency."

4 TECHNICAL ISSUES ASSOCIATED WITH PWR SUMP PERFORMANCE

Technical issues surrounding the debris accumulation on PWR sump and its impact on long term cooling and containment atmospheric cleanup requirements during the design basis accidents are highly complex. Included are the debris generation by jet forces from the pipe rupture, transport of the generated debris and foreign material in the containment to the pool of water formed on the containment floor, chemical reactions in a post-accident containment environment, accumulation of debris on the recirculation sump screen, and the potential for passing the debris through sump screen and subsequent lodging at a downstream flow restriction such as fuel assembly.

Figure 2 depicts the important phenomena and processes that affect the PWR sump performance issue. In the event of a LOCA, energetic pressure waves and fluid jets would impinge upon materials in the vicinity of the break, such as thermal insulations, coatings, and concrete, damaging and dislodging them. In addition to debris generated by jet forces from the pipe rupture, debris could also be generated through secondary mechanisms, such as flooding of the lower containment, and the impact of containment spray droplets. Debris could also be created by the chemical reaction between the materials in containment and the chemically reactive spray solutions used following a LOCA. These reactions might generate additional debris such as disbanded coatings and chemical precipitants.

Through transport methods such as entrainment in the steam/water flows issuing from the break and containment spray washdown, a fraction of the generated debris and pre-existing (latent) debris in the containment building would be transported to the pool of water formed on the containment floor. Subsequently, if the ECCS or CSS pumps took suction from the recirculation sump, the debris suspended in the containment pool would begin to accumulate on the sump screen or be transported through the associated system. The accumulation of this suspended debris on the sump screen could create a roughly uniform covering on the screen, referred to as a debris bed, which would tend to increase the head loss across the screen through a filtering action. If a sufficient amount of debris accumulated, the debris bed would reach a critical thickness at which the head loss across the debris bed would exceed the net positive suction head (NPSH) margin required to ensure the successful operation of the ECCS and CSS pumps in recirculation mode. A loss of NPSH margin for the ECCS or CSS pumps as a result of the accumulation of debris on the recirculation sump screen, referred to as sump clogging, could result in degraded pump performance and eventual pump failure and consequential loss of ECCS and CSS functions.

The debris or materials suspended within the water could also pass through the sump strainer. If the materials pass, they may cause damage to downstream components. For instance, the debris could plug or excessively wear close-tolerance components or deposit on surfaces within the ECCS or CSS systems. The plugging or wear might cause a component to degrade to the point where it could not perform its designated function. Debris passing the strainer could deposit on the reactor fuel, reducing the efficiency of heat transfer.

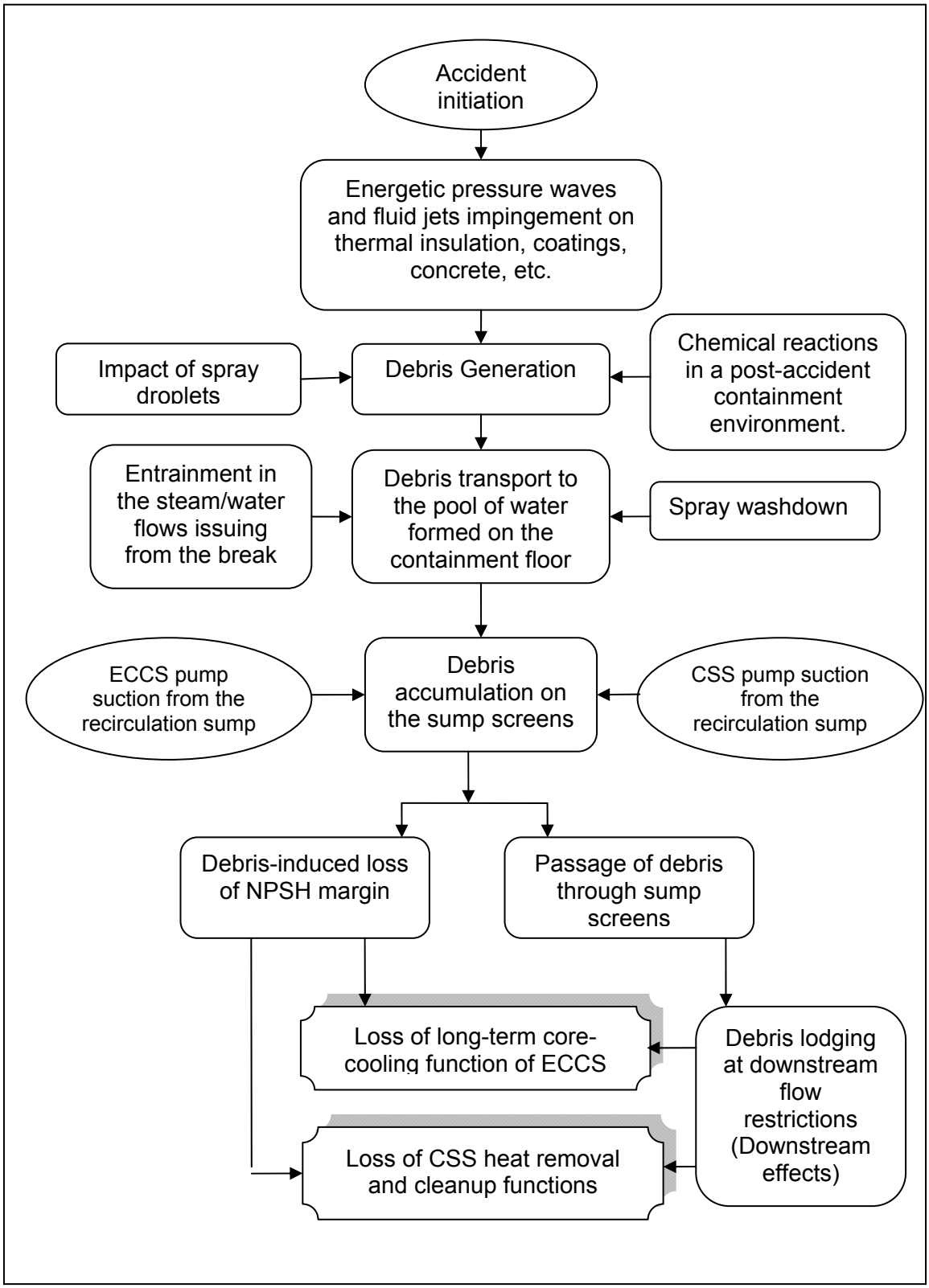

Figure 2. Important Phenomena and Processes Associated with GSI-191

5 INSIGHTS FROM PREVIOUS ACRS REVIEW OF PWR SUMP PERFORMANCE ISSUE

The ACRS review of the PWR sump performance issue has a long history, dating back to early 1980s, when the Committee discussed containment emergency sump performance as a part of the Unresolved Safety Issue A-43. Table 1 lists all ACRS reports and the dates of ACRS meetings in which the Issue of PWR sump performance has been discussed. The ACRS recommendations, observations, and comments with respect to PWR sump Performance are presented below.

SEPTEMBER 7, 1983: ACRS REVIEW OF NRC STAFF RESOLUTION FOR UNRESOLVED SAFETY ISSUES A-1, "WATER HAMMER," AND A-43, "CONTAINMENT EMERGENCY SUMP PERFORMANCE,

During its 281st meeting, August 31-September 1, 1983, the Committee reviewed the NRC staff proposed resolution to USI A-43, documented in NUREG-0869. In its letter, dated September 7, 1983, while the Committee generally concurred with the proposed resolution of USI A-43, it made several recommendations including:

> "*the final resolution of USI A-43 include an explicit consideration of the consequences of particulate ingestion on pump performance as well as other possible effects, such as the plugging of various System's components*."

The Committee also noted that:

> *"the probabilistic and fracture mechanics arguments concerning leak before break, which were developed in support of a proposed resolution of the asymmetric loads issue, should not be too quickly nor too generally applied to the other issues without very thorough analysis and review."*

SEPTEMBER 16, 1985: ACRS REVIEW OF PROPOSED RESOLUTION TO USI A-43, "CONTAINMENT EMERGENCY SUMP PERFORMANCE" AND REGULATORY GUIDE 1.82, REVISION 1, "WATER SOURCES FOR LONG TERM RECIRCULATION COOLING FOLLOWING A LOSS OF COOLANT ACCIDENT"

During its 305th meeting, September 12-14, 1985, the Committee reviewed the proposed resolution to USI A-43 and companion Revision 1 to RG 1.82. This topic was also discussed during a joint meeting on August 27, 1985 of the ACRS Subcommittee on ECCS and on Fluid Dynamics. In its letter, dated September 16, 1985, while the ACRS concurred with the proposed resolution of USI A-43 and the regulatory positions of RG 1.82, Revision1, the Committee offered several comments including:

> *"We believe that Positions C.1.g. and C.2.f., relating to screen or strainer blockage due to LOCA-generated debris, and Positions C.1.h. and C.2.g., relating to the effects of debris on pump seals and bearing assemblies, should be the basis for any safety review if a change from metallic to fibrous insulation is proposed. For this reason, we recommend that the implementation section of this Guide be changed to make these positions applicable for such future modification. We believe that such a requirement ought not to be considered a backfit."*

Table 1 ACRS Reports and Review Activities with Respect to Sump Performance

ACRS Report/Letter Date	Title of ACRS Report/Letter	Subcommittee Meetings	Full Committee Meeting Date
Sep 7, 1983	ACRS Review of NRC Staff Resolution for Unresolved Safety Issues A-1, "Water Hammer," and A-43, "Containment Emergency sump Performance	Dec 2-3 1981 May 10, 1983	Aug 31-Sep 1, 1983
Sep 16, 1985	ACRS Review of Proposed Resolution to USI A-43, "Containment Emergency Sump performance" and regulatory Guide 1.82, Revision 1, "Water Sources for Long Term Recirculation Cooling Following a Loss of Coolant Accident"	Joint Subcommittees on ECCS and Fluid Dynamics Aug 27, 1985	Sep 12-14, 1985
Oct 14, 1994	Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris		Oct 6-7, 1994 Also Briefings in: April 1994, July 1993, and January 1993
Feb 26, 1996	Proposed Final NRC Bulletin 96-XX, "Potential Plugging of Emergency Core Cooling Suction Strainer by Debris in Boiling Water Reactors" and an Associated Draft Revision 2 of Regulatory Guide 1.82, "Water Sources for Long-term Recirculation Cooling Following a Loss-of-Coolant Accident"		Feb 8-10 1996

Table 1 ACRS Reports and Review Activities with Respect to Sump Performance (Continued)

ACRS Report/Letter Date	Title of ACRS Report/Letter	Subcommittee Meetings	Full Committee Meeting Date
Sept 14, 2001	Generic safety Issue-191, "Assessment of Debris Accumulation on PWR Sump Performance"		July 11-13, 2001 Sep 5-7 2001
Feb 20, 2003	Proposed Resolution of Generic Safety Issue-191, "Assessment of Debris Accumulation on PWR Sump Performance"	Subcommittees on Thermal-Hydraulic Phenomena Feb 4, 2003	Feb 6-8, 2003
Sept 30, 2003	Draft final Revision 3 to Regulatory Guide 1.82, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident"	Subcommittees on Thermal-Hydraulic Phenomena Aug 19, 2003	
July 19, 2004	Proposed Draft Final Generic Letter on Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at PWRs	Subcommittees on Thermal-Hydraulic Phenomena June 22-23, 2004	July 7-9, 2004
Oct 18, 2004	Safety Evaluation of the Industry Guidelines related to Pressurized Water Reactor Sump Performance	Subcommittees on Thermal-Hydraulic Phenomena Sep 22-23, 2004	Oct 18, 2004

Table 1 ACRS Reports and Review Activities with Respect to Sump Performance (Continued)

ACRS Report/Letter Date	Title of ACRS Report/Letter	Subcommittee Meetings	Full Committee Meeting Date
Dec 10, 2004	Safety Evaluation of the Industry Guidelines related to Pressurized Water Reactor Sump Performance		Dec 2-4, 2004 (Response to Nov. 26, 2004 EDO Letter)
April 10, 2006	Generic Safety Issue 191 – Assessment of Debris Accumulation on PWR Sump Performance	Subcommittees on Thermal-Hydraulic Phenomena Feb 14-16, 2006	March 9-11, 2006
August 1, 2006	Generic Safety Issue -191, "Assessment of Debris Accumulation on PWR Sump Performance"	Subcommittees on Thermal-Hydraulic Phenomena June 13-14, 2006	July 12-13, 2006 (Response to May 2, 2006 EDO Letter)
Oct 22, 2008	Status of Resolution of Generic Safety Issue -191, "Assessment of Debris Accumulation on PWR Sump Performance"	Subcommittees on Thermal-Hydraulic Phenomena May 16, 2007, March 19, 2008 September 23, 2008	Oct 2-3 2008
Sept xx, 2010			

OCTOBER 14, 1994: POTENTIAL FOR BWR ECCS STRAINER BLOCKAGE DUE TO LOCA GENERATED DEBRIS

In January 1993, July 1993, April 1994, and October 1994, the ACRS was briefed by the NRC staff on the ECCS recirculation strainer blockage issue raised by the event that occurred at the Barsebäck plant in Sweden on July 28, 1992. In its letter, dated October 14, 1994, while the ACRS commented on a proposed Revision 2 to RG 1.82 and the staff plan for issuing a generic letter on BWR ECCS strainer blockage due to LOCA generated debris, it also offered its assessment of the Barsebäck event, noting that :

> *" Our assessment of this event indicates that strainer blockage due to accident generated debris is an important safety issue for at least some BWRs and that strainer blockage was not adequately addressed in the 1985 resolution of the Unresolved Safety Issue (USI) A-43"*

FEBRUARY 26, 1996: PROPOSED FINAL NRC BULLETIN 96-XX, "POTENTIAL PLUGGING OF EMERGENCY CORE COOLING SUCTION STRAINER BY DEBRIS IN BOILING WATER REACTORS" AND AN ASSOCIATED DRAFT REVISION 2 OF REGULATORY GUIDE 1.82, "WATER SOURCES FOR LONG-TERM RECIRCULATION COOLING FOLLOWING A LOSS-OF-COOLANT ACCIDENT"

During the 428th meeting of the ACRS, February 8-10, 1996, the Committee heard presentations by and held discussions with representative of the NRC staff and the Boiling Water Reactor Owners Group (BWROG) concerning the proposed final Bulletin and Revision 2 to RG 1.82. In its letter, dated September 26, 1996, while the ACRS commented on a proposed Revision 2 to RG 1.82 and the staff proposed options for resolution for BWR ECCS strainer blockage due to LOCA generated debris, it also noted the following regarding the need for further action for PWRs:

> *"We note that the staff is reviewing the need for further action for PWRs beyond that taken in the 1985 resolution of Unresolved Safety Issue A-43, Containment Sump Performance. We believe that this is appropriate in light of what has been learned about debris generation and transport."*

SEPTEMBER 14, 2001: GENERIC SAFETY ISSUE-191, "ASSESSMENT OF DEBRIS ACCUMULATION ON PWR SUMP PERFORMANCE"

During the 484th and 845th meetings of the ACRS, July 11-13 and September 5-7, 2001, the Committee heard presentations by and held discussions with representatives of the NRC staff regarding the Office of Nuclear Regulatory Research recommendation for resolving GSI-191. In its letter, dated September 14, 2001, while the ACRS agreed with the staff that potential issues associated with the performance of PWR containment sump has been identified, it made the following recommendations:

> *"The NRC Staff should expeditiously resolve GSI-191. If plant–specific analyses are required as part of the resolution, guidance for performing these analyses should be developed."*

FEBRUARY 20, 2003: PROPOSED RESOLUTION OF GENERIC SAFETY ISSUE-191, "ASSESSMENT OF DEBRIS ACCUMULATION ON PWR SUMP PERFORMANCE"

During the 499th meeting of the ACRS, February 6-8, 2003, The Committee reviewed the proposed NRC Generic Letter 2003-XX, "Potential Impact of Debris Blockage on Emergency Recirculation during Design-Basis Accidents at Pressurized-Water Reactors," and Draft Regulatory Guide DG-1107, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," associated with the resolution of GSI-191. The ACRS Subcommittee on Thermal-Hydraulic Phenomena also reviewed this matter during its meeting on February 4, 2003. In its letter, dated February 20, 2003, while the ACRS agreed with the staff's proposal to issue the DG-1107 and the proposed Generic Letter for public comment, it made the following recommendations:

> *"The staff should evaluate the possibility that strainers may prove to be so susceptible to debris blockage that alternative solutions may be required to ensure long-term cooling. The staff should invite public comments on this matter."*
>
> *"The "acceptable methods" discussed in DG-1107 should be peer reviewed after technical reports from the Office of Nuclear Regulatory Research (RES) contractors become available."*

SEPTEMBER 30, 2003: DRAFT FINAL REVISION 3 TO REGULATORY GUIDE 1.82, "WATER SOURCES FOR LONG-TERM RECIRCULATION COOLING FOLLOWING A LOSS-OF-COOLANT ACCIDENT"

During the 505th meeting of the ACRS, September 10- 13, 2003, the Committee met with representatives of the NRC staff to discuss the draft final Revision 3 to RG 1.82, The ACRS Subcommittee on Thermal-Hydraulic Phenomena also reviewed this matter during its meeting on August 19, 2003. In its letter, dated September 30, 2003, while the ACRS agreed that the draft final Revision 3 to RG 1.82 be issued in order to facilitate licensee response and resolution of technical issues, it made the following conclusions and recommendations:

> *"The technical basis for analyzing the phenomena described in RG 1.82 is not mature, the available information is inconsistent, and the knowledge base is evolving. Therefore, it is likely that the licensees' responses will be disparate and difficult to evaluate unless more consistent guidance is developed."*
>
> *"The zone of influence (ZOI) models need revision and resolution of inconsistencies".*
>
> *"Neither RG 1.82 nor the knowledge base report [NUREG/CR-6808] gives adequate consideration to chemical reactions."*
>
> *"..the staff should carefully review implementing guidance being developed by the Nuclear Energy Institute (NEI) because of the issues identified, the complex phenomena involved, and the need for more accurate plant-specific assessments."*

"The knowledge base report [NUREG/CR-6808] is a compendium of research results relevant to the problem, but it is confusing and it cannot be used directly as guidance for the analysis of sump blockage. Acceptable methods should be developed for use in satisfying the functional requirements described in RG 1.82."

"An adequate technical basis should be developed to resolve the issues related to chemical reactions."

"The staff should consider the possibility that the uncertainties associated with the calculational methodology may be so large, or that strainers may prove to be so susceptible to debris blockage, that alternative solutions may be required to ensure long-term cooling. This might involve, for example, changing the types of insulation used within containment or implementing diverse means of providing long-term cooling."

"The staff should investigate a risk-informed approach to sump screen blockage."

JULY 19, 2004: PROPOSED DRAFT FINAL GENERIC LETTER ON POTENTIAL IMPACT OF DEBRIS BLOCKAGE ON EMERGENCY RECIRCULATION DURING DESIGN BASIS ACCIDENTS AT PWRs

During the 514th meeting of the ACRS on July 7-9, 2004, the Committee reviewed the staff's proposed draft final GL on the potential impact of debris blockage on emergency recirculation during design basis accidents at PWRs. The ACRS Subcommittee on Thermal-Hydraulic Phenomena also reviewed this matter during a meeting held on June 22-23, 2004. In its letter, dated July 19, 2004, while the ACRS agreed that the generic letter be issued for implementation, it made the following recommendation:

"The staff should continue confirmatory research in areas where the technical basis of the guidance is uncertain, and on issues such as chemical and downstream effects that are not directly addressed by the guidance proposed by the Nuclear Energy Institute (NEI)."

The Committee also noted that some technical issues raised by ACRS previously had not yet been fully resolved. The Committee further noted that research, such as the currently ongoing investigation of chemical effects and studies of downstream effects, was needed for the final resolution of the sump blockage issue. The Committee also recommended that the staff "*initiate any research necessary to confirm that the guidance used by the licensees is adequate. For example, there are still several different models for the zone of influence. Coupling an existing computational fluid dynamic code, such as FLUENT, to the steam-water properties available as a subprogram, would make it possible to model the homogeneous supersonic jets issuing from various break geometries. This work would show the shock wave patterns and mechanisms for energy dissipation and would be very helpful in evaluating the simplified zone of influence models."*

OCTOBER 18, 2004: SAFETY EVALUATION OF THE INDUSTRY GUIDELINES RELATED TO PRESSURIZED WATER REACTOR SUMP PERFORMANCE

During the 516th meeting of the ACRS, October 7-9, 2004 the Committee met with representatives of the NRC staff, its contractors, and the industry to review the staff's draft safety evaluation (SE) related to Nuclear Energy Institute (NEI) Guidance Report (NEI 04-07), "Pressurized Water Reactor Sump Performance Evaluation Methodology" The guidance report and the associated SE were intended to describe a methodology that is acceptable to the staff for use by licensees in responding to GL 2004-02. The ACRS Subcommittee on Thermal-Hydraulic Phenomena reviewed this matter during a meeting on September 22-23, 2004. In its letter, dated October 18, 2004, the ACRS made the following recommendation:

> *"The SE should not be issued in its present form. Both it and the NEI guidance contain too many technical faults and limitations to provide the basis for a defensible and robust long-term solution to Generic Safety Issue (GSI) 191, Assessment of Debris Accumulation on Pressurized Water Reactor (PWR) Sump Performance."*
>
> *"The faults and limitations in the present technical knowledge base need to be addressed so that acceptable guidance can be developed. The staff should develop sufficient understanding to determine either the uncertainty or the degree of margin resulting from the application of the methodology."*
>
> *"If licensees are to be responsible for filling gaps in the analytical and experimental data base, the staff should clearly state the agency's expectations for the necessary quality and acceptability requirements."*
>
> *"The risk-informed approach should be extended to treat the entire sequence of phenomena that lead from the break to the end effects on the pump net positive suction pressure (NPSH) and thus the effectiveness of recirculation cooling. This would provide a technical basis for application of the Regulatory Guide (RG) 1.174 process. It will require a quantitative assessment of model uncertainties related to the physical phenomena."*

DECEMBER 10, 2004: SAFETY EVALUATION OF THE INDUSTRY GUIDELINES RELATED TO PRESSURIZED WATER REACTOR SUMP PERFORMANCE

In a letter, dated November 26, 2004, Executive Director for Operations (EDO) responded to the October 16, 2004 letter of ACRS, disagreeing with the Committee's recommendations including that the SE not be issued in its present form due to concerns about technical errors and limitations in the knowledge base. In a letter, dated December 10, 2004, the ACRS responded to the November 26, 2004 EDO letter, indicating the Committee's disagreement with the EDO statement that the knowledge limitations are clearly identified and addressed in the SE. In this letter, it was also noted that the Committee "*continue[s] to believe that both the SE and Nuclear Energy Institute guidance document contain technical faults and limitations that will have to be corrected at some stage in order for the methods to be sufficiently robust and durable to support sound regulatory decisions.*"

APRIL 10, 2006: GENERIC SAFETY ISSUE 191 - ASSESSMENT OF DEBRIS ACCUMULATION ON PWR SUMP PERFORMANCE

During the 530th meeting of the ACRS, March 9-11, 2006, the Committee considered several reports by the NRC staff regarding their efforts to resolve GSI-191. The staff discussed licensee responses to GL 2004-02 and presented the results of efforts by the Office of Nuclear Regulatory Research to understand several phenomenological issues that have arisen as part of the GSI-191 effort, including chemical effects, downstream effects, and head loss correlations through debris beds. The results were also presented to ACRS Thermal-Hydraulics Phenomena Subcommittee on February 14-16, 2006. In its letter, dated APRIL 10, 2006, the ACRS made the following conclusions and recommendation:

> *"In response to GL 2004-02, many licensees plan to increase the size of their sump screens as quickly as feasible. Based on the current state of knowledge, we concur with this intent. However, it is not evident that this measure will be sufficient to resolve all long-term core cooling issues."*
>
> *"Results of prototypical experiments planned by industry to validate screen effectiveness will be difficult to extrapolate to plant conditions. Further work is required to provide the technical basis by which the staff can assess the adequacy of the planned modifications to the plants. Guidance should be developed to support the staff's review."*
>
> *"Recent research has revealed significant influences of particle/fiber mixtures and chemical reaction products on screen pressure drop for which improved predictive methods and guidance should be developed."*
>
> *"Increasing screen size to reduce the pressure drop may increase the amount of fine debris and chemical products that passes through the screen. Methods for predicting the quantity and properties of this bypassed debris should be developed. Potential adverse effects on downstream components, including pumps, valves, the core entrance regions, and the core itself, should be evaluated*."
>
> *"There has been some success at using adjustable parameters in an equilibrium chemistry model to match the chemical species that form in sumps. The methods should be validated further and guidance should be developed for their use."*
>
> *"The results of tests of coating debris formation and transport should be included in the assessment of core coolability as they become available. Future work should include the development of adequate predictive capability for the effects of coating debris on screen pressure drop and bypass."*

AUGUST 1, 2006: GENERIC SAFETY ISSUE 191 - ASSESSMENT OF DEBRIS ACCUMULATION ON PWR SUMP PERFORMANCE

In a letter, dated May 2, 2006, EDO responded to the April 10, 2006 letter of ACRS, indicating the staff's intent to terminate research activities related to GSI-191 in June 2006 and that additional work by the industry and the staff may be needed to address

some remaining issues such as chemical and downstream effects. Because of the complexity of the phenomena that affect the pressure drop across debris beds, particularly when chemical effects are include, the staff concluded that the development of predictive models was "a challenging and long-term effort which may not achieve timely closure of GSI-191 issues."

In a letter, dated August 1, 2006, the ACRS responded to the May 2, 2006 EDO letter. In its letter, while the Committee agreed that the industry's integral experiments would help to support the safety case, it noted that it is important to recognize the limitation of these tests. The Committee further noted the following:

> *"Historically, integral tests have been used to validate predictive analytical tools. These tools are used to evaluate the performance of safety systems. Integral tests have not been used as "proof tests" as an alternative to analytical tools because of the difficulty of achieving conditions that are truly prototypic. In addition, it is not practical to examine system behavior experimentally over the full range of variability of input conditions. The planned tests of full-size screen modules will be performed using conditions that vary substantially from prototypic, including differences in water temperature, water chemistry, pre-conditioning of insulation debris, and the actual system configuration, such as multiple modules. In order to understand the impact of these experimental non-typicalities, it is necessary to have some level of quantitative understanding of the phenomena. The staff must have the capability to perform an independent technical assessment of the approaches used by licensees to address GSI-191issues."*
>
> *"A continued regulatory research program to address key areas of uncertainty is a risk management strategy for reducing the likelihood of erroneous regulatory conclusions. We recommend that confirmatory research on GSI-191 be continued."*

OCTOBER 22, 2008: STATUS OF RESOLUTION OF GENERIC SAFETY ISSUE-191, "ASSESSMENT OF DEBRIS ACCUMULATION ON PWR SUMP PERFORMANCE"

During the 556th meeting of the ACRS, October 2-3, 2008, the Committee discussed progress made towards GSI-191. The ACRS Subcommittee on Thermal Hydraulic Phenomena also reviewed this matter during meetings on May 16, 2007, and March 19 and September 23, 2008. In its letter, dated October 22, 2008, the ACRS made the following conclusions and recommendation:

> *"Significant progress has been made towards resolving GSI-191."*
>
> *"All licensees have installed significantly larger sump screens and some have undertaken further actions, such as changing fibrous insulation and chemical buffer."*
>
> *"Nearly all licensees have conducted head loss testing for their new screen systems. The staff has developed adequate guidance to support its review of tests that are conducted using procedures which ensure that substantially all the fine scale debris is transported to the screens."*

"To ensure the prototypicality of tests for extrapolation to plant conditions, further guidance should be developed for the test cases in which a significant portion of the debris is allowed to settle out upstream of the screens."

"Adequate guidance has been developed to support review of the testing of the effects of chemical reaction products on screen head loss."

"Programs are being put in place to determine the amount of debris and chemical products that passes through sump screens, as well as their effects on core cooling. Guidance should be developed to ensure that these tests cover a wide enough range of conditions to support the staff's review of in-vessel downstream effects."

"The staff has proposed a systematic process that, with the development of the guidance we have recommended, will provide an acceptable framework for closure of GSI-191."

5. INTERNATIONAL PERSPECTIVES ON PWR SUMP PERFORMANCE ISSUE

The 1992 clogging of intake strainers for containment spray water in Barsebäck-2, a BWR in Sweden, renewed the focus of regulators around the world on safety questions associated with strainer clogging which, until then, had been considered as resolved. Research and development efforts of varying intensity were launched in many countries. Extensive studies have been performed to assess the amount of insulation materials that could be dislodged during pipe break events inside the containment. In many countries, the analyses were based on the double cone model developed by the NRC. The analyses have also included specific studies of the transport of insulation materials and other debris in the containment, and of strainer pressure drops. Such efforts resulted in a number of corrective actions being taken in BWRs and some PWRs around the world. For a number of plants, actions were taken as direct responses to requirements issued by regulatory authorities, while for other plants back-fitting measures were introduced voluntarily or because of anticipated requirements [7].

Table 2 provides a summary overview of approaches to resolution of PWR sump performance safety issue in different countries. This table has been prepared primarily based on the information presented at the CNRA/CSNI International Workshop on Taking Account of Feedback on Sump Clogging, held on December 4-5, 2008 in Paris, France. Plant modifications to address PWR sump performance issue include reduction in source of debris and/or change in the insulation that might block the sump strainers, as well as modification of the design of strainers themselves by increasing significantly the strainer area [8].

Table 2 Approaches to Resolution of PWR Sump Performance Safety Issue in Different Countries

Country	Approaches to Resolution of PWR Sump Performance Issue
United States of America	• New strainer installation (ALL PWRs) • Sump buffer replacement • Major (20% or more) insulation change out • Major ECCS modification (e.g., throttle valve/pump changes and cyclone separator removal) • Major containment spray system modification • Installation of debris interceptors upstream of strainers • Installation of trash racks over refueling canal drains • Increasing minimum required refueling water tank level • Modification of gates in bioshield wall to prevent debris blockage and water hold up
France	• Replacing the filters with a new design that provides more strainer surface. • Replacement of microtherm insulation materials (in some cases) • Implementation of measures on reactor building cleaning
Germany	• Increase of strainer size (4 PWRs) • Reduction of mesh size (All PWRs) • Optimization of insulation material combination (exchange of micro-porous material with mineral wool) • Back-flushing procedure at the strainer
Japan	• Adoption of larger passive screen, similar to those for US PWR plants • Smaller screen mesh size than openings or gaps in downstream • Consideration of qualified coatings or replacement with less fiber insulator
Spain	Westinghouse Plants • Installation of new filters (3 out of 5 PWRs) • Elimination of " No RMI" inside the ZOI • Minimization of latent debris • Total elimination of calcium silicate and aluminum in submerged zones of containment • Change of HP injection valves German Design Plant • Thermal insulation partially substituted • Strainer mesh size reduced • Pending on the applicability of other actions (Germany)

6 SUMMARY AND CONCLUSIONS

An overview of PWR sump performance safety issue, current regulations and guidance documents related to ECCS capability and sump performance for PWRs, and the role of ACRS in resolution of safety issues were presented.

The ACRS has played an important role toward resolution of PWR sump performance issue. In particular the Committee raised the issues such as chemical and downstream effects that were not originally considered. The past ACRS observations and recommendations regarding PWR sump performance issue were also presented to provide insights and perspectives on previous Committee's review of this matter. An overview of international perspectives on PWR sump performance was also presented.

7 REFERENCES

1. *Code of Federal regulations,* Title 10, part 50, *Domestic Licensing of Production and utilization Facilities.*

2. U.S. Nuclear Regulatory Commission, PWR Sump Performance, http://www.nrc.gov/reactors/operating/ops-experience/pwr-sump-performance.html

3. U.S. Nuclear Regulatory Commission, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," NUREG-0800.

4. U.S. Nuclear Regulatory Commission, Generic Letter 2004-02, “Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors,” dated September 13, 2004.

5. Nuclear Energy Institute, ““Pressurized Water Reactor Sump Performance Evaluation Methodology,” NEI-04-07, dated May 28, 2004.

6. U.S. Nuclear Regulatory Commission, “Staff Requirements Memorandum, Meeting with Advisory Committee on Reactor Safeguards (ACRS),” dated December 20, 2005.

7. OECD/NEA, “Knowledge Base for Strainer Clogging-Modifications Performed in Different Countries since 1992,” Committee on the Safety of Nuclear Installations, Organization for Economic Cooperation and development (OECD) Nuclear Energy Agency (NEA), Final Report, NEA/CSNI/R(2002)6, October 2002.

8. OECD/NEA, “Proceedings of the CNRA/CSNI International Workshop on Taking Account of Feedback on Sump Clogging,’” NEA/CSNI/R(2009), dated January 8, 2010.