BACKGROUND DISCUSSION AND TECHNICAL ISSUES

DESCRIPTION OF DEBRIS-INDUCED SUMP CLOGGING

A fundamental function of the emergency core cooling system (ECCS) is to recirculate water through the reactor core that has settled at the bottom of containment following a break in the reactor cooling system (RCS) piping. Breaks in RCS piping, hypothetical scenarios known as loss-of-coolant accidents (LOCAs), are part of every plant's design basis. Hence, nuclear plants are designed and licensed with the expectation that they are able to remove reactor decay heat following a LOCA to prevent core damage.

If a LOCA occurs, piping thermal insulation and other materials will be dislodged by the two-phase jet emanating from the broken RCS pipe. This debris may transport, via flows coming from the RCS break or from the containment spray system, to the pool of water that would be present at the bottom of containment following a LOCA. Once transported to the sump pool, the debris could be drawn towards the ECCS sump strainers, which are designed to prevent debris from entering the ECCS system and the reactor core. If this debris were to clog the strainers, reactor core cooling would be lost and core damage would occur.

HISTORICAL BACKGROUND

In 1979, as a result of evolving staff concerns related to the adequacy of pressurized-water reactor (PWR) recirculation sump designs, the U.S. Nuclear Regulatory Commission (NRC) opened Unresolved Safety Issue (USI) A-43, "Containment Emergency Sump Performance." To support the resolution of USI A-43, the NRC undertook an extensive research program, the technical findings of which are summarized in NUREG-0897, "Containment Emergency Sump Performance," issued October 1985. The staff subsequently documented the resolution of USI A-43 in Generic Letter (GL) 85-22, "Potential for Loss of Post-LOCA Recirculation Capability Due to Insulation Debris Blockage," dated December 3, 1985. Although the staff's regulatory analysis concerning USI A-43 did not support imposing new sump performance requirements on licensees of operating PWRs or boiling-water reactors (BWRs), the staff found in GL 85-22 that the 50-percent blockage assumption (under which most nuclear power plants had been licensed) identified in Regulatory Guide (RG) 1.82, "Sumps for Emergency Core Cooling and Containment Spray Systems," Revision 0, should be replaced with a more comprehensive requirement to assess debris effects on a plant-specific basis. As a result, the staff updated the NRC's regulatory guidance in Section 6.2.2 of NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," and RG 1.82 to reflect the USI A-43 technical findings documented in NUREG-0897.

Following the resolution of USI A-43 in 1985, several BWR ECCS suction strainer plugging events occurred (e.g., Barseback Unit 2 in Sweden, Perry Unit 1 and Limerick Unit 1 in the United States) that challenged the conclusion that no new requirements were necessary to prevent the clogging of ECCS strainers at operating BWRs. In response to these ECCS suction strainer plugging events, the NRC issued several generic communications (Bulletin 93-02, Supplement 1, "Debris Plugging of Emergency Core Cooling Suction Strainers," dated February 18, 1994, and Bulletins 95-02, "Unexpected Clogging of a Residual Heat Removal

Pump Strainer While Operating in Suppression Pool Cooling Mode," dated October 17, 1995, and 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling-Water Reactors," dated May 6, 1996) over the period 1993 to 1996. These bulletins requested that BWR licensees implement appropriate procedural measures, maintenance practices, and plant modifications to minimize the potential for the clogging of ECCS suction strainers by debris accumulation following a LOCA. The NRC staff subsequently concluded that all BWR licensees had sufficiently addressed these bulletins.

However, findings from research to resolve the BWR strainer clogging issue raised questions concerning the adequacy of PWR sump designs. In comparison to the technical findings of the earlier USI A-43 research program on PWRs, the BWR research findings demonstrated that the amount of debris generated by a high-energy line break (HELB) could be greater, that the debris could be finer (and thus more easily transportable), and that certain combinations of debris (e.g., fibrous material plus particulate material) could result in a substantially greater headloss than an equivalent amount of either type of debris alone. These research findings prompted the NRC to open Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance," in 1996. This resulted in new research for PWRs in the late 1990s. GSI-191 focuses on reasonable assurance that the provisions of Title 10 of the *Code of Federal Regulations* (10 CFR) 50.46(b)(5) are met. This rule, which is deterministic, requires maintaining long-term core cooling after initiation of the ECCS. The objective of GSI-191 is to ensure that post accident debris blockage will not impede or prevent the operation of the ECCS and containment spray system (CSS) in recirculation mode at PWRs during LOCAs or other HELB accidents for which sump recirculation is required. The NRC completed its review of GSI-191 in 2002 and documented the results in a parametric study which concluded that sump clogging at PWRs was a credible concern.

On June 9, 2003, after completing the technical assessment of GSI-191, the NRC issued Bulletin 03-01, "Potential Impact of Debris Blockage on Emergency Recirculation during Design-Basis Accidents at Pressurized-Water Reactors." The Office of Nuclear Reactor Regulation (NRR) requested (Agencywide Documents Access and Management System (ADAMS) Accession No. ML030830459) and obtained (ADAMS Accession No. ML031210035) the review and endorsement of the bulletin from the Committee to Review Generic Requirements (CRGR). As a result of the emergent issues discussed in the bulletin, the staff requested an expedited response from PWR licensees on the status of their compliance on a mechanistic basis with regulatory requirements concerning the ECCS and CSS recirculation functions. The staff asked addressees who chose not to confirm regulatory compliance to describe any interim compensatory measures that they had implemented or will implement to reduce risk until the analysis could be completed. All PWR licensees have responded to Bulletin 03-01.

In developing Bulletin 03-01, the NRC staff recognized that it might be necessary for addressees to undertake complex evaluations to determine whether regulatory compliance exists in light of the concerns identified in the bulletin and that the methodology needed to perform these evaluations was not currently available. As a result, that information was not requested in the bulletin, but addressees were informed that the staff was preparing a generic letter that would request this information. GL 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004, was the follow-on information request referenced in the bulletin. This document set the expectations for resolution of PWR sump performance issues identified in GSI-191. NRR requested (ADAMS Accession No. ML040430074) and obtained (ADAMS Accession No. ML040840034) the review and endorsement of the generic letter from the CRGR. In addition, the staff issued substantial guidance on the subject, including a detailed safety evaluation (SE) in 2004 for Nuclear Energy Institute (NEI) 04-07, "Pressurized Water Reactor Sump Performance Methodology" (ADAMS Accession No. ML043280007). The SE provided a conservative "baseline" evaluation method and a more risk-informed alternative method that accounted for the extremely low probability of the largest postulated pipe breaks. The CRGR also reviewed the SE (ADAMS Accession No. ML042710247).

Guided by the GL, the staff's SE, and other staff correspondence, the PWR licensees made significant progress in addressing GSI-191. In addition to strainer enlargements at all PWRs, individual licensees made various plant-specific changes. Some removed fibrous or particulate insulation, while others changed their sump pH buffers or installed debris interceptors. However, encouraged by the NRC to take near-term actions to improve expected strainer performance, licensees often made plant changes before testing had been done to demonstrate the adequacy of the changes. Most licensees engaged various vendors to build and test a section of their strainer in a test flume at the vendor's facility. The NRC staff found a number of issues with the testing. The staff communicated extensively with the vendors and licensees to address these issues, and by and large, the staff now considers the latest vendor test protocols to be acceptable.

RECENT DEVELOPMENTS

The staff also knew at the time of the GL and the SE that certain aspects of the strainer performance evaluations needed further research and evaluation. Notable among these phenomena were chemical effects and downstream effects. Chemical effects refer to the potential for chemical species in the containment to interact with materials, such as insulation debris, to form a product that could cause or aggravate the potential for impeding flow through the strainer. Downstream effects refer to the potential for materials that bypass the ECCS strainer to impact downstream components (e.g., valves, pumps, and the nuclear core).

From vendor testing, it became clear that the results in terms of head-loss were quite sensitive to a number of factors under the control of the test vendor. For example, the order of arrival of debris types at the strainer was observed to have an unexpectedly significant impact on the potential for strainer blockage. Since it is difficult to predict that any given debris type would arrive first, the staff expected that the licensees would test with what appeared to be the worst sequence, unless the licensees could justify an alternate approach. The staff's evaluation of the strainer performance and test practices took various forms, including plant-specific audits, reviews of vendor protocols and testing, and detailed reviews of licensee supplemental responses to the GL. To clarify expectations for GL written responses that were due at the end of 2007, the NRC staff issued a content guide for GL 2004-02. Despite issuance of the content guide, licensees' written responses to the GL did not provide the level of detail in many cases necessary to determine that testing and evaluation methods were acceptable. This resulted in the NRC staff issuing a large number of requests for additional information (RAIs).

On November 16, 2007, the staff updated the Commission on the resolution status of GSI-191 (ADAMS Accession No. ML071930243). The update noted that the industry had not made progress in resolving the remaining technical issues as rapidly as the staff had anticipated and discussed completed research regarding chemical effects which showed that these effects required extensive evaluation and were a more significant concern than initially thought. The update also noted that some licensees might need to replace problematic insulation to attain successful strainer headloss tests. Additionally, as the staff's knowledge increased from evaluations of licensee-sponsored test and evaluation protocols, as well as the results of chemical effects research, the staff issued supplemental review guidance in early 2008 (ADAMS Accession No. ML080230234) to address headloss testing, coatings evaluation, and chemical effects.

Prompted by comments made by the Advisory Committee on Reactor Safeguards (ACRS) on a draft SE on the in-vessel effects topical report in 2008, the staff reexamined its views on the PWROG approach to demonstrating that adequate core cooling would be provided in the presence of debris that bypasses the ECCS strainer. This reexamination resulted in substantial additional testing. The test results indicated significantly greater core differential pressure for one vendor's fuel as compared to the other. This led the staff to request more testing to determine whether the differences were because of fuel design differences or test facility differences. This testing has not yet occurred. Discussions with fuel vendors and the PWROG regarding the possible test are ongoing.

Because of the complex nature of GSI-191 issues, the staff performed detailed reviews in each of the technical aspects of the problem. The detailed review process led some licensees and other industry stakeholders to express frustration that the staff has focused too much on achieving conservatism in each of the review areas pertinent to strainer performance. Recognizing that conservatism, if present in multiple areas, could result in an overly conservative result, the staff put a review process in place to attempt to avoid this problem (ADAMS Accession No. ML073380168). A three-member team of senior staff with the requisite technical expertise (different from the GSI-191 review team) is tasked with reviewing the staff review packages for each licensee to determine whether, given the conservatisms, nonconservatisms, and uncertainties in the various review areas, the licensee has provided reasonable assurance of successful strainer function. This process has been effective in closing sump performance issues for many licensees.

As licensees responded to RAIs, the staff utilized the integrated review process. This eventually resulted in substantial resolution of strainer performance issues for over half the PWR fleet (currently 44 of 69 units), with the exception of in-vessel effects. The Pressurized-Water Reactor Owners Group (PWROG) is addressing in-vessel effects generically through submittal of a topical report, which is under NRC staff review. The plants that have not yet achieved closure tend to be those with relatively large amounts of fibrous insulation or that have significant testing issues. In general, plants with relatively large amounts of such insulation attempted to remove conservatisms in the testing and analysis methodologies that were accepted in the guidance provided in the staff's SE in 2004. Examples include testing that attempted to credit settling of debris or testing that attempted to reduce the zone of influence (ZOI). The ZOI is the volume around a pipe break location within which insulation or coatings are assumed to be damaged and available to transport to the sump during a LOCA. Extensive interactions among the NRC and licensees, vendors, and the PWROG have not achieved resolution of staff questions on these subjects.

One member of the staff's sump review team filed a differing professional opinion (DPO) in 2008. The DPO (ADAMS Accession No. ML100990063) expressed the opinion that the staff procedure and closure process has resulted in a review that is unnecessarily focused on compliance versus a determination that the underlying safety issue has been satisfactorily addressed. The DPO panel agreed that the resolution of GSI-191 is focused on compliance, but also stated that compliance with the regulatory requirements presumptively ensures that adequate safety is maintained. Therefore, the panel found the current approach to be appropriate. The NRR Office Director also concurred with the panel (ADAMS Accession No. ML100990069).

As stated earlier, a number of plants that have not yet achieved closure tend to be those with relatively large amounts of fibrous insulation or which have significant testing issues. The review process alone cannot overcome many of the uncertainties or nonconservatisms of potentially large significance. This is because of the lack of reliable predictive models for some aspects of strainer behavior, the observed fact that relatively small amounts of the right combination of debris types can lead to significant headloss, and the difficulty in determining margins with confidence. Having concluded that industry attempts to refine the test and evaluation methods to reduce perceived conservatisms would not be successful in the foreseeable future, the staff planned to issue letters under 10 CFR 50.54(f) to the affected licensees asking them to provide information on how they would show compliance with the relevant regulations without crediting ZOI reductions and debris settling. The letters would have communicated an expectation that licensees commit to show adequate strainer performance by a date certain using methods consistent with the 2004 SE. Such licensees could continue to propose refinements, but with a fallback plan to show compliance. The staff recognized that an inability to use refinements to the testing and evaluation methodology, or the resolution of the in-vessel effects issue, had the potential to lead to additional modifications. Such modifications would likely involve replacement of fibrous insulation with less problematic reflective metal insulation. It was understood that these replacements would be dose sensitive and could be more complex if asbestos was involved. The staff halted plans to issue these letters in accordance with Commission direction in Staff Requirements Memorandum M100415, dated May 17, 2010.

ZONE OF INFLUENCE

Background and Discussion

The ZOI is a significant parameter in the evaluation of the sump screen performance. The ZOI represents the zone around a postulated break in which a given material is assumed to be destroyed by the high-energy water/steam jet emanating from the break. The ZOI is assumed to be spherical, and the size is described in terms of pipe diameters. For example, a 17D ZOI represents a spherical zone of destruction that has a radius equal to 17 times the pipe diameter of the postulated break. The ZOI is material specific, meaning that every material has a different ZOI. More robust materials have smaller ZOIs, while weaker, more easily damaged materials have larger ZOIs.

The first step in determining the ZOI for a particular material is to conduct destruction testing. A sample of the material is typically placed at a distance from a test nozzle and blasted with a jet to determine if the material survives. Based on whether the material survives or is destroyed, subsequent samples of the same material are tested at closer or further distances from the nozzle to identify the threshold distance at which damage becomes insignificant. Subsequently, the test jet pressure at the threshold distance is typically measured or known based on previous measurements. This pressure is used as the destruction pressure for the tested material.

The second step is to determine the volume of the jet from a postulated LOCA break that would exist at pressures equal to or greater than the destruction pressure for the material. This volume is typically calculated using the American National Standard Institute/American Nuclear Society (ANSI/ANS) 58.2-1988, “Design Basis for Protection of Light Water Nuclear Power Plants against the Effects of Postulated Pipe Rupture,” jet model. Plant conditions like RCS water temperature and pressure are entered into the model to determine a three-dimensional representation of the jet in terms of jet isobars. Each isobar represents all locations within the jet that are at an equal pressure. Isobars that are very close to the jet represent very high pressures, while distant isobars represent very low pressures. All of the isobars taken together are intended to represent the entire jet volume. From this model, the isobar corresponding to the material destruction pressure is identified. The volume of the isobar is calculated, including all isobars located within the destruction isobar, because all internal isobars represent higher jet pressures that would also destroy the material. This portion of the jet assumed to destroy the material represents its ZOI volume.

The ZOI volume is then doubled to represent both sides of a pipe break. The total volume is then assumed to be a sphere, the radius of the sphere is calculated, and this radius is expressed in terms of the number of pipe diameters surrounding a postulated pipe break. The volume is set equal to a sphere in recognition that jet deflections and reflections in a congested containment are likely to result in a more spherical ZOI than a jet-shaped ZOI. Using a spherical ZOI also greatly simplifies licensees’ analysis for debris generation.

This method will always result in a spherical ZOI with a radius much smaller than the axial distance of a destruction isobar for a jet focused in a single direction. To illustrate using the currently accepted jet model, a typical PWR jet pressure isobar of 40 pounds per square inch gauge (psig) will extend axially to about 8 pipe diameters (8D) from the break. However, when the jet volume associated with the 40 psig isobar is calculated, doubled, and converted to a spherical equivalent ZOI, the radius of the ZOI is only 4 pipe diameters (4D). As such, the spherical ZOI assumption has been criticized as potentially nonconservative because the actual jet shape, in all possible directions, is not used to get the worst-case zone of destruction. The staff’s response to this concern is that the jet is likely to reflect off of and be redirected by targets and obstructions surrounding the break location such that a spherical equivalent is a reasonable simplification that also results in easier destruction zone analysis for licensees. While the spherical ZOI concept represents a potential nonconservatism, the staff believes treatment of the ZOI area remains conservative overall because it is balanced by other ZOI analysis conservatisms such as not accounting for jet deflection losses and the fact that the accepted jet model very likely over predicts jet volumes for low jet pressures because the ANSI model is unbounded in the downstream direction. This means that, for very small jet impingement pressures, the isobar volume will grow unrealistically large.

Why Past Industry Attempts To Reduce ZOIs Have Been Unsuccessful

In 2008, while reviewing licensee evaluations for GSI-191, the NRC staff became aware of industry (Westinghouse) ZOI testing that had recommended much smaller ZOIs for some insulation than was accepted in the staff's 2004 SE for NEI 04-07. Many licensees credited the reduced ZOIs recommended in the reports. The NRC staff reviewed two industry technical reports referenced by some licensees in submittals to the NRC: Westinghouse Commercial Atomic Power (WCAP)-16710-P, Revision 0, "Jet Impingement Testing to Determine the ZOI of Min-K and NUKON® Insulation for Wolf Creek and Callaway Nuclear Operating Plants," and WCAP-16851-P, Revision 0, "Florida Power and Light Jet Impingement Testing of Cal-Sil Insulation." The NRC staff identified significant concerns with the testing. The reports documented jet impingement testing performed at Wyle Laboratories and were intended to justify a reduced ZOI.

During a teleconference on February 20, 2009 (ADAMS Accession No. ML090570671), the PWROG, on behalf of affected licensees, requested that the NRC staff's questions regarding these technical reports be resolved generically through the PWROG to the extent feasible. Based on this request, the NRC staff discussed questions regarding the technical reports with the PWROG during the teleconference. Additional detailed technical discussions with the PWROG continued until the end of 2009.

As a result of NRC staff questions, on December 11, 2009, Westinghouse identified several locations in the Wyle test loop where the inside diameter of the piping was significantly smaller than the nozzle. In particular, the nozzle size used to calculate the jet pressures at most of the jet impingement targets was 3.54 inches in diameter; however the smallest piping diameter was 2.313 inches and was located approximately 26 inches upstream of the nozzle exit. During a public meeting between NRC staff and the PWROG on December 16, 2009, the NRC informed the PWROG that the small diameter locations upstream of the jet nozzle likely resulted in a much weaker jet than the tests assumed, and the staff would likely reject the test results unless testing showed that the jet was not affected by the upstream choke locations. The PWROG performed confirmatory testing in January 2010 to determine actual jet pressures that existed during the previous ZOI tests. The January 2010 testing revealed that the jet pressures were much lower than Westinghouse had assumed in the ZOI testing reports.

The PWROG submitted a letter dated March 5, 2010 (ADAMS Accession No. ML100710710), to respond to all staff questions regarding the test reports. This letter included a rationale to explain that the upstream choke was not the reason for the much weaker jet. The PWROG instead argued that the reason for the much lower jet pressures was because the staff-accepted ANSI jet model grossly overpredicts axial jet pressures. The staff rejected the PWROG position because it lacked adequate technical basis and did not address the effect of upstream choke locations on the jet. Also, while the staff believes that the ANSI jet does overpredict axial pressures, the ANSI model was not intended to be used in this way for GSI-191. The ANSI model is accepted in the SE for converting an empirically derived (e.g., measured) damage pressure into a three-dimensional isobar to calculate a damage volume. Overprediction of axial pressure, even if experimentally confirmed using a jet with no upstream chokes, does not necessarily mean that jet volume is also overpredicted. For example, the jet model may also underpredict radial expansion and subsequently the location of a particular pressure isobar.

While the NRC staff concluded that the test report ZOIs were not valid based on the available information, the PWROG did resolve some of the staff's testing concerns. A letter sent to the

PWROG dated March 31, 2010 (ADAMS Accession No. ML100570364), discusses those items that were resolved technically, as well as those that were not. The PWROG currently plans to perform additional ZOI testing to further resolve previous test issues. This includes testing that does not involve an upstream choke location. The industry testing is planned to begin in spring 2011 and is further described under Option 1 of Enclosure 2.

Areas in which Additional Testing Might Refine Current Spherical ZOI SE Values

A realistic model for the ZOI would not use spherical ZOIs. It would consider a realistic jet shape in all possible directions along all possible pipe locations to identify the most limiting scenario for debris generation. Jet deflections and reflections off major components would be considered. These deflections, if applicable for the worst break location, would be expected to widen the radial influence for the jet while also reducing the axial influence of the jet due to interaction losses. This type of ZOI analysis would yield more realistic determinations for plant-specific ZOIs, but would significantly increase the complexity of licensee sump performance evaluations. Additionally, because a realistic jet-shaped ZOI would be used instead of a simplistic volume-equivalent spherical ZOI, it is expected that many materials currently considered outside the spherical ZOI would be easily reachable by the realistic jet-shaped ZOI. This may result in realistic calculated debris volumes that are greater than those calculated using the currently accepted spherical ZOI method. However, even if this were the case, development of a more realistic jet model that predicts much smaller jet volumes than the current ANSI model may more than counter this effect such that the total debris source term is less under an integrated realistic ZOI analysis. On the other hand, if the ANSI model is determined to underpredict realistic jet volumes, then the realistic calculated debris source terms would likely go up for all licensees. The staff does not believe the latter scenario is likely because of the significant conservatisms in the current ANSI model, especially for materials with low destruction pressures.

In summary, the staff does not think a more realistic ZOI model is necessary to adequately evaluate the potential debris generation of a postulated break. While the spherical concept is an approximation, it likely approximates a true destruction zone shape assuming multiple reflections and deflections while greatly simplifying licensee evaluations related to GSI-191. Additionally, the destruction pressures for various materials that are used as an input to the ANSI jet model for determining ZOI volumes have been determined using a large body of testing from various sources. The staff believes these data are reliable. Lastly, while the ANSI jet model likely overpredicts jet volumes at low destruction pressures, it is not expected that jet volume calculations using a more realistic model would be significantly different.

SETTLEMENT CREDIT

Background and Discussion

All PWR licensees have performed analyses to determine how much of the debris generated during a postulated LOCA would transport to the recirculation sump strainers. With several exceptions, licensees' transport analyses for the sump recirculation phase of a LOCA typically assume that fine debris (e.g., 10-micron particulate, individual fibers) remains in suspension in the containment pool and transports to the strainers. For more sizeable pieces of debris that may transport along the containment pool floor rather than in suspension (e.g., 1-inch pieces), analyses typically determine transportability by comparing experimentally determined threshold velocities necessary for the motion of a single piece of a given type of debris to the velocities that are predicted to occur in the post-LOCA containment pool. The NRC staff has considered this general approach for determining debris transport to the strainers to be appropriate.

In performing strainer testing to determine the headloss from the limiting debris loading, most PWR licensees have used test protocols that ensure, through agitation of the fluid in the test tank, that most of the debris analyzed to reach the strainers through the approach discussed above is collected on the strainer surfaces. Therefore, because these strainer tests do not permit significant debris settlement, licensees following this approach do not need to undertake a complex analysis to demonstrate that the flow conditions within the test tank are prototypical of the plant condition. The NRC staff has considered this general approach for performing strainer headloss testing to be appropriate.

Licensees for approximately 15 PWRs, however, have attempted to take credit for debris settlement during scaled strainer testing. Results from completed tests have shown significantly reduced transport of many types of floor-transporting debris and have further shown settlement of fine, suspendable debris. However, as explained in more detail below, the NRC staff has not accepted the results of these tests because licensees have been unable to demonstrate to the staff's satisfaction that the debris settlement that occurred under the test conditions is representative of what would occur under actual plant conditions.

Although the staff considers a combined test of debris transport and strainer headloss to be appropriate conceptually, in practice it has proven very challenging for licensees to implement these complex tests in a manner that simultaneously scales requisite test parameters for transport and headloss within a range that is prototypical of plant conditions. The two most significant technical challenges associated with justifying tests performed according to this protocol are related to the scaling of parameters associated with debris transport. These challenges are described below:

(1) Demonstrate that the flow conditions (e.g., velocity and turbulence) in the test flume are prototypical of the plant's post-LOCA containment pool. Turbulence is a governing factor in the resuspension of fine debris, which is particularly significant with respect to headloss, and the staff has observed that it was significantly underrepresented in these tests.

(2) Demonstrate that testing with flumes as narrow as 4–6 inches does not inhibit debris transport in a nonprototypical manner through dampening of turbulence and increased interactions between debris pieces, as well as between debris pieces and the flume walls. All of these effects can significantly reduce the transport of debris. At many plants, containment pool flow channels can be an order of magnitude wider than these test flumes, leading to different flow behavior and much lower debris concentrations. The flume widths used for testing are not scaled to the plant, but follow from the scaling of the test strainer area and desired flume velocity; the test vendor does not consider it feasible to test with representative flume widths.

Additional concerns that have affected the acceptance of some licensees' strainer tests that have credited debris settlement have included the following:

- preparation of the test debris in a consistent manner that is representative of expected plant debris; and
- addition of debris in a manner that represents the expected plant condition.

IN-VESSEL EFFECTS

Background and Discussion

During the post-LOCA sump recirculation phase of ECCS operation, a fraction of suspended insulation fibers, particulate, and chemical precipitates passes through the sump strainers and transports to the reactor core where it can collect on the core inlet nozzle or the fuel grid straps located throughout the core. GL 2004-02 noted this concern.

In response to GL 2004-02, the PWROG sponsored the development and submittal of WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," to provide the owners of PWRs an NRC-accepted method for evaluating the effects on core cooling of debris and dissolved chemicals transported to the reactor pressure vessel.

The ACRS raised questions regarding a 2008 draft SE for the in-vessel downstream effects topical report, causing the staff to reexamine its views on the subject. The NRC staff is close to being able to issue an SE for in-vessel effects pending evaluation of proposed cross-testing of Westinghouse and AREVA fuel designs.

The in-vessel effects topical report contains acceptance limits for the quantity of fibrous, particulate, and chemical precipitate debris that can be deposited at the core entrance or spacer grids without impeding adequate long-term core cooling flows to the core. The debris limits were derived through tests performed by AREVA and Westinghouse, at separate test facilities, using mockup fuel assemblies of their respective design. The proposed WCAP limit on fiber transported to the core during a hot-leg break scenario varies by a factor of 10 between the two fuel vendors' fuel designs. The NRC staff, the PWROG, and the fuel vendors believe that the difference in behavior is likely the result of design differences between the two fuel types. However, because the testing of the two fuel designs was performed at separate test facilities, the staff cannot rule out the possibility that the disparity in test results may be partially caused by differences in the vendors' test equipment.

The fuel assembly testing revealed that the susceptibility of the reactor core to blockage is very sensitive to coolant flow rate, the ratio of the various debris types in the mix, and the fuel design. Further, for certain combinations of fuel design and debris mix, the tolerance for fiber appears to be low. Although many tests were run using the various combinations of debris mix, fuel type, and flow rate, uncertainties remain given the wide range in test results. Some of this uncertainty could be resolved by testing one or both vendors' fuel assembly in the other's test facility. NRC discussions with the fuel vendors and the PWROG regarding the proposed testing are ongoing. Further, sensitivity of core blockage to coolant flow rate has not been thoroughly investigated and is currently under discussion with the PWROG. Option 1 in Enclosure 2 presents the potential for additional vendor-sponsored fuel testing, assuming both vendors agree to perform additional testing.