POLICY ISSUE
NOTATION VOTE

August 26, 2010 SECY-10-0113

FOR: The Commissioners

FROM: R. W. Borchardt
Executive Director for Operations

SUBJECT: CLOSURE OPTIONS FOR GENERIC SAFETY ISSUE – 191, ASSESSMENT OF DEBRIS ACCUMULATION ON PRESSURIZED WATER REACTOR SUMP PERFORMANCE

PURPOSE:

This paper responds to Staff Requirements Memorandum (SRM) M100415, dated May 17, 2010, and requests a decision on policy issues and options that the U.S. Nuclear Regulatory Commission (NRC) staff has considered in bringing Generic Safety Issue (GSI) 191, "Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance," to closure.

SUMMARY:

Long-term cooling following a loss of coolant accident (LOCA) is a basic safety function for nuclear reactors. Failure of long-term cooling results in core damage. The sump recirculation function of the emergency core cooling system (ECCS) is the design feature in a pressurized-water reactor (PWR) that provides this safety function. Success of sump recirculation is therefore necessary for reactor safety and for providing adequate protection of public health and safety following a LOCA. GSI-191 concluded that debris clogging of sump strainers could lead to recirculation system failure as a result of a loss of net positive suction head (NPSH) for the ECCS recirculation pumps. The NRC issued Generic Letter (GL) 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004, to ensure the reliability of the long-term cooling safety function at PWRs.

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Resolution of GSI-191 involves two distinct but related safety concerns: (1) potential clogging of the sump strainers that results in ECCS pump failure; and (2) potential clogging of flow channels within the reactor vessel because of debris bypass of the sump strainer (in-vessel effects). Clogging at either the strainer or in-vessel channels can result in loss of the long term cooling safety function. Currently, the staff has concluded that the first aspect (sump strainer performance) has been adequately demonstrated for 44 of 69 PWRs. The in-vessel effects issues remain open for nearly all plants.

This paper presents three options for bringing GSI-191 to closure: (1) maintain the current holistic integrated resolution process for remaining plants, including evaluating new licensee methods or testing to justify assumptions that the staff has determined have not been technically justified in the past; (2) develop new risk-informed implementing guidance for GSI-191 using either the existing regulatory framework or the proposed risk-informed rulemaking, “Risk-Informed Redefinition of Large Break LOCA ECCS Requirements” at Title 10 of the *Code of Federal Regulations* (10 CFR) 50.46a, should it be approved, or (3) allow General Design Criterion (GDC) 4, “Environmental and Dynamic Effects Design Bases,” leak-before-break (LBB) credit for GSI-191.

The staff recommends a combination of Options 1 and 2 with an implementation schedule that is both risk-informed and takes into account the amount of planning and effort required for licensee implementation. The schedule is risk-informed, in that issues associated with the more likely accident scenarios would be resolved by a near-term schedule, and issues associated with the less likely scenarios may be resolved on a longer schedule consistent with their lower risk significance.

BACKGROUND:

Most of the plants that have not yet achieved closure with regard to strainer performance have large amounts of fibrous insulation. Others have attempted to demonstrate adequate strainer performance using test methods that are unacceptable to the staff. The resolution process is complicated by large uncertainties associated with dynamics of jet impingement, robustness of insulation and coatings, and debris transport in a LOCA environment. These uncertainties are important because testing has demonstrated the significant deleterious effects of debris on strainer performance and in-vessel flow, as well as an unpredictable sensitivity of these effects to differences in debris characteristics. Any option selected in this paper to address the resolution of strainer performance issues for the remaining PWRs will likely have similar impacts on evaluating in-vessel effects because the potential for clogging is dominated by the fibrous debris source term. Even relatively small amounts of the right combination of debris types can lead to significant strainer headloss and in-vessel blockage. For plants with high fiber loading, all of these issues are exacerbated.

The in-vessel effects issue remains open for nearly all plants and is the last aspect of GSI-191 for which the staff has not yet issued guidance regarding acceptable generic models and methods. At the time of this writing, the staff is reviewing an industry topical report on plant-specific methods to demonstrate that a core will not clog. These methods will rely on a plant’s conservatively determined debris loading, strainer bypass flow, and fuel testing that was performed under various combinations of debris. The staff plans to issue a safety evaluation (SE) for in-vessel effects in 2010, although unexpected differences in the apparent behavior of the two fuel vendors' fuels may necessitate additional testing to support the staff's issuance of this SE.

Prior to the Commission meeting on April 15, 2010, the staff had concluded that industry attempts to refine test and evaluation methods to reduce perceived conservatisms would not likely be successful in the near term. As such, the staff had developed a format for draft letters under 10 CFR 50.54(f) to the affected licensees, that would ask them to provide information on how they would show adequate strainer performance by a date certain using methods consistent with the 2004 SE for NEI-04-07, "Pressurized Water Reactor Sump Performance Methodology" (Agencywide Documents Access and Management System (ADAMS) Accession No. ML043280007).

In response to SRM M100415, issuance of these letters is in abeyance pending additional Commission direction. Enclosure 1 provides further discussion regarding the history and complexities of the issue, as well as the basis for why the staff has not accepted the proposed refinements to test and evaluation methods.

During the April 15, 2010, Commission meeting, licensee speakers expressed concern that the NRC staff's approach to issue resolution (issuing 10 CFR 50.54(f) letters to licensees expecting issue resolution in the near-term using staff-accepted methods) would lead to large radiation exposures to plant staff without significant safety benefit. The Nuclear Energy Institute and the Union of Concerned Scientists (UCS) each submitted two letters in conjunction with the April Commission meeting, detailing their respective views on whether GDC 4 credit should be allowed for GSI-191. In developing its recommendations on a path forward for GSI-191, the staff has carefully evaluated these stakeholder views, which are discussed elsewhere in this document and its enclosures, and/or in correspondence to the stakeholders.

DISCUSSION:

The staff recognizes the significant costs associated with replacing or reinforcing insulation materials and acknowledges that compensatory actions and modifications made to date have reduced the risk of strainer clogging. All PWR licensees have implemented interim compensatory measures and have made their sump strainers substantially larger. Some licensees also removed fibrous and/or particulate insulation, while others changed their sump pH buffers or installed debris interceptors. In addition, while smaller LOCAs are more probable than larger LOCAs, the probability of all LOCAs is low, and smaller LOCAs proceed more slowly allowing time for additional mitigation and operator intervention that may not be credited in design basis analyses. For these reasons, and additional reasons documented in GL 2004-02 that are still applicable today, the staff has determined that continued operation is justified, consistent with the time frame of the recommended options in this paper, to allow additional time to fully address the issue.

However, given the clogging potential of fibrous insulation, the NRC staff does not think it is prudent to allow these materials to remain within containment, or that continued operation is justified indefinitely, without an analysis of adequate sump performance that demonstrates compliance with the regulations and provides reasonable assurance that long-term cooling will be maintained. Therefore, assuming Commission approval of the staff recommended options, the staff intends to use additional regulatory measures, as appropriate, for those licensees that do not provide information that demonstrates adequate sump performance within the implementation schedule set forth in this paper. Licensees have been cooperative on addressing these issues, so any measures beyond information requests under 10 CFR 50.54(f) should not be needed.

Lastly, given that relatively small amounts of the right combination of debris types can lead to significant headloss, none of the options below provide an "analysis-only" option to resolving GSI-191. Each would rely either on past strainer test results, if determined to be bounding, or on new strainer testing.

Options To Bring GSI-191 To Closure

Enclosure 2 describes the options presented below in more detail, including pros and cons, as well as some options the staff considered but determined were not viable.

- *Option 1: Maintain the current holistic integrated resolution process for remaining plants including evaluating new refinement methods.*

This option continues to make use of the current holistic integrated review process until closure is reached for all plants. It includes a three-member team of senior staff with the requisite technical expertise (not part of the GSI-191 review team), which evaluates the staff review packages for each PWR to determine whether, given the conservatisms, nonconservatisms, and/or uncertainties in the various review areas, the licensee has demonstrated adequate strainer performance and therefore compliance with the regulations. Additionally, this option includes evaluation of new proposed approaches by licensees and industry to justify some GSI-191 analysis assumptions that the NRC staff has not previously accepted. For example, industry currently plans to perform new testing to justify reduced zones of influence (ZOIs) and credit for debris settling.

The staff identified the following three suboptions to Option 1:

(a) Set a near-term schedule for licensees to address the full spectrum of LOCAs.
(b) Set a near-term schedule for smaller LOCAs, and set a longer term schedule for the less likely larger LOCAs.
(c) Do not set a schedule for licensees to address remaining issues.

The staff proposed Suboption 1.a during the Commission meeting held on April 15, 2010. Suboption 1.b is, in part, a risk-informed alternative that would require near-term resolution of the more likely, and thus more risk-significant, accident scenarios while allowing modifications needed to resolve the less risk-significant scenarios to be completed within a longer timeframe commensurate with their lower risk-significance. Schedules could be established using 10 CFR 50.54(f) letters (and additional regulatory measures if appropriate) and would, for the near-term schedule, call for an affected licensee to complete testing and evaluation using staff-accepted methods and to complete all needed modifications within two refueling outages. Suboption 1.c is the continuation of the current process, which has no resolution schedule.

- *Option 2: Develop additional risk-informed implementing guidance for GSI-191.*

Risk-informed implementing guidance would be developed based on a risk-informed approach described in SECY-04-0150, “Alternate Approaches for Resolving the Pressurized Water Reactor Sump Blockage Issue (GSI-191), Including Realistic and Risk-Informed Considerations,” dated August 16, 2004, which resulted in Section 6 of the SE for NEI 04-07, or based on the proposed 10 CFR 50.46a rule, if the rule is promulgated. This guidance would provide analysis relaxations for larger LOCAs (14-inches in diameter and above at most PWRs), based on their low likelihood. Thus, there are two suboptions for developing risk-informed implementing guidance for GSI-191 as follows:

(a) Expand limited risk-informed guidance in Section 6 of the SE for NEI 04-07.
(b) Generate new guidance assuming that the proposed 10 CFR 50.46a is approved.

- *Option 3: Allow application of the GDC 4 exclusion of jet effects to debris generation for GSI-191.*

This option would require a Commission policy decision as discussed in the policy section of this paper and would allow licensees to exclude from sump performance analyses the effects of debris that could be generated from LOCAs in piping that is LBB qualified. A policy decision to expand GDC 4 to allow credit for GSI-191 would require an initial Commission decision that expanding GDC 4 does not result in an unacceptable reduction in defense-in-depth, is appropriate given that there is no perceived safety benefit, and that it would not result in unintended consequences (e.g., unacceptable precedent for the use of LBB). This would be followed by a staff evaluation of how primary water stress corrosion cracking (PWSCC) should be addressed for LBB piping under an expanded GDC 4, and subsequently, a final Commission policy decision. Implementation of this final policy decision would require exemptions to GDC 4, rulemaking to revise GDC 4, or rulemaking to issue a new Statement of Considerations (SOC) for the rule. A detailed discussion of GDC 4 and industry views is provided in Enclosure 3.

Option 1 would continue the current review process until closure is reached at all plants. However, until resolution is achieved, the reliability of sump recirculation at affected plants remains in question. Option 1.a would likely require significant insulation removal at plants with large fiber loads, but would bring the issue to final closure and completion of all needed modifications in the shortest time (e.g. two operating cycles). The staff has determined that two operating cycles is the minimum reasonable amount of time necessary to plan, design, and install insulation modifications using “as low as is reasonably achievable” (ALARA) methods. The near-term schedule would also be consistent with the time needed to issue an SE for in-vessel effects and for licensees to evaluate in-vessel effects using the guidance. Additionally, based on current industry timelines for proposed new testing, setting a near-term schedule would allow sufficient time for the staff to evaluate the results of currently planned industry ZOI and settling tests before the schedule is exceeded. Thus, if the staff were to accept these new industry methods, licensees could decide not to make modifications potentially called for by the current staff-accepted approaches.

Option 1.b would address any outstanding issues associated with more likely and risk-significant smaller LOCAs (14 inches and below) in the short term, but would allow more time to address issues associated with the low-likelihood larger break LOCAs (above 14 inches). In this way, the more risk-significant issues would be closed quickly, and licensees would have the flexibility to reduce the impact (cost and dose) of addressing the less risk-significant LOCAs through planning, testing, or refined analyses. However, a deadline would still be defined for final resolution. The longer schedule for larger breaks (if directed by the Commission) could be set to allow the time needed to implement Option 2, followed by sufficient additional time to perform ALARA planning of any needed modifications. It is expected that the longer schedule would delay additional modifications, if needed, for larger LOCAs by approximately 2 years beyond the near-term schedule (e.g., about one additional operating cycle).

Option 1.c (wherein no schedule is specified) has the potential for long-term vulnerability, particularly for plants with the highest fiber loads. Without a schedule, the industry is likely to continue to pursue further refinements to evaluation methodologies to avoid making additional modifications. Experience with the sump issue suggests that the reviews of such refinements are often complex, span several years, and may not result in staff approval of the refinements.

Option 2 would provide more flexibility to licensees for addressing larger LOCAs than is currently permitted under Section 6 of the SE for NEI 04-07, which no licensee has credited. While Section 6 was intended to be consistent with the proposed 10 CFR 50.46a rule at the time NEI 04-07 was issued, there are important differences between using Section 6 (e.g., exemptions required) and the proposed 10 CFR 50.46a that are discussed in Enclosure 4. The staff expects that the non-design basis analyses possible if proposed 10 CFR 50.46a is promulgated would result in more analysis flexibility than an expanded Section 6, but the degree of difference has not yet been established. Despite these differences, given the current improved state of knowledge as compared to 2004, the NRC staff believes that some additional relaxations may be possible to the existing Section 6 approach. However, the extent of the benefit under either approach may be limited unless proposed industry testing of ZOI and settling yield more favorable results than the staff expects. For plants with high fiber loads, it is likely that significant testing, system modifications or insulation removal may still be necessary. Option 2 would, however, provide more flexibility for achieving resolution and could potentially be used to reduce the cost and dose impacts of issue closeout. One drawback of this approach is the potential need for separate small-break and large-break demonstration tests of adequate strainer performance. Preparation of risk-informed guidance could be completed about 12 months after a Commission decision to expand Section 6, or 12 months after a Commission decision on the proposed 10 CFR 50.46a rule. The proposed 10 CFR 50.46a rule is due to the Commission in December 2010. The implementation of Option 2 would be expected to delay any needed modifications to address larger LOCAs by about 2 years as compared to sub-option 1.a.

The proposed 10 CFR 50.46a reflects rigorous development of the basis for an alternate ECCS rule. If the 10 CFR 50.46a rule is not issued, the staff would need to consider the implications of the Commission's decision on the existing Section 6 approach. It might be appropriate to eliminate the approach entirely, depending on the Commission's views on the subject.

Option 3 would exclude consideration of debris generated from LOCAs in LBB-qualified piping. Since all PWR licensees have LBB qualifications in place for the largest reactor coolant system piping, this option would provide significant relaxation for licensees in their analyses of debris generation for GSI-191. This option might eliminate the need for additional modifications at some or all remaining high-fiber plants. However, breaks in piping outside the scope of LBB credit would likely generate enough debris to still require a demonstration test of adequate strainer performance. Additionally, other potential breaks could occur where LBB credit is not applicable, including failed pump seals; leaking valve packing; blow-out of valve bonnets, flange connections, bellows, manways and rupture discs; and actuation of valves that discharge directly into the containment atmosphere (e.g., safety/relief valves and squib valves). Therefore, additional modifications at some high-fiber plants might still be required.

Feasibility of Alternate Regulatory Treatment for In-Vessel Effects

As noted above, the in-vessel effects issue remains unresolved for nearly all plants. As such, the staff considered separating in-vessel effects from GSI-191 into a new generic issue. While this approach is possible, the staff believes that this action would not significantly speed up closure of GSI-191, because sump strainer performance and in-vessel effects are closely linked. Given the apparent susceptibility of reactor fuel to debris-induced clogging, separate regulatory treatment for in-vessel effects is not recommended because it may simply delay additional needed modifications (e.g., replacement of fibrous insulation with less problematic materials such as reflective metal). Pursuit of a solution to the sump clogging issue without concurrently addressing in-vessel effects could result in a strainer that would not clog, and a core that would, clearly an unacceptable result. It is possible that a “high-fiber” plant could succeed in showing adequate strainer performance using one of the options above, yet still have to replace insulation to address in-vessel effects. Lastly, while the staff has not yet issued an SE for in-vessel effects, an SE has been drafted and is under management review. The staff expects to issue the draft in September 2010. Success in near-term issuance of a final SE would lead to near-term resolution of in-vessel effects, and would allow that resolution to not interfere with the expected timelines for the options discussed above. Enclosure 1 presents a more detailed description of the in-vessel issue, as well as the basis for the staff’s recent request for at least one fuel vendor to perform a “cross-test” of another vendor’s fuel.

Deterministic versus Risk-Informed Treatment of Remaining Items

The NRC’s current ECCS requirements, at 10 CFR 50.46, “Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors,” allow licensees to select among two types of deterministic evaluation models that can be used to demonstrate compliance with the ECCS systems design requirements, one of which is a bounding analysis and the other a best-estimate analysis. Currently, accepted evaluation methods for GSI-191 are bounding analyses that are used to generate the parameters and inputs for plant-specific demonstration testing of strainer performance. A best-estimate analysis of the probability of successful sump performance, which would be necessary to support a best-estimate compliance evaluation permitted by 10 CFR 50.46, is not presently possible because of the complex phenomena that are not understood well enough for industry to develop, or staff to evaluate, an integrated model of debris generation, transport, and deposition on the sump screens. Similarly, a more complete understanding of the complex phenomena would be needed to develop more detailed models to support risk-informed analysis via a probabilistic risk assessment. Enclosure 5 provides a detailed discussion regarding risk-informed and deterministic treatment.

In addition, the staff recognized several years ago that some relaxations could be made to 10 CFR 50.46 based on the low probability of large LOCAs. As a result, the staff worked with industry and stakeholders to develop a proposed risk-informed alternate ECCS rule, 10 CFR 50.46a, which would provide some analyses relaxations but still require mitigation of large LOCAs as discussed in Option 2.

Dose Considerations

Licensees are required to perform those activities that ensure public health and safety in a manner that maintains radiation exposure ALARA. There is no established standard for how much collective dose is, or is not, warranted in any specific operational situation. Historically, the NRC has typically not accepted requests by reactor licensees to delete or defer safety-related tests based solely on the regulatory requirement to maintain occupational dose ALARA. Enclosure 6 provides a detailed discussion of radiation protection as practiced internationally and in the United States.

Based on a limited staff survey of 9 licensees known to have performed significant insulation replacements associated with steam generator replacement and activities associated with GSI-191, the average total reported dose for insulation replacements was 19 person-rem. In contrast, the highest estimated dose of future insulation replacements provided by the industry in presentations at the April 15, 2010, Commission meeting was 600 person-rem with an average dose of 200 person-rem. Although the modification scope for the plants surveyed may be less than could be required for some plants to fully address sump performance issues, these latter values seem excessively conservative compared to the actual industry experience noted above and further described in Enclosure 6. Regardless of the accuracy of the industry estimates, the staff recognizes that the need to resolve GSI-191 could result in significant collective occupational dose at some plants as a consequence of insulation replacements, and that the amount of such dose could vary depending on the option for path forward chosen by the Commission. However, the staff does not believe that the dose likely to be received in support of resolving GSI-191 is excessive given the safety and compliance issues stated in this paper.

Backfit Considerations and the Committee To Review Generic Requirements

When the staff issued GL 2004-02, it determined, under 10 CFR 50.54(f), that the information requested was necessary in order for the NRC to determine compliance with 10 CFR 50.46(b)(5), because adequate sump performance is necessary following a LOCA to maintain long-term core cooling. In addition, consistent with the staff's practice that actions that the NRC may impose as a result of a GL 2004-02 be evaluated for backfitting at the time of issuance of the GL, the staff determined that any actions that the NRC may impose as a result of GL 2004-02 would fall under the compliance exception of the backfit rule, for largely the same reason that the 10 CFR 50.54(f) information request was necessary to determine compliance with 10 CFR 50.46(b)(5).

The staff believes that any additional information requests, which would be issued in the future to provide the basis for NRC resolution and closure of GSI-191, are necessary to determine compliance with 10 CFR 50.46, and that the compliance backfit exception in 10 CFR 50.109(a)(4)(i) continues to apply for any future modifications a licensee determines are necessary to resolve GSI-191.

Several times during the staff's consideration of GSI-191, the staff consulted with the Committee to Review Generic Requirements (CRGR) regarding GSI-191 as discussed in Enclosure 1. At each consultation, the CRGR concurred with the staff's determination that information requests were justified to determine compliance with 50.46, and that the compliance backfit exception applied to any actions that may be imposed on a licensee to resolve GSI-191. In preparing this paper, the staff again consulted the CRGR (ADAMS Accession Nos. ML101720380 and ML102090113) to determine whether the staff's proposed path forward, including the staff's planned issuance of 10 CFR 50.54(f) letters to some remaining licensees, would be in accordance with 10 CFR 50.54(f) and the compliance exception to the backfit rule. The staff additionally consulted with CRGR on whether the adequate protection exception to the backfit rule also applied. In the most recent instance, the CRGR stated the following:

> *The CRGR supports the conclusion by the staff that, as documented in GL 2004-02, the information requested of licensees regarding the operability of their ECCS system post-accident falls under the provisions of 10 CFR 50.109(a)(4)(i), the compliance exception to the backfit requirements... In addition, the CRGR concluded that the compliance exception to the backfit rule was sufficient for the staff to proceed without a cost-benefit analysis, and therefore did not approve the use of the adequate protection exception, 10 CFR 50.109(a)(4)(ii).*

POLICY DISCUSSION:

Expanding the scope of GDC 4 to allow LBB credit for resolving ECCS performance issues is a policy issue. The staff believes that excluding consideration of debris generated from LOCAs in LBB-qualified piping is inconsistent with the agency's longstanding implementation of basic defense-in-depth principles. Specifically, an important consideration in defense-in-depth is that the initiating event for accidents included in a plant's licensing analyses should not result in core damage in the absence of additional independent failures. Strainer testing however has repeatedly demonstrated potential for LOCA-generated debris to cause sump failure, and, given a LOCA, no additional independent protection system failures are needed for debris-induced sump failure. A second consideration in defense-in-depth is the independence of features that prevent severe accidents from those features that mitigate accident consequences. Implementation of the principle of independence of prevention and mitigation features means minimizing the likelihood that failure of a prevention feature will also fail a mitigation feature. However, sump failure causes a loss of the ECCS core cooling (a prevention feature) and also results in the loss of the containment spray system (a mitigation feature). Therefore, the staff believes that excluding consideration of debris from LOCAs in LBB-qualified piping is inconsistent with the agency's longstanding implementation of basic defense-in-depth principles in that an initiating event in the licensing basis could proceed to a severe accident state without any additional protection system failures, and could, at the same time, degrade accident mitigation systems.

A policy decision to expand GDC 4 to allow credit for GSI-191 would require an initial Commission decision that expanding GDC 4 does not result in an unacceptable reduction in defense-in-depth, is appropriate given that there is no perceived safety benefit, and that it would not result in unintended consequences (e.g., unacceptable precedent for the use of LBB). The staff would then complete an evaluation of how PWSCC should be addressed for LBB piping susceptible to PWSCC under an expanded GDC 4 such that there is sufficient technical basis for the expansion. Lastly, the staff would present its findings to the Commission for a final policy decision. Implementation of this final policy decision would require exemptions to GDC 4, rulemaking to revise GDC 4, or rulemaking to issue a new SOC for the rule.

An expansion in scope of GDC 4 for GSI-191 is inconsistent with the intent of the exclusion in the rule, because the staff is unaware of any safety benefit in allowing the dynamic effects exclusion in GDC 4 to be applied to GSI-191 to reduce assumed debris generation. On the contrary, large amounts of problematic insulation would potentially remain in containment. The dynamic effects exclusion in GDC 4, as described in the SOC, provides an exception to the way in which the dynamic effects of postulated pipe breaks are considered for the purpose of removing plant hardware that negatively affects plant performance; specifically, removal of pipe whip restraints and jet impingement barriers to permit accessibility for in-service inspections of safety-related structures, systems and components. The staff has also not performed the evaluation that is described in the SOC as needed prior to allowing credit that would affect ECCS system performance. Furthermore, the application of expanded LBB may be inconsistent with the implementation of proposed 10 CFR 50.46a, and specifically with Commission direction in its SRM dated July 1, 2004, related to SECY-04-0037, "Issues Related to Proposed Rulemaking to Risk-Inform Requirements Related to Large Break Loss-Of-Coolant Accident (LOCA) Break Size and Plans for Rulemaking on LOCA with Coincident Loss-Of-Offsite Power," dated March 3, 2004. In that SRM, the Commission stated the following:

> *Licensees should be required, by regulation, to retain the capability to successfully mitigate the full spectrum of LOCAs for break sizes between the new maximum break size and the double-ended guillotine break of the largest pipe in the reactor coolant system.*

The staff views the use of 10 CFR 50.46a as a more technically complete and defensible approach to assist in the resolution of the GSI-191 sump performance issue than would be implementation of LBB for this purpose. The 10 CFR 50.46a rulemaking developments represent the agency's current approach to risk-informing ECCS performance issues.

<u>NEW REACTORS</u>:

In its review of new reactor designs, the staff continues to incorporate experience gained from the evaluations of operating reactors. New reactor designs have advanced strainers with large screen areas and typically generate fewer debris types and less problematic debris during a postulated accident as compared to operating plants. In addition, new reactor testing is being reviewed with the guidance developed for operating reactors and has resulted in design changes to address issues identified during testing. New reactor designs use staff-accepted ZOIs and do not credit debris settlement during testing. In-vessel effects are being considered for all new reactor designs and, when applicable, data from design-specific fuel assembly headloss tests will be evaluated to ensure that long-term core cooling will be maintained.

<u>RECOMMENDATION</u>:

The staff recommends a combination of Options 1 and 2 with an implementation schedule that is both risk-informed and takes into account the amount of planning and effort required for licensee implementation. The staff recommends the implementation schedule of Option 1.b because it brings to near-term closure the issues associated with more risk-significant smaller

LOCAs. It also maintains defense-in-depth for long-term operation while still providing licensees sufficient time to efficiently schedule and implement solutions. This option utilizes an integrated resolution approach that balances known conservatisms against potential nonconservatisms in licensees' analyses to avoid a requirement for overly conservative demonstration of adequate sump performance and sets an overall schedule for resolution. The staff also recommends Option 2 in combination with Option 1.b. because it would likely reduce the scope of modifications needed to address GSI-191 for some plants and would be consistent with agency policy regarding risk-informed regulation.

The staff does not recommend Option 3. The staff evaluated the recent request by industry to credit LBB for sump evaluations and agrees that all PWR sumps are less likely to clog because of larger strainers and additional modifications made to date. However, the emergence of issues regarding sump performance has prevented the staff from concluding that the modifications made to date have been sufficient for the plants that have not yet demonstrated adequate strainer performance. The staff believes that applying LBB credit for sump evaluations would still result in an unacceptable reduction in defense-in-depth because it would allow large amounts of problematic insulation to remain in PWR containments. Given this option, a LOCA in LBB-qualified piping could proceed to a severe accident state without any additional protection system failures, and could at the same time degrade accident mitigation systems. If the Commission selects this option, it would also not reduce the closure time for GSI-191 because the staff would need to complete an evaluation of how PWSCC should be addressed for LBB piping susceptible to PWSCC under an expanded GDC 4 such that there is sufficient technical basis for the expansion. In addition, implementation of this option would require exemptions to GDC 4, rulemaking to revise GDC 4, or rulemaking to issue a new SOC for the rule.

For new reactors, the staff plans to continue its reviews using current staff guidance and design-specific testing; and will resolve the GSI-191 issue as part of issuing new Design Certifications and Combined Licenses.

<u>RESOURCES</u>:

Estimated resource needs of 6 full-time equivalents (FTE) are included in the fiscal year (FY) 2010 budget as Option 1 is the current process, 7 FTE and $115K are included in the FY 2011 President's Budget; FY 2012 resources have been included in the Commission-approved budget; FY 2013 resources and beyond will be addressed through the PBPM process. A detailed resource discussion for each option is presented in Enclosure 2.

Fiscal Year	**Option 1**	**Option 2**	**Option 1.b. and 2**	**Option 3**
FY 2010	6.0 FTE for reviews			
FY 2011	6.0 FTE for reviews 115K ZOI test review for 1.a, 1.b, and 1.c	1.0 FTE for guidance	7.0 FTE, 115K	1.0 FTE for evaluation 1FTE for GDC 4 SOC
FY 2012	3.6 FTE for reviews 60K ZOI test review for 1.a, 1.b, and 1.c	2.0 FTE for reviews	5.6 FTE, 60K	0.5 FTE to complete evaluation 0.5 FTE for GDC 4 SOC
FY 2013	None for 1.a or 1.b TBD for 1.c	0.5 FTE for reviews 0.5 FTE margin reviews	1.0 FTE	0.5 FTE for GDC 4 SOC 3.5 FTE for reviews 1 FTE margin reviews
FY 2014	None for 1.a or 1.b TBD for 1.c	0.5 FTE margin reviews	0.5 FTE	1.5 FTE for reviews 1 FTE margin reviews

COORDINATION:

The Office of the General Counsel has reviewed this paper and has no legal objection. The Office of the Chief Financial Officer has reviewed this paper for resource implications and concurred.

/RA by Martin J. Virgilio for/

R. W. Borchardt
Executive Director
for Operations

Enclosures:
1. Background Discussion and Technical Issues
2. Evaluation of GSI-191 Closure Options
3. Discussion of Leak-Before-Break
4. Discussion of Proposed 10 CFR 50.46a
5. Risk-Informed Versus Deterministic Treatment
6. Radiation Protection and Dose Evaluation

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.

<u>Why Past Industry Attempts To Reduce ZOIs Have Been Unsuccessful</u>

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.

EVALUATION OF GENERIC SAFETY ISSUE-191 CLOSURE OPTIONS

Option 1: Maintain the current holistic integrated resolution process for remaining plants, including evaluating new refinement methods.

Description: The U.S. Nuclear Regulatory Commission (NRC) staff would continue its holistic integrated review process for remaining licensee analyses related to Generic Safety Issue (GSI) -191, "Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance," and associated strainer demonstration tests. This includes evaluating new proposed approaches to justify some licensees' GSI-191 analysis assumptions that the NRC staff has not previously accepted (e.g., reduced zones of influence (ZOIs) and settling credit).

Pros:

- As long as a schedule for resolution is established, this option supports bringing the issue to closure relatively quickly, so it is the most supportive of nuclear safety.
- This option best maintains defense-in-depth.
- This option balances known conservatisms against potential nonconservatisms and uncertainties in licensees' analyses to reduce the likelihood of the NRC requiring overly conservative demonstration of adequate sump performance.
- The NRC staff continues to review new industry-proposed approaches to justify assumptions which differ from those recommended by the staff in an effort to reduce the likelihood for needed modifications to show adequate sump performance.
- This option utilizes current resources already budgeted.
- This option represents a demonstrably successful process which has led to resolution of sump performance issues (except in-vessel effects) for 44 of 69 pressurized-water reactors (PWRs).

Cons:

- Licensees with large amounts of fibrous insulation have not been able to bring the issue to closure under the existing regulatory framework.
- Continuance of this approach would likely lead to replacement of substantial amounts of problematic insulation at approximately 15 or so affected units, resulting in dose and monetary cost.
- Absent a new regulatory framework, new approaches that would remove the need for additional modifications for some remaining licensees may never materialize. These new approaches may simply delay needed modifications.

- The staff has had technical concerns with past industry test methods and is skeptical that new approaches or testing will be successful in supporting demonstrations of adequate strainer performance.

- Allowing time for staff evaluation of each new industry-proposed method results in additional delays in issue closure (likely to be several years).

<u>Suboption to require a date or dates by which licensees must evaluate GSI-191 using staff-accepted methods</u>

The staff identified the following three suboptions to Option 1:

(a) Set a near-term schedule for licensees to address the full spectrum of LOCAs.
(b) Set a near-term schedule for smaller LOCAs, and set a longer term schedule for the less likely larger LOCAs.
(c) Do not set a schedule for licensees to address remaining issues.

In early 2010, the NRC staff determined that it would reject the industry-sponsored reduced ZOI testing. Having concluded that industry attempts to refine test and evaluation methods to reduce perceived conservatisms would not be successful in the near term, the staff planned to issue letters under Title 10 of the *Code of Federal Regulations* (10 CFR) 50.54(f) to some licensees (Option 1.a) requesting that they provide information on how they would show adequate strainer performance by a date certain using methods consistent with the 2004 safety evaluation (SE) for Nuclear Energy Institute (NEI 04-07), "Pressurized Water Reactor Sump Performance Methodology" (Agencywide Documents Access and Management System (ADAMS) Accession No. ML043280007). Additional regulatory measures would be taken as warranted. As such, the staff intended to set a schedule for further evaluations of new methods. The Commission halted these plans in Staff Requirements Memorandum (SRM) M100415, dated May 17, 2010 (ADAMS Accession No. ML101370261), pending further direction. Therefore, the staff believes it is appropriate to also present this suboption of setting a schedule for further discussions under Option 1.

Within this suboption, the Commission could choose a separate schedule for smaller versus larger breaks (Option 1.b). The rationale for this distinction is based on the differing risk for sump performance posed by smaller breaks versus larger breaks and the possibility of revised regulatory treatment of the latter.

Smaller break loss-of-coolant accidents (LOCAs) are orders of magnitude more likely than larger break LOCAs. In addition, for some plants, smaller break LOCAs are the limiting pipe breaks for sump performance. Testing experience has shown that a relatively small amount of debris of the right type can lead to a clogged strainer with high headloss. The thickness of a filtering debris bed that could lead to such losses is on the order of 1/8 inch or less. Therefore, given the very small probability of the largest pipe breaks, smaller breaks are potentially of more significant concern, depending on the plant. Further, smaller breaks would not be affected by the potential for leak-before-break (LBB) credit (Option 3) or risk-informed treatment (Option 2). Hence, the staff believes it would be reasonable to expect a near-term resolution for smaller breaks, with additional time allotted for larger breaks if the Commission also chooses Option 2.

If the Commission determines that a schedule should be implemented for Option 1, the staff could set schedules using 10 CFR 50.54(f) letters, and additional regulatory measures if warranted, which would call for an affected licensee to complete testing and evaluation using staff-accepted methods and to complete all needed modifications within a near-term schedule. The near-term schedule (for either smaller breaks or all breaks, as the Commission directs) would allow sufficient time (e.g., two operating cycles) for as low as reasonably achievable (ALARA) planning for any needed modifications. The longer term schedule for larger breaks (if directed by the Commission) would be set to allow sufficient time to develop implementing guidance either for the existing risk-informed framework or for the final rule under 10 CFR 50.46a rulemaking, "Risk-Informed Redefinition of Large Break LOCA ECCS Requirements" (Option 2), assuming it is approved by the Commission. It is expected that the longer schedule would extend approximately 2 years beyond the near-term schedule.

The following pros and cons apply to the suboptions (Option 1.a or Option 1.b) of requiring a date or dates by which licensees must evaluate GSI-191 using staff-accepted methods:

<u>Pros</u>:

- This option includes all of the pros listed above.
- This option would likely result in nearer term closure of GSI-191.
- This option would likely result in replacement of large amounts of problematic fibrous insulation with less problematic materials (e.g., reflective metallic insulation (RMI)) for strainer performance,
- This option would free up staff resources sooner.
- This option would ensure equitable treatment for those licensees that made modifications early in response to GSI-191.
- Given staff skepticism about the likelihood of proposed industry refinements to sump methodology being successful, this option avoids unnecessary delay in issue resolution.

<u>Cons</u>:

- This option would likely result in near-term capital expenditure for additional modifications at some remaining high-fiber plants in the form of insulation replacements, banding of installed insulation, or new mitigation systems.
- Modifications would result in additional occupational exposures.
- If insulation replacements are selected, replacement insulation may not have the same performance characteristics. (RMI is not as effective an insulator for a given thickness as fibrous insulation. Nevertheless, numerous PWRs have operated successfully for many years using effectively all RMI insulation in containment).

Some of the cons could potentially be mitigated by setting different schedules for smaller and larger breaks, since configurations subject to larger breaks might not need to be subjected to insulation replacement in the near term. The downside to this approach is that the issue resolution framework would be more complex. Affected plants would need to make two submittals, one for smaller breaks and one for larger breaks. The NRC staff would need to review those submittals and carry the affected plants in a "partially resolved" status for some time. As a result, two strainer tests that demonstrate adequate strainer performance may also be needed.

Regardless of whether a schedule is implemented for this option or not, the staff believes that the issue of in-vessel effects needs to be resolved before GSI-191 is considered resolved. The timeline for resolution of in-vessel effects depends on the issuance of an NRC SE on the subject. The SE has been drafted and is under management review, and the staff expects to issue the draft in September 2010. Issuance of the final SE may await the conclusion of the cross-testing discussed in this paper. It is possible that some licensees, having resolved emergency core cooling system (ECCS) strainer performance issues, may find that further modifications are needed to address in-vessel effects. Certain aspects of enhancing strainer performance (e.g., making strainers larger) may have a deleterious effect on intrusion of debris into the core, since more strainer surface area will allow more debris to pass through the strainer and potentially into the core. This is one principal reason the staff believes that in-vessel effects should be resolved in conjunction with the resolution of strainer performance issues.

The issue resolution process for GSI-191 focuses on the licensee's evaluation and testing methods. Once the methods are acceptable, the staff will be confident that the licensee is on a path to successful issue resolution. The staff SE on the subject will provide the method for in-vessel effects evaluations, while strainer testing and evaluation methods are being resolved on a plant-specific basis. The sequence of strainer performance issue resolution and issuance of the in-vessel effects SE will depend on several factors and will be plant specific. In any event, each plant must address both before the staff will close GSI-191 and Generic Letter (GL) 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004, for that plant.

Resources to support evaluation of remaining PWR licensee submittals and issuance of 10 CFR 50.54(f) letters to approximately 15 plants are 5 full-time equivalents (FTEs) in fiscal year (FY) 2011 and 3 FTEs in FY 2012. As the staff has already drafted 10 CFR 50.54(f) letters, no additional resources are necessary for this activity. Therefore, the resources in FY 2011 and FY 2012 are identical for options 1.a, 1.b. and 1.c. The resources in FY 2011 are included in the FY 2011 President's Budget; FY 2012 resources will be addressed through the planning, budgeting, and performance management (PBPM) process and are included in the FY 2012 Performance Budget to the Office of Management and Budget (OMB). FY 2013 and beyond resources necessary for Option 1.c (no schedule for issue resolution) would depend on as yet to be proposed industry refinements and would be requested through the PBPM process.

Resource Estimate for Evaluating Industry-Proposed New Testing To Justify Settling Credit

The NRC staff is currently interacting with affected licensees and test vendors regarding the development of a revised strainer test protocol that credits debris settlement. Although the industry vendors that perform these tests have recently suggested test protocol revisions that would likely address the staff's concerns regarding debris preparation and addition for future tests, limited progress has been made with respect to the most significant issues associated with prototypical flows and the narrowness of the test flume. It remains uncertain whether the revised methodology being developed by the test vendors could ultimately result in a successful testing approach. The staff expects that the effort necessary to evaluate revised testing methodology, as well as new tests and test results, assuming they are performed, would be as follows:

Fiscal Year	NRR Budget
FY 2011	0.5 FTE
FY 2012	0.3 FTE

These resources are included in the FY 2011 President's Budget; FY 2012 resources will be addressed through the PBPM process and are included in the FY 2012 Performance Budget to OMB.

<u>Resource Estimate for Evaluating Industry-Proposed New Testing To Justify Reduced ZOIs</u>

The Pressurized-Water Reactor Owners Group (PWROG) has proposed a project to perform testing combined with computational fluid dynamics modeling to determine realistic jet impingement damage thresholds for insulation systems. The staff has proposed that a contract be awarded to an expert in this area to validate the PWROG work. The industry has not yet funded this testing because the PWROG membership has not approved this project to date. If the PWROG membership elects to fund and perform new ZOI testing, the PWROG plan is to complete the work in order to issue the associated topical report in October 2011. The staff would write an SE on the topical report, a task that typically consumes a year or more. This work could help to define the debris generation that could occur during a LOCA. As stated elsewhere in this paper, the staff is not confident, even if it were to accept the methods for testing and evaluation, that the results will support significantly reduced ZOIs. However, the effort should enhance the industry and staff understands of the debris generation issue. The staff expects that the effort necessary to evaluate revised testing methodology, as well as new tests and test results, assuming they are performed, would be as follows:

Fiscal Year	NRR Budget
FY 2011	0.3 FTE, $115 K
FY 2012	0.3 FTE, $60 K

These resources are included in the FY 2011 President's Budget; FY 2012 resources will be addressed through the PBPM process and are included in the FY 2012 Performance Budget to OMB.

<u>Resource Estimate for Evaluating In-Vessel Cross-Tests of Westinghouse and AREVA Fuels Assuming Both Vendors Agree To Perform Tests</u>

The staff has requested that Westinghouse and AREVA perform cross-tests because of the large, unexpected differences in test results between the two fuel vendors at low particulate-to-fiber ratios. Such tests would involve placing one vendor's mockup fuel assembly in the other vendor's test facility. Discussions with the vendors on performing these tests are ongoing. The staff expects the effort necessary to evaluate cross-tests would be small and is provided below:

Fiscal Year	NRR Budget
FY 2011	0.2 FTE

These resources are included in the FY 2011 President's Budget.

<u>Total Resources for Option 1</u>

Description	FY 2011		FY 2012	
	CS&T	FTE	CS&T	FTE
Evaluation of remaining PWR submittals and additional regulatory measures as needed		5.0		3.0
Evaluation of industry ZOI testing	$115 K	0.3	$60 K	0.3
Evaluation of industry settling testing		0.5		0.3
Evaluation of cross-tests of AREVA fuel		0.2		0.0
Total Resources	$115 K	6.0	$60 K	3.6

If the industry proposes any other refinements, they would need to be timely in response to the timeframe of the suboption selected by the Commission, if applicable. The staff would request resources for any such refinement reviews through office reallocation or as an item on the shortfall list during future PBPM processes.

<u>Option 2: Develop additional risk-informed implementing guidance for GSI-191.</u>

<u>Description</u>: If the Commission issues the proposed 10 CFR 50.46a rule, it would potentially provide flexibility to licensees whose limiting challenge to strainer performance is posed by larger LOCAs. The transition break size (TBS) associated with the proposed rule would result in a much smaller ZOI for which design-basis analysis conservatisms would be required. While the ZOI for breaks larger than the TBS up to the double-ended guillotine break of the largest pipe in the reactor coolant system would still need to be addressed, mitigation could credit use of nonsafety equipment and less stringent model assumptions, inputs, and justification. The staff believes that the following two options exist for developing risk-informed implementing guidance for GSI-191:

a) Expand existing guidance in Section 6 of the 2004 SE for NEI 04-07.
b) Generate new guidance assuming the proposed 10 CFR 50.46a rule is approved.

Enclosure 4 presents a more detailed description of the 10 CFR 50.46a rulemaking, including a review of the differences between new implementing guidance and the current risk-informed approach in Section 6 of the 2004 staff SE.

Pros:

- The technical basis for this option is already established.
- This option allows more flexibility for addressing larger LOCAs based on reclassification as beyond-design-basis accidents, if the proposed 10 CFR 50.46a rule is promulgated.
- This option is consistent with policy on risk-informed regulation.
- Mitigation of larger breaks is still maintained.
- This option involves no exemptions or additional policy questions.
- The initial burden on licensees could be offset by future risk-informed changes enabled by the proposed 10 CFR 50.46a rule.
- This option relaxes conservatisms for the less likely breaks, but still retains the rigorous design-basis evaluations for the higher probability smaller breaks.
- This option would likely result in a reduction in the scope of modifications needed for some plants to address GSI-191.

Cons:

- Modifications could still be required at some plants to support resolution of GSI-191 based on design-basis breaks below the TBS, beyond-design-basis breaks above the TBS, or both.
- Additional analysis would be needed to adopt 10 CFR 50.46a for GSI-191, although this is not expected to be difficult for most licensees.
- Analyses for breaks above the TBS would still be required, using different assumptions than those for smaller breaks, leading to additional complexities in each plant’s licensing basis, including the potential for separate demonstration tests of adequate strainer performance.
- Sufficient basis for “realistic” ZOI, debris transport, and debris characteristics for beyond-design-basis accidents still needs to be worked out. Relaxations in these areas may be limited unless proposed industry testing of ZOI and settling yields favorable results.

- Implementation guidance would need to be developed and licensee submittals would need to be evaluated, which would extend GSI-191 issue closure by approximately 2 years.

Section 6 of the 2004 staff SE for GSI-191 is an existing limited risk-informed approach to sump evaluations. This approach was the result of a risk-informed effort described in SECY-04-0150, “Alternate Approaches for Resolving the Pressurized-Water Reactor Sump Blockage Issue (GSI-191), Including Realistic and Risk-Informed Considerations,” dated August 16, 2004, and based on an early proposed version of 10 CFR 50.46a. The staff understands from discussions with the industry that licensees have not taken advantage of this alternate approach because it requires exemptions and it does not provide relaxations in the areas of debris generation and debris transport analyses because of the lack of realistic models. Given the current improved state of knowledge, as compared to 2004, the NRC staff believes that some relaxations may be possible in these and other areas in the form of new implementing guidance for GSI-191, either in conjunction with the proposed 10 CFR 50.46a rule or as an enhancement to the existing SE Section 6 approach. However, the staff does not believe that the currently approved assumptions in these areas are grossly overconservative, so the benefit of adding realism to the larger break analyses may be limited unless new industry ZOI and settling testing yields favorable results. The benefits would also depend on limiting factors for a given plant.

Assuming the Commission approves the 10 CFR 50.46a rule, Section 6 of the SE for NEI 04-07 would likely be superseded by issuance of the new rule and would no longer exist in its current form. The guidance in Section 6 would be used as a starting point for new implementing guidance for licensees that adopt 10 CFR 50.46a for GSI-191. Working with industry, the staff would expand on the guidance in Section 6, to the extent feasible, to include alternate guidance for additional technical areas for beyond-design-basis breaks. The staff would modify any guidance in Section 6 that differs from the final version of 10 CFR 50.46a to align with the rule. For example, the transition break defined in Section 6 would be reduced from a double-sided break to a single-sided break to be consistent with the break area included in the proposed 10 CFR 50.46a rule. Additionally, guidance for beyond-design-basis breaks would focus on best-estimate realistic methods, rather than on methods that are conservative with respect to the worst possible conditions, including uncertainties. This guidance could be updated at a later date if industry testing currently planned for completion by the end of 2011 shows that major changes in realistic assumptions for ZOI and settling are justified. The staff estimates that new implementation guidance could be issued within 12 months after final issuance of the new rule with 1 FTE of staff effort in FY 2011. Additionally, the resources required to evaluate new submittals for breaks above the TBS, using assumptions different from those for smaller breaks and potentially new strainer tests, would require 2 FTEs in FY 2012, 1 FTE in FY 2013, and 0.5 FTE in FY 2014, including review of additional submittals from some licensees that have already shown adequate strainer performance but wish to reclaim margin. These resources are included in the FY 2011 President’s Budget in addition to resources needed for Option 1; FY 2012 resources and beyond will be addressed through the PBPM process and FY 2012 resources are included in the FY 2012 Performance Budget to OMB. Additionally, resources included under this option regarding proposed 10 CFR 50.46a implementation guidance and evaluation activities are specific to GSI-191 and do not include rulemaking activities associated with the proposed rule.

Should the 10 CFR 50.46a rule not be issued, the staff would need to consider the implications of the Commission's decision on the existing Section 6 approach. It might be appropriate to expand the Section 6 guidance or to eliminate the approach entirely, depending on the Commission's views on the subject. Total resources for Option 2 are shown below:

Fiscal Year	NRR Budget
FY 2011	1 FTE
FY 2012	2 FTEs
FY 2013	1 FTE
FY 2014	0.5 FTE

<u>Total Resources for Option 1.b and Option 2 combined</u>

	FY 2011		FY 2012		FY 2013		FY 2014	
	CS&T	FTE	CS&T	FTE	CS&T	FTE	CS&T	FTE
Option 1.b	$115K	6.0	$60K	3.6	0	0	0	0
Option 2	0	1.0	0	2.0	0	1.0	0	0.5
Total Resources	$115K	7.0	$60K	5.6	0	1.0	0	0.5

The resource for Option 1.b and Option 2 are included in the FY 2011 President's Budget; FY 2012 resources and beyond will be addressed through the PBPM process and FY 2012 resources are included in the FY 2012 Performance Budget to OMB.

<u>Option 3: Allow application of GDC 4 exclusion of jet effects to debris generation for GSI-191</u>.

<u>Description</u>: The staff had previously rejected, a number of years ago, the industry's request to use LBB to resolve GSI-191 concerns because the staff had seen expanding the scope of LBB application as beyond the Commission's intent with regard to General Design Criterion (GDC) 4, "Environmental and Dynamic Effects Design Bases," and representing a reduction in defense-in-depth. The staff believes that such expansion would require a policy decision by the Commission and would require revision to the rule or a new Statement of Considerations to be issued for the rule. Additionally, the expansion in scope might set a precedent for the use of GDC 4 that could affect other areas of accident analyses. However, SRM M100415 requested that the staff evaluate potential approaches and options to bring GSI-191 to closure, including a discussion of the use of GDC 4. Enclosure 3 presents a detailed discussion of staff views on GDC 4, as well as a review of past and recent correspondence from NEI and other stakeholders.

The staff considers it likely that application of GDC 4 to GSI-191 would have a significant impact on licensee analyses regarding debris generation because the debris source term would likely be zero for all LBB-qualified piping. The staff notes that not all piping inside PWR containments would meet LBB qualification requirements; therefore, the need for additional modifications at some high-fiber plants could not be ruled out. Additionally, other potential debris generation sources exist for which LBB credit is not applicable, including failed pump seals; leaking valve packing; blow out of valve bonnets, flange connections, bellows, manways, and rupture discs; and actuation of valves that discharge directly into containment atmosphere (e.g., safety/relief and squib valves). But for many PWR plants, the NRC staff believes that GDC 4 credit would significantly reduce the amount of potential modifications at remaining plants with large quantities of fibrous insulation. The staff also believes that GDC 4 credit could result in substantial operational margins for those plants that have already shown acceptable strainer performance with respect to debris-induced sump clogging using analysis methods acceptable to the staff. In general, the staff evaluated the pros and cons of crediting LBB to close out GSI-191 as follows:

Pros:

- This option would likely eliminate the need for some additional modifications, though some reduced-scope modifications cannot be ruled out, particularly at plants for which smaller breaks are limiting breaks from non-LBB piping or breaks from components such as manways.
- This option might eliminate the need for additional strainer testing, since reduced calculated debris generation might compensate for staff questions on some licensee test and evaluation methods.
- Application of GDC 4 credit to licensees already considered complete for GSI-191 could permit recovery of calculated operational margins.
- Large margins could allow the use of simplified bounding assumptions, which would simplify staff technical reviews for GSI-191 and reduce needed GSI-191 staff resources.

Cons:

- This option would leave large amounts of problematic materials inside containment in some plants that could result in ECCS system failure if a larger break occurred in LBB-qualified piping despite the low probability of the event. The staff believes that applying GDC 4 credit to GSI-191 would represent a decrease in defense-in-depth.
- Applying LBB credit to GSI-191 is not consistent with the Statement of Considerations for GDC 4 (Volume 52, page 41288, of the *Federal Register*) which stated, "The proposed rule allows the removal of plant hardware which it is believed negatively affects plant performance, while not affecting emergency core cooling systems, containments, and environmental qualification of mechanical and electrical equipment."
- The staff believes a new Statement of Considerations or revision to GDC 4 is needed if LBB is applied to GSI-191 to redefine the scope of LBB and to minimize the chance of unintended consequences (licensees taking LBB credit for other applications, such as other areas of ECCS analysis, containment accident pressure analysis, and environmental qualifications).

- Consistent with concerns expressed by the Commission in the Statement of Considerations for the rulemaking, expansion of GDC 4 would effectively reduce regulatory requirements with no perceived safety benefit.

- Applying GDC 4 to GSI-191 could create regulatory inconsistency with the intent of the proposed risk-informed ECCS regulation, 10 CFR 50.46a. With GDC 4, no evaluation of sump performance would be required for larger breaks, while under the proposed 10 CFR 50.46a mitigation would still be required, albeit with more realistic assumptions and evaluations.

- Most PWR owners are still in the process of addressing PWSCC in Alloy 82/182 dissimilar welds in their large LBB piping (nominal diameter of 20 inches and greater) through mitigation, enhanced inspection, or both. The staff believes that this is adequate from a safety perspective to address the current application of LBB with respect to GDC 4. However, the staff does not believe it is appropriate to expand the use of LBB beyond current application of GDC 4 since licensees are still in the process of addressing PWSCC issues. If GDC 4 is expanded to apply to resolving GSI-191 issues, the staff believes that the application of GDC 4 will require additional analyses and potentially additional requirements and guidance to address PWSCC in LBB piping. This may result in additional licensee costs and outage schedule impacts if the staff determines that mitigation of the nickel-Alloy 82/182 welds in LBB piping is needed to support GSI-191.

- Would delay resolution of GSI-191 for all LOCA sizes because a policy decision to expand GDC 4 to allow credit for GSI-191 would require an initial Commission decision that expanding GDC 4 does not result in an unacceptable reduction in defense-in-depth, is appropriate given that there is no perceived safety benefit, and that it would not result in unintended consequences (e.g., unacceptable precedent for the use of LBB). The staff would then complete an evaluation of how PWSCC should be addressed for LBB piping susceptible to PWSCC under an expanded GDC 4 such that there is sufficient technical basis for the expansion. Lastly, the staff would present its findings to the Commission for a final policy decision. Implementation of this final policy decision would require exemptions to GDC 4, rulemaking to revise GDC 4, or rulemaking to issue a new Statement of Considerations for the rule.

- Identification of large operational margins may result in licensees installing more problematic materials in containments in the future, a result with which the staff has a concern given the large uncertainties involved with this issue.

For reasons discussed above, the staff believes that expansion of GDC 4 for GSI-191, if this option is chosen by the Commission, involves a deliberate process that permits further staff evaluation while also considering stakeholder input and an evaluation of its effects on dissimilar metal butt welds in LBB piping. The staff estimates that resource needs for this option would be 2.0 FTEs in FY 2011, 1 FTE in FY 2012, and 0.5 FTE in FY 2013. These resources would be budgeted through a reallocation of resources from Option 1 because plant-specific holistic reviews for many remaining plants would likely be delayed until after Option 3 was implemented. Additionally, plant-specific holistic reviews of remaining plants following expansion of GDC 4 credit are expected to require 3.5 FTEs in FY 2013 and 1.5 FTEs in FY 2014, as compared to 5 FTEs in FY 2011 and 3 FTEs in FY 2012 under Option 1, in large part because of expected GSI-191 evaluation simplifications resulting from GDC 4 credit. However, under Option 3, 1 additional FTE is expected in both FY 2013 and FY 2014 to support likely submittal of new evaluations by licensees whose methods are already acceptable but who want to recover operating margin. The total resources needed for Option 3 are currently bounded in FY 2011 and FY 2012 by the combined resources of Option 1.b and Option 2, and therefore the FY 20122 resources are included in the FY 2011 President's Budget; FY 2012 resources and beyond would be addressed through the PBPM process and FY 2012 resources are included in the FY 2012 Performance Budget to OMB. The total funding for Option 3 is shown in the table below:

Fiscal Year	NRR Budget
FY 2011	2.0 FTEs
FY 2012	1.0 FTE
FY 2013	5.0 FTE
FY 2014	2.5 FTEs

<u>Options Considered but Determined Not Viable</u>

- The NRC staff considered whether it might attempt to determine that remaining plants have demonstrated adequate protection without having demonstrated compliance, and therefore, forcing compliance would not be worth the occupational dose and capital costs some remaining plants might incur from additional modifications. The staff considered the question of whether the regulatory requirement that criteria are not exceeded for the "most severe" break may be more than what is needed for adequate protection.

  The staff determined that there is insufficient technical information at this time to support an NRC decision that current operating license holders need not comply with current ECCS regulations. Assuming that such a decision can be made in the future, the NRC could implement such a decision through issuance of exemptions, or by rulemaking, or both (to amend the rules to address future plant designs). One implication of such a decision would be that some LOCAs that could lead directly to core damage do not represent undue risk to public health and safety apparently based solely on their low probability of occurrence. In evaluating the viability of this option, the staff considered the proposed 10 CFR 50.46a rulemaking, which is a risk-informed effort that is intended to determine what relaxations in ECCS analyses are appropriate. In its July 1, 2004, SRM directing the staff to develop 10 CFR 50.46a, the Commission determined that LOCAs with a frequency of occurrence of 1 in 100,000 reactor years is an appropriate guideline for selecting the maximum design-basis LOCA, since it is complemented by the requirement that appropriate mitigation capabilities must be retained for beyond-design-basis LOCAs. As such, the staff believes the Commission would need to modify its previous position for this option to be viable.

- The staff considered an option of attempting to generate an integrated probabilistic model for sump phenomena that would risk inform remaining aspects of sump modeling for which large uncertainties still exist. The staff could update and enhance early generic and simplistic integrated probabilistic models of sump performance in an effort to provide insights into plant-specific sump failure probabilities accounting for plant-specific improvements completed to date. Licensees might use such a generic integrated model as a template to generate plant-specific integrated models that might support realistic determinations of sump performance under the requirements of 10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors." However, absent additional research and test data evaluation to develop realistic models that would further delay the generic effort by an estimated additional five years and involve significant resources and costs, large uncertainties in some vital modeling aspects, if accounted for as required, would likely show that some remaining plants still need to make modifications. Additionally, results of additional research might also show, after uncertainties were reduced, that some modifications were still required. Initial estimates are that the staff could generate a generic integrated model absent additional research at a cost of four FTEs over five to seven years and multimillions of dollars. Based on the discussion above, the staff does not consider this option viable because it would not likely provide any tangible benefit in the foreseeable future related to issue resolution.

- The staff also considered an option under which the staff might conclude that a separate conservatism associated with a nonsafety system with mitigation capability related to GSI-191 (e.g., strainer backflush capability) could result in a holistic conclusion of adequate strainer performance where a strainer is successfully tested by a licensee but uncertainties exist, either in the test assumptions or methods, that would normally cause the staff to determine that adequate strainer performance had not been demonstrated. This would be distinct from the risk-informed Option 2 in that the representative conservatism associated with the nonsafety system could be credited for mitigation of any break, whereas the risk-informed Option 2 would only allow nonsafety system credit for the less likely larger breaks that are intended to be beyond-design-basis breaks, assuming the proposed 10 CFR 50.46a is approved. It is also distinct from the existing holistic staff review process for GSI-191 in that the holistic process requires an overall conclusion of adequate sump performance, given the uncertainties, without reference to a nonsafety system.

  The staff considered this option nonviable for design-basis accidents because crediting the conservatism of a nonsafety system to account for an ECCS analysis that does not meet the regulations because of inadequate consideration of uncertainties would still be relying on a nonsafety system for design-basis accidents. Additionally, extensive analysis and stakeholder interactions on the proposed 10 CFR 50.46a rule were specifically focused on defining a TBS that serves to identify the largest break size that would need to be treated as a design-basis LOCA. While this approach would be allowed for breaks larger than the TBS that would be beyond-design-basis LOCAs, extending the relaxations afforded by the proposed 10 CFR 50.46a (such as credit for nonsafety systems) to LOCAs equal to or smaller than the TBS would be inconsistent with the conclusions of the lengthy 10 CFR 50.46a rulemaking process.

  Such an approach may be feasible for design-basis LOCAs for a limited application on a plant-specific basis, however. But, given the findings of the technical basis development for 10 CFR 50.46a, such a request would likely need to be supported by a risk-informed licensing action in accordance with Regulatory Guide 1.174, “An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis.” The feasibility of performing an adequate risk analysis would depend upon the extent of credit being requested. It is also likely than an exemption would be required because of the following definition of safety-related structures, systems, and components provided in 10 CFR 50.2, “Definitions”:

> *Those structures, systems, and components that are relied upon to remain functional during and following design basis events to assure: (1) the integrity of the reactor coolant pressure boundary, (2) The capability to shut down the reactor and maintain it in a safe shutdown condition; or (3) The capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures comparable to the applicable guidelines set forth in 50.34(a)(1) or 100.11 of this chapter, as applicable.*

However, the option of using a risk-informed exemption request has always been available to licensees and does not need any Commission action.

DISCUSSION OF LEAK-BEFORE-BREAK

1.0 Background

By Staff Requirements Memorandum (SRM) M100415 dated May 17, 2010 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML101370261), the U.S. Nuclear Regulatory Commission (NRC) requested that the staff report on a number of aspects of the sump performance issue as it is preparing to close out Generic Safety Issue (GSI) -191, "Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance." Among those aspects is the potential application of General Design Criterion (GDC) 4, "Environmental and Dynamic Effects Design Bases," in Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," to sump performance evaluations. In the SRM, the Commission also asked the staff discuss letters from the Nuclear Energy Institute (NEI) dated April 7, 2010 and April 27, 2010 (ADAMS Accession Nos. ML101050354 and ML102280039), and from the Union of Concerned Scientists (UCS) dated April 14, 2010 (ADAMS Accession No. ML101680215). The UCS submitted an additional letter dated April 26, 2010 (ADAMS Accession No. ML101680254), which this enclosure also discusses.

The concept of leak-before-break (LBB) as implemented in GDC 4 is based on the experimental testing and fracture mechanics analyses of pipes that have demonstrated that certain pipe material has sufficient fracture toughness (ductility) to resist a through-wall crack from becoming unstable and uncontrollable so as to prevent pipe rupture. The other aspect of LBB technology depends on the capability of the reactor coolant leakage detection system to detect the leak early enough to allow the operator to take corrective actions to avoid pipe rupture. The combination of fracture mechanics analysis and the reactor coolant leakage detection system demonstrates that the probability of a rupture for LBB-qualified piping is extremely low. After the NRC approves a licensee's LBB evaluation, the licensee may remove pipe whip restraints and jet impingement barriers.

GDC 4 and the associated Statement of Considerations provide the technical basis of the LBB application. Section 3.6.3 of NUREG-0800, "Standard Review Plan (SRP) for the Review of Safety Analysis Reports (SAR) for Nuclear Power Plants: LWR Edition" (hereafter referred to as the SRP), presents the regulatory guidance for LBB. Volume 3 of NUREG/CR-1061 describes the LBB analytical analyses.

The industry first proposed to credit LBB in the resolution of GSI-191 in a 1997 letter from the Pressurized-Water Reactor Owners Group (PWROG) and later in related letters in 2002 and 2003 from NEI. By letter dated March 4, 2004, the NRC provided four reasons for not accepting the industry's proposal (ADAMS Accession No. ML040410433). By letters dated April 7, 2010, and April 27, 2010, the industry requested that the NRC staff reconsider LBB application to the resolution of GSI-191. By letter dated April 14, 2010, UCS suggested that the NRC not give LBB credit in the resolution of GSI-191. However, in a subsequent letter dated April 26, 2010, UCS suggested that LBB credit may be appropriate in some instances.

The purpose of this enclosure is to discuss the acceptability of the LBB technology as an approach to addressing the debris generation aspect of sump strainer evaluations and thus to support closure of GSI-191 as suggested in the NEI letters. This enclosure also discusses the UCS suggestions.

2.0 Industry's Leak-before-Break Proposal

2.1 Nuclear Energy Institute Letter Dated April 7, 2010

NEI stated in its April 7, 2010, letter that it believes that GDC 4 allows local dynamic effects associated with pipe ruptures in LBB-qualified piping to be excluded from the design bases. NEI stated that debris generation is a dynamic effect and as such should be excluded from the design basis for addressing emergency core cooling system (ECCS) performance concerns under GSI-191. This argument was similar to the arguments NEI had made in its earlier correspondence on the subject. In its March 4, 2004, letter to NEI, the staff raised concerns regarding the acceptability of applying GDC 4 to resolve the GSI-191 issues. In its April 7, 2010, letter, NEI grouped the staff's concerns into four reasons for not accepting the industry's proposal. These reasons, and the results of the NRC staff's reconsideration of each reason in light of recent NEI requests and developments since 2004, are provided below.

Reason No. 1: Application to loss-of-coolant accident (LOCA)-generated debris is not the intent of current GDC 4 rule.

In its April 2010 report, "Reconsideration of Application of GDC-4 Exclusion of Local Dynamic Effects to Local Debris Generation" (ADAMS Accession No. ML101050356), NEI cited the NRC LBB Knowledge Management Document, page 3 (Memorandum, Evans to Grobe, "Leak-Before-Break Knowledge Management Document," dated May 29, 2007, ADAMS Accession No. ML092430585) as demonstrating that application of GDC 4 extends beyond removal of pipe whip restraints and jet impingement barriers. Section C2, page 3, of the LBB Knowledge Management Document states the following:

> When LBB is approved for a particular piping system, applicants are to exclude from the design basis only local dynamic effects associated with postulated pipe ruptures in that system in the nuclear power unit. The local dynamic effects are:
>
> - Missiles,
> - Pipe whipping,
> - Pipe break reaction forces, and
> - Discharging fluids.
>
> For each local dynamic effect listed above, the applicant, upon NRC approval, is permitted to perform a well-defined plant activity as a result of excluding this dynamic effect from the design basis. The permitted plant activities are, in the order of local dynamic effects:
>
> - Remove jet impingement barriers or shields,
> - Remove pipe whip restraints,
> - Redesign pipe connected components their supports and their internals, and other related changes, and

- Disregard jet impingement forces on adjacent components, decompression waves within the intact portion of the piping system, and dynamic or nonstatic pressurization in cavities, subcompartments, and compartments.

NEI also stated in its letter that local dynamic effects were excluded from LBB piping for the design of the sump strainers at Oconee Units 1 and 2.

The NRC staff does not dispute the point made by NEI that the generation of debris from jet impingement and generation of acoustic/rarefaction waves could logically be considered a dynamic effect associated with the postulated pipe rupture. However, the NRC staff did not consider the application of LBB in the LOCA-generated debris evaluations at the time the changes to GDC 4 were enacted. The NRC staff's intent when GDC 4 was modified can best be summarized by the following excerpt from the Statement of Considerations (Volume 52, page 41288, of the *Federal Register*) accompanying the final rule modifying GDC 4:

> *The Commission recognizes the need to address whether and to what extent leak-before-break analysis techniques may be used to modify present requirements relating to other features of facility design. However, this is a longer term evaluation. For the present, the proposed rule allows the removal of plant hardware which it is believed negatively affects plant performance, while not affecting emergency core cooling systems, containments, and environmental qualification of mechanical and electrical equipment*.

The staff's position is that the dynamic effects of the LBB piping can be excluded from the design basis if they are local phenomena. However, debris generation can be a global phenomenon. When a pipe ruptures, the steam/water jet exiting from the break will impinge on fibrous insulation on adjacent pipes, and some insulation will become liberated from the pipe as small pieces of transportable debris. This debris will likely fall into the sump pool or be washed into the sump pool via containment spray. Some of this debris will then transport to ECCS strainers via recirculation currents in the sump pool where clogging of the sumps can occur. Clogging of the sump strainer would lead to common-mode failure of the ECCS system and core damage. The intent of LBB technology as approved by the NRC was to eliminate pipe whip restraints and impingement barriers in nuclear power plants so that licensees have access to perform nondestructive examinations of pipes, thus increasing plant safety. It was not the intent of the GDC 4 rule to credit LBB for the containment design, ECCS performance, or post-LOCA analyses.

By letters dated August 18, 2005, and September 15, 2005, Duke Energy Corporation submitted a request to modify Oconee Nuclear Station, Units 1 and 2, Technical Specifications (TS) 3.5.2.6 and 3.5.3.6. The requested changes to the TS sections were related to the replacement of the reactor building emergency sump suction inlet trash racks and screens with new sump strainers. By letter dated November 1, 2005, the NRC approved the TS changes. Oconee demonstrated that the design function of the sump strainers would not be compromised by jet impingement or pipe whip from any pipes in the vicinity of the emergency sump. For the reactor coolant system (RCS) cold leg, the staff based its conclusion on crediting LBB technology. The staff permitted the exclusion of the dynamic effects from LBB piping for the design of the sump strainers at Oconee, Units 1 and 2, because the Oconee situation was related to local dynamic effects on the specific equipment (the sump strainers) and is confined to the certain location of the containment. Oconee did not ask for or receive LBB credit for application to debris generation calculations, so the NRC's approval of Oconee's application does not support NEI's view that LBB should be credited for debris generation evaluations.

In the staff's opinion, one significant difference between the Commission's intent when the GDC 4 rule change was enacted to permit the use of LBB to address the dynamic effects of pipe rupture versus the current proposal made by the industry is documented in the Statement of Considerations accompanying the final rule modifying GDC 4, as quoted above. The GDC 4 rule change allowed for the removal of, for example, pipe whip restraints, which in some cases severely restricted access to the associated piping impacting inservice inspection. Hence, the Commission found enabling the use of LBB to the extent provided for in the GDC 4 rulemakings offered a potential safety benefit associated with the ability to better inspect the LBB piping and thereby reduce the likelihood of pipe rupture through the early identification of degradation mechanisms. The industry's request to expand the LBB scope does not enhance any safety benefit which has not already been realized by the original scope of LBB. The staff is unaware of any safety benefit that would be realized by expanding LBB scope to be used as the basis for not making modifications to address the sump performance issue (e.g., further enlarging strainers or replacing fibrous insulation with reflective metal insulation). On the contrary, application of LBB credit to debris generation evaluations appears to only result in a decrease in defense-in-depth.

Reason No. 2: Application of LBB to LOCA-generated debris is a detriment to defense-in-depth principles and would require Commission approval.

The staff believes excluding consideration of debris generated from LOCAs in LBB qualified piping is inconsistent with the agency's longstanding implementation of basic defense-in-depth principles. Specifically, an important consideration in defense-in-depth is that the initiating event for accidents included in a plant's licensing analyses should not result in core damage in the absence of additional independent failures. Strainer testing however has repeatedly demonstrated a significant potential for causing sump failure from LOCA-generated debris and, given a LOCA, no additional independent protection system failures are needed for debris-induced sump failure.

A second consideration in defense-in-depth is the independence of features that prevent severe accidents from those features that mitigate accident consequences. Implementation of the principle of independence of prevention and mitigation features means minimizing the likelihood that failure of a prevention feature will also fail a mitigation feature. Sump failure however causes a loss of the ECCS core cooling (a prevention feature) and also results in the loss of the containment spray system (a mitigation feature).

Therefore, the staff believes that excluding consideration of debris from LOCAs in LBB-qualified piping is inconsistent with the agency's longstanding implementation of basic defense-in-depth principles in that an initiating event in the licensing basis could proceed to a severe accident state without any additional protection system failures and could, at the same time, degrade accident mitigation systems.

In its April 7, 2010, letter, NEI stated that since 2004 every pressurized-water reactor (PWR) has installed significantly larger strainers, enhanced operational and emergency procedures, and performed conservative design analyses to demonstrate the capability of the ECCS to withstand postulated LOCAs with no credit taken for the GDC 4 exclusion. NEI suggested that application of the GDC 4 exclusion today no longer presents the potential for a significant reduction in defense-in-depth that was possible in 2003.

The staff acknowledges that PWR licensees have achieved significant progress toward resolving GSI-191 issues by installing larger strainers at all plants, reducing debris sources at some plants, and enhancing plant procedures. However, the staff does not agree that all plants have performed conservative analyses to demonstrate the capability of ECCS sump performance. Further, the significance of various aspects of the sump performance issue, such as chemical effects, is greater than was known at the time the staff denied the earlier request for LBB credit. If the staff agreed with the NEI statement that all plants have demonstrated conservative analyses, GSI-191 would be closed for all plants. Additionally, the staff does not agree with NEI that, if the GDC 4 exclusion were permitted today, defense-in-depth would not be reduced significantly. The staff believes that if the dynamic effects of LBB-qualified piping are excluded from the design basis, defense-in-depth will be reduced, notwithstanding the reduced debris sources and increased strainer size, because strainer tests have repeatedly shown that relatively small amounts of the right combination of debris types can lead to significant strainer headloss that can challenge the ECCS system. If a large break were to occur in LBB-qualified piping, it would likely generate large quantities of debris.

In addition, if LBB is permitted to be used for the global ECCS performance issue of GSI-191, it may set a precedent to apply LBB to other aspects of the plant design, such as containment design, ECCS design, or post-LOCA analyses.

Reason No. 3: Primary water stress-corrosion cracking (PWSCC) is a concern.

In its April 2010 report, NEI stated that PWSCC is a generic issue potentially affecting all past and future approval of piping systems. NEI also acknowledged that PWSCC potentially affects the piping systems for which the GDC 4 exclusion can be applied. In September 2005, the Electric Power Research Institute's Materials Reliability Program issued MRP-139, "Materials Reliability Program: Primary System Piping Butt Weld Inspection and Evaluation Guideline," which all PWR plants agreed to implement under the industry's Materials Initiative. MRP-139 provides industry guidance for the inspections of dissimilar metal butt welds in PWR primary systems and discusses volumetric inspection techniques that the industry has qualified for the detection of PWSCC. PWR licensees are addressing the potential for PWSCC to occur in Alloy 82/182 butt welds through a rigorous program of inspecting and mitigating susceptible welds.

The staff notes that piping containing Alloy 82/182 dissimilar metal welds (which exist in some LBB-qualified piping) is susceptible to PWSCC. The staff acknowledges that, since the issuance of the staff's March 4, 2004 letter, the industry and the NRC have made significant progress in resolving PWSCC in PWRs. Some PWR owners have mitigated susceptibility of PWSCC at Alloy 82/182 dissimilar butt welds by installing weld overlays or applying the mechanical stress improvement process in some LBB-qualified piping (e.g., pressurizer surge lines).

Since 2004, the staff has incorporated American Society of Mechanical Engineers (ASME) Code Case N-722, with conditions, by reference into 10 CFR 50.55a(g)(6)(ii)(E), which requires augmented visual inspection of Alloy 600 components, including Alloy 82/182 dissimilar metal welds. On June 8, 2010, the staff issued Regulatory Information Summary (RIS) 2010-07, "Regulatory Requirements for Application of Weld Overlays and Other Mitigation Techniques in Piping Systems Approved for Leak-Before-Break," which clarifies the regulatory requirements for updating the original LBB evaluation if weld overlay and other mitigation techniques have been applied to LBB piping. The staff is incorporating ASME Code Case N-770 in the proposed rule for 10 CFR 50.55a, "Codes and Standards." ASME Code Case N-770 requires PWR licensees to perform augmented inspection of Alloy 82/182 dissimilar metal welds. The staff believes that this is adequate, from a safety perspective, to address the current scope of LBB with respect to GDC 4.

However, since most PWR owners are still in the process of addressing PWSCC in Alloy 82/182 dissimilar welds in their large LBB piping (nominal diameter of 20 inches and greater) through mitigation, enhanced inspection, or both, the staff does not believe it is appropriate to expand the use of LBB beyond current application of GDC 4. If GDC 4 is expanded to be applied to resolving GSI-191 issues, the staff believes that the application of GDC 4 will require additional analyses, and potentially additional requirements and guidance, to address PWSCC in LBB piping. This may result in additional licensee costs and outage schedule impacts if the staff determines that mitigation of the nickel-Alloy 82/182 welds in LBB piping is needed to support GSI-191.

Reason No. 4: ECCS functional performance is directly affected by the containment sump performance.

In its April 7, 2010, letter, NEI stated that Section C3 of the NRC's LBB Knowledge Management Document covers the GDC 4 rule's limitations on applying LBB to containment design, ECCS, and equipment qualification. NEI stated that Section C3 of the NRC's LBB Knowledge Management Document allows local dynamic effects to be excluded from the design basis of ECCS hardware.

NEI's letter also stated that pipe rupture dynamic effects that can be excluded from an LBB applicant's plant design bases for containment, ECCS, and equipment qualification are further explained in a letter dated March 4, 2004, from Suzanne C. Black of the NRC to Anthony Pietrangelo of NEI, subject: "Nuclear Energy Institute's Proposals for Determining Limiting Pipe Break Size Used in Assessing Debris Generation Following a Design Basis LOCA." In the referenced letter, the NRC stated the following:

> Local dynamic effects uniquely associated with pipe rupture may be deleted from the design basis of containment systems, structures and boundaries, from the design basis of ECCS hardware (such as pumps, valves accumulators, and instrumentation). And from the design bases of safety related electrical and mechanical equipment when leak-before-break is accepted….

The staff notes that Section C3 of the NRC's LBB Knowledge Management Document states that "It is apparent that there is no inconsistency if one considers that although pipe whip effects and jet impingement effects are local, their effects on containment pressure boundaries and primary structures are global…." The staff's position is that LBB may be applied to local dynamic effects but it cannot be applied to global dynamic effects. The containment systems, ECCS, and equipment qualifications are related to global effects; therefore, LBB cannot be applied to the containment systems, ECCS, and equipment qualifications. The staff considers debris generation in the GSI-191 issue to be a global effect.

Furthermore, Section C4 of the NRC's LBB Knowledge Management Document gives examples of LBB applications that have been approved and rejected and includes the following example in which an industry request to apply LBB to debris generation related to sump performance was rejected:

> Example 2: Containment sump performance
>
> This issue concerns a proposed containment sump strainer performance requirement. Specifically, the industry requested that local debris generation due to the dynamic effects associated with the postulated double-ended guillotine breaks of LBB-approved piping be excluded from facility design and licensing basis. The LBB application was rejected in 2004 because: (1) although an acceptable LBB evaluation provides assurance with regard to the low probability of piping failure, it is consistent with the Commission's defense-in-depth principle, given the consequences of sump failure, to expect containment sump operability under such circumstances, (2) the NRC staff concluded that any decision to extend LBB for the purpose of addressing LOCA-generated debris and sump performance to the detriment of defense-in-depth principles is, at a minimum, a policy decision which would require Commission approval, and (3) PWSCC was a concern.
>
> Although one may not consider the sumps serving the ECCS and the containment spray system part of the ECCS, the ECCS functional performance is directly affected by the containment sump performance. Therefore, requiring the dynamic effects such as debris generation associated with the postulated DEGBs [double-ended guillotine breaks] of LBB-approved piping be included in the sump performance evaluation is a logical extrapolation of the Section C3 limitations on LBB.

Lastly, the staff has noted the following Commission's statement in the SRM dated July 1, 2004, related to SECY-04-0037, "Issues Related to Proposed Rulemaking to Risk-Inform Requirements Related to Large Break Loss-Of-Coolant Accident (LOCA) Break Size and Plans for Rulemaking on LOCA with Coincident Loss-Of-Offsite Power," dated March 3, 2004, regarding the risk informing of ECCS acceptance criteria:

> Licensees should be required, by regulation, to retain the capability to successfully mitigate the full spectrum of LOCAs for break sizes between the new maximum break size and the double-ended guillotine break of the largest pipe in the reactor coolant system

The staff believes that allowing LBB to be used as the basis for not removing sources of debris, such as fibrous insulation, which may prevent the ECCS system from performing its design function in the event of a double-ended guillotine break of the largest pipe in the RCS, would seem contrary to the ability of licensees to "successfully mitigate the full spectrum of LOCAs," even under severe accident mitigation strategies.

The staff concludes that the above four reasons and considerations are still appropriate today; therefore, they do not support a basis to expand the application of LBB to GSI-191.

2.2 Nuclear Energy Institute Letter Dated April 27, 2010

In a letter dated April 27, 2010, NEI provided information to support the two resolution paths discussed during the Commission briefing on April 15, 2010: (1) use of the GDC 4 rule, and (2) potential use of proposed changes to 10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors" (e.g., redefine large break LOCA). NEI cited the NRC LBB Knowledge Management Document, which permits the local dynamic effects from the break of a LBB piping to be excluded from the debris generation calculation.

NEI stated the following:

> To deny application of GDC-4 to debris generation introduces a major inconsistency in the rule application…Several PWRs currently exclude, under GDC-4, local dynamic effects from breaks that would directly impinge upon the strainers. Local dynamic effects that directly impact strainer operation are allowed to be excluded, yet exclusion of local dynamic effects that indirectly impact the strainers through debris generation is not allowed….

As discussed under Reason No. 1 in Section 2.1 of this enclosure, the NRC staff approved the use of LBB in the strainer modification at Oconee because Oconee was able to demonstrate that the jet impingement from the LBB pipe on the strainer was a local dynamic effect. In general, the NRC staff considers use of LBB on the plant-specific strainers acceptable within the GDC 4 rule; however, use of LBB on debris generation is beyond the scope of the GDC 4 rule, as discussed above. The jet exiting from certain pipe break locations that directly impinges on the sump strainer may be considered a local dynamic effect. However, debris generation is a global dynamic effect because the fibrous insulation could travel in the containment over a much wider area. The debris could eventually clog the sump strainer and degrade the ECCS performance. The staff's position is that LBB would not be permitted to be applied to this global dynamic effect.

NEI further stated the following:

> because PWR designs and supporting analyses do not exclude debris generation for GDC-4 qualified piping systems, the designs conservatively account for debris generation for the full spectrum of breaks, up to and including a full double-ended guillotine break of the largest pipe in the reactor coolant system.

The NRC staff agrees that PWRs are conservatively designed to consider the full spectrum of pipe breaks, and this design approach should continue to be maintained.

According to NEI, in applying GDC 4 to debris generation, the existing debris generation calculations and strainer designs, based on the full break spectrum, would continue to stand. To demonstrate compliance with 10 CFR 50.46 and resolve GSI-191, a licensee would need to show that existing calculations conservatively bound debris generation for breaks in piping systems that do not meet GDC 4 qualification requirements. This could be accomplished using debris generation modeling readily acceptable to the NRC staff, and any deltas between calculated and tested debris volumes would be retained as margin. If GDC 4 credit is applied for GSI-191, the NRC staff agrees with NEI that, for those pipes that have not been approved for LBB, pipe breaks will have to be postulated and debris generation resulting from the breaks should be evaluated.

NEI stated the following:

> Although local debris generation would be excluded for LBB-qualified piping, debris generation would continue to be assessed for non-LBB qualified piping systems. For most PWRs, the largest non-LBB piping is approximately 12" in diameter. The debris generation assessment for non-LBB piping is greatly simplified in instances where it can be shown that current calculations and strainer test results for postulated breaks in large bore piping (LBB qualified piping) bound the debris generation for postulated breaks in non-LBB piping. Such bounding assessments would enable PWRs to demonstrate that current designs meet 10 CFR 50.46 acceptance criteria, using NRC approved methods, with minimal additional effort….

To the extent these statements can be shown to be true for a given plant, the staff agrees that expansion of LBB to debris generation evaluations would simplify that licensee's resolution of sump performance issues. The staff does not know the extent of this benefit for a given plant. The staff notes that one plant's limiting break for GSI-191 is a 3-inch break. The staff also notes that another plant's analysis of a 6-inch postulated break was predicted to generate twice the amount of fibrous insulation necessary to generate a filtering bed on the largest strainer (over 8,000 square feet) currently installed in the PWR fleet. Additionally, other potential debris generation sources exist for which LBB credit is not applicable, including failed pump seals; leaking valve packing; blow out of valve bonnets, flange connections, bellows, manways, and rupture discs; and actuation of valves that discharge directly into containment atmosphere (e.g., safety/relief and squib valves). Therefore, additional modifications at some high-fiber plants might still be required. Thus, removal of large breaks from consideration might or might not substantially assist a particular plant. In any event, as stated above, the staff believes that the global dynamic effects (such as debris generation) from breaks of the LBB-approved piping and non-LBB qualified piping must be considered for the debris generation calculation.

3.0 Union of Concerned Scientists Letters

3.1 Union of Concerned Scientists Letter Dated April 14, 2010

In its April 14, 2010, letter, UCS recommended that the NRC reject the industry's proposal of using GDC 4 to close out GSI-191 because leakage from LBB pipes may not trigger the timely response (i.e., safe shutdown and depressurization) necessary to preclude the pipe break. UCS cited instances for which leakage occurred but the plant did not shut down until hours after the required shutdown period in the plant's TS. Examples cited included control rod drive mechanism (CRDM) nozzle leakage at Davis Besse in 2002; pressurizer heater sleeve leakage at Calvert Cliffs, Unit 1, in 2008; CRDM leakage at Oconee, Unit 1, in 2005; pressurizer heater sleeve leakage at Palo Verde, Unit 3, in 2004; and CRDM housing leakage at Palisades in 2002.

The staff notes that the leakage cases discussed in the USC letter dated April 14, 2010, were related to either the CRDM nozzles or pressurizer heater sleeve nozzles. These leakage events are not relevant to LBB piping, the LBB technical basis, or the GDC 4 rule. The GDC 4 rule is not applicable to leakage from the CRDM nozzles or pressurizer heater sleeve nozzles. The CRDM cracking and leakage are inspected to the requirements of 10 CFR 50.55a (g)(6)(ii)(D). The pressurizer heater sleeve nozzles that contain Alloy 82/182 welds are inspected to the requirements of 10 CFR 50.55a (g)(6)(ii)(E). Nevertheless, the Davis Besse situation does serve as a reminder that new phenomena and failure modes can appear.

UCS cited through-wall cracking in an Alloy 82/182 dissimilar metal weld of the RCS loop A hot-leg pipe at V.C. Summer. This leakage event is applicable to GDC 4 because the hot-leg pipe at V.C. Summer had been approved for LBB. PWR operating experience has shown that Alloy 82/182 is susceptible to PWSCC. Since the V.C. Summer event, the NRC has actively engaged the industry and national laboratories to resolve the issue of PWSCC. The strategy has been to investigate PWSCC growth rates to assist in analytical prediction, implement enhanced examination requirements, and apply mitigation methods such as weld overlay on the existing Alloy 82/182 welds. The NRC is incorporating ASME Code Case N-770 into the current 10 CFR 50.55a rulemaking to require PWR licensees to inspect more frequently the unmitigated Alloy 82/182 dissimilar metal welds.

UCS also cited the inadequacy of the reactor coolant leakage detection system as a basis for not permitting LBB in the resolution of sump performance issues. The staff notes that the leak rate in the LBB analysis is assumed to be sufficiently large to enable the RCS leakage detection system to detect it accurately and reliably. The RCS leakage detection system for most of PWRs can detect 1 gallon per minute (gpm) within 1 hour. In general, the RCS leakage detection system consists of a containment gaseous monitor, a containment atmosphere particulate radioactivity monitor, containment sump monitors, and a containment fan cooler condensate collection monitor. The technical basis for LBB approval is that the RCS leakage detection system should have the capability of detecting 1 gpm in 1 hour. However, the staff has allowed 1 gpm in 7 hours because it has determined that current RCS leakage detection systems would allow operators sufficient time to safely shut down the plant before a crack in an LBB pipe would grow to become unstable and cause pipe rupture. Based on the fracture mechanics evaluation of the applied loads and pipe material properties, the staff believes that LBB pipes have sufficient fracture toughness (ductility) to resist uncontrollable crack propagation for a considerable amount of time.
Nevertheless, the staff does not believe allowing PWR licensees to use LBB to resolve GSI-191 is prudent, based on the reasons cited in Section 2.1 of this document.

3.2 Union of Concerned Scientists Letter Dated April 26, 2010

In its April 26, 2010, letter, UCS reiterated the concern that the RCS leakage detection system is not able to detect leakage in time to allow the operator to take corrective actions. UCS suggested that plant-specific analyses are needed for certain postulated leakage from a segment of an LBB-qualified pipe to determine that the leakage could be detected within the allowed time at the TS action limit (1 gpm). UCS stated further that, if the plant-specific analyses are performed, there would be no need to do the zone-of-influence family of analyses currently needed to resolve GSI-191 for a postulated piping break in that segment. Therefore, there is no need for the insulation replacement driven by those analyses.

For the plant-specific analyses, UCS suggested the NRC consider the two following issues:

(1) Will any of the berms and barriers currently in containment to restrict the transport of debris to the containment sumps also impede the flow of leaked water to the leakage detection systems?

(2) Will allowable out-of-service periods for leakage detection systems in the TS cause a leak not to be detected in a sufficiently timely manner?

As discussed in the above staff response to the UCS letter dated April 14, 2010, nuclear plants have RCS leakage detection systems that maintain adequate detection capability. RCS leakage detection systems typically follow the guidance in Regulatory Guide (RG) 1.45, Revision 1, "Guidance on Monitoring and Responding to Reactor Coolant System Leakage," issued May 2008, in terms of sensitivity, diversity, and redundancy in the design and implementation of the leakage detection systems. Also, licensees are required for GSI-191 to evaluate all potential holdup locations for sources of water that might impact the final sump water level as part of the overall net positive suction head determinations for ECCS pumps. For this reason, installed debris interceptors are perforated or have floor openings or parallel flowpaths intended to allow passage of water to the sump. As such, there should be no new areas where water could collect undetected as a result of modifications performed in response to GSI-191.

In accordance with SRP Section 3.6.3, every LBB evaluation is required to include a leak rate calculation to demonstrate that the leak rate from the leakage crack is 10 times the detection capability of RCS leakage detection systems. SRP Section 3.6.3 recommends this safety margin for leakage detection. SRP Section 3.6.3.III.4 recommends that the RCS leakage detection system follow the guidance in RG 1.45, Revision 1, which specifies a detection capability of 1 gpm in 1 hour. NUREG/CR-1061, Volume 3, allows 1 gpm in 4 hours for plants that do not meet RG 1.45, Revision 1. The staff has approved plant-specific analysis in license amendment requests to allow 1 gpm in 7 hours.

The UCS statement regarding zone-of-influence analyses appears to imply that UCS might support the industry's proposed GDC 4 credit for resolution of GSI-191 to disregard the potential for debris generation for postulated breaks in LBB qualified piping in some instances. However, the staff does not agree that GDC 4 should be applied to GSI-191 for the reasons stated in Section 2.1 of this enclosure.

4.0 Discussion

The staff had not previously accepted the industry's proposal of using LBB in the GDC 4 rule to resolve GSI-191 concerns because the staff believes that such expansion would reduce defense-in-depth and might set a precedent for the use of GDC 4 that could affect other areas of accident analyses. Expanding GDC 4 would also require a policy decision by the Commission and would require revision to the rule or a new Statement of Considerations to be issued for the rule. However, as stated in the SRM dated May 17, 2010, the Commission requested that the staff discuss the potential approaches and options to bring GSI-191 to closure. One of the means that the Commission requested the staff discuss in its response was the possibility of giving GDC 4 credit for the resolution of GSI-191.

The staff recognizes that the benefits of crediting GDC 4 are that some PWR owners potentially would not be required to remove fibrous insulations or perform additional plant-specific tests. This would expedite satisfaction of the requirements of GSI-191 by the industry.

However, the following concerns and considerations outweigh the potential benefits of crediting GDC 4 for sump debris generation evaluations:

(1) Approving LBB to close out GSI-191 would not be consistent with the Statement of Considerations for GDC 4, which specifically limits the scope of LBB to the removal of pipe whip restraints and jet impingement barriers. Therefore, it is inappropriate to use the GDC 4 criterion to support debris generation evaluations unless the course of action involves a deliberate rulemaking process that permits further staff evaluation while also considering stakeholder input. For the reasons stated in this enclosure, the staff does not recommend undertaking such rulemaking.

(2) The end result of the NEI proposal to extend LBB to cover debris generation would not be to justify “the removal of plant hardware which it is believed negatively affects plant performance,” as was the Commission’s intent with GDC 4. The staff notes that the NRC’s approval of LBB has permitted the removal of pipe whip restraints and jet impingement barriers to allow enhanced accessibility for inservice inspection of safety-related structures, systems, and components. Rather, the staff believes that the NEI proposal would potentially permit licensees to alleviate the need to further modify their PWR containment sumps or remove fibrous pipe insulation that could threaten successful strainer performance. In effect, this could place the staff in the position of accepting large uncertainties in ECCS strainer performance in the event of a large-break LOCA. The staff does not find this reduction of defense-in-depth acceptable.

(3) GDC 4 provided an exception to the way in which dynamic effects of postulated pipe breaks were considered in the design of structures, systems, and components important to safety. It also provided a basis for removing plant hardware, specifically pipe whip restraints and jet impingement barriers, to permit enhanced accessibility of inservice inspection of safety-related structures, systems, and components that negatively affected plant performance. The NRC did not intend GDC 4 to be used as an equivalent alternative to the ECCS regulations. The NRC staff has not performed the longer term evaluation that is described in the Statement of Considerations for GDC 4 as necessary before allowing credit that would affect ECCS system performance. The longer term evaluation would involve analysis of the impact of relaxed pipe rupture requirements on the containment design, ECCS performance, and environmental qualification of electrical and mechanical equipment. This evaluation would incur staff and industry resources.

(4) The staff is unaware of any safety benefits of permitting LBB to be used for GSI-191 closure other than the potential elimination of occupational doses from future modifications that otherwise might be required. On the contrary, the staff believes that plant safety may be affected if LBB is expanded because fibrous insulation might not need to be removed from containment and more debris could be generated, potentially reducing ECCS performance should an unexpected large-break LOCA occur.

(5) Approving LBB for debris generation evaluations would be inconsistent with the proposed rulemaking, ““Risk-Informed Redefinition of Large Break LOCA ECCS Requirements,” at 10 CFR 50.46a, regarding the performance of ECCS. The staff believes that the risk-informed approach in the proposed rule, which requires mitigation of large breaks (albeit with more realistic assumptions than for design-basis accident events), appropriately maintains a level of defense-in-depth that application of GDC 4 would not retain. Permitting licensees to remove, a priori, the calculated debris generation associated with some, or all, large-break LOCA scenarios from their licensing basis by application of LBB would appear to conflict with the Commission’s statement in its SRM dated July 1, 2004, related to SECY-04-0037, in which the Commission requires that licensees “provide effective mitigation capabilities…directed at break sizes greater than the alternate maximum break size permitted by the rule, to maintain the core in a coolable geometry,” upon application of 10 CFR 50.46a.

(6) Since 2004, the industry and the NRC have made significant progress in resolving PWSCC in PWRs. Some PWR licensees have addressed PWSCC by installing weld overlays, applying mechanical stress improvement process, and implementing augmented inspections. The staff has incorporated by reference ASME Code Case N-722 in 10 CFR 50.55a which requires augmented visual examination of Alloy 82, 182, and 600 components. The staff also incorporated by reference ASME Code Case N-770 in the proposed rule for 10 CFR 50.55a which requires augmented examination of Alloy 82/182 dissimilar metal welds. The staff believes that this is adequate from a safety perspective to address the current scope of LBB with respect to GDC 4. However, since most PWR owners are in the process of addressing PWSCC in Alloy 82/182 dissimilar welds in their large LBB piping (nominal diameter of 20 inches and greater) through mitigation, enhanced inspection, or both, the staff does not believe it is appropriate to expand the use of LBB beyond the current application of GDC 4. If GDC 4 is expanded to be applied to resolving GSI-191 issues, the staff believes that the application of GDC 4 will require additional analyses, and potentially additional requirements and guidance, to address PWSCC in LBB piping. This may result in additional licensee costs and outage schedule impacts if the staff determines that mitigation of the nickel-Alloy 82/182 welds in LBB piping is needed to support GSI-191.

(7) Allowing LBB credit for resolving ECCS performance issues would require revision to GDC 4 or a new Statement of Considerations to be issued for the rule. Additionally, the expansion in scope might set a precedent for the use of GDC 4 that could affect other areas of accident analyses.

For the reasons stated above, the NRC staff views the use of 10 CFR 50.46a as a more technically complete and defensible approach to assist in the resolution of the GSI-191 sump performance issue than would be implementation of LBB for this purpose. The 10 CFR 50.46a rulemaking developments represent the agency's current approach to risk-informing ECCS performance issues.

DISCUSSION OF PROPOSED 10 CFR 50.46a

Overview of the Proposed Risked Informed Rule

The proposed rulemaking, "Risk-Informed Redefinition of Large Break LOCA ECCS Requirements" at Title 10 of the *Code of Federal Regulations* (10 CFR) 50.46a, if promulgated, will be a risk-informed alternative to the current emergency core cooling system (ECCS) rule at 10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors." This risk-informed rulemaking is intended to determine what relaxations in ECCS analyses are appropriate. Based on the new proposed risk-informed ECCS rule, 10 CFR 50.46a, licensees would still be required to consider the impacts of larger breaks, albeit with more realistic methods. The rule significantly reduces the loss-of-coolant accident (LOCA) break area that must be treated as a design-basis accident (DBA). Under the proposed 10 CFR 50.46a, the largest DBA break area is called the "transition break size (TBS)." For a pressurized-water reactor (PWR), the TBS is defined as a break area equal to the cross-sectional flow area of the inside diameter of the largest piping attached to the reactor coolant system. The largest main coolant pipes in PWRs are on the order of 30–40 inches in diameter. The inside diameter of the largest attached pipe at any PWR is less than 14 inches. Further, under the proposed 10 CFR 50.46a rule, breaks in the main coolant loops would not need to be considered double-ended breaks. As a result, for the main loop piping, this change could reduce the largest break area that must be analyzed as a design-basis LOCA by more than an order of magnitude.

The proposed rule would classify LOCAs smaller than the TBS as DBAs, and LOCAs larger than the TBS as beyond-design-basis accidents. In the proposed 10 CFR 50.46a, design-basis LOCAs (LOCAs smaller than, or equal to, the TBS) would be analyzed using the same requirements included in 10 CFR 50.46 to demonstrate the adequacy of the ECCS. The analysis of LOCAs smaller than the TBS would be required to include a coincident loss of offsite power, worst single failure, and credit only for safety-grade equipment. The staff of the U.S. Nuclear Regulatory Commission (NRC) reviews and approves DBA analysis methods. Approval of the methods is based on a rigorous justification of models, assumptions, and inputs. Design-basis analysis methods typically include a clearly conservative bias for parameters or models for which a less rigorous justification is provided, even when the "best-estimate" option is exercised.

Under the proposed 10 CFR 50.46a, LOCAs with a break area larger than the TBS (beyond-design-basis LOCAs) would still require mitigation. However, because these events are expected to be much less likely to occur, the analysis assumptions and the rigor associated with the justification of models, assumptions, and inputs would be reduced relative to design-basis events. For the beyond-design-basis LOCAs, credit would be allowed for offsite power and for use of nonsafety equipment. No coincident random failure would be required. Although licensees would still need to provide sufficient justification to ensure that models, parameters, and assumptions are representative of actual plant operation, greater uncertainty in the justification would be permissible given the low likelihood of the larger LOCAs. Therefore, the use of reasonably justified unbiased parameters would be acceptable.

Implications of the Proposed Rule for GSI-191, If Promulgated and Adopted by Licensees

One of the most significant aspects for evaluations related to Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance," involves the debris source term that must be assumed for strainer headloss testing and for evaluating in-vessel effects. The debris source term is uncertain because of a number of factors, the most important of which are the jet impingement zone of influence (ZOI), debris characteristics, and debris transport to the sump strainers. As such, the primary sump implementation issue associated with the proposed rule is the establishment of an adequate level of rigor for justification of unbiased parameters in the debris source term determinations for beyond-design-basis accidents. Based on the current state of knowledge, the staff believes that some relaxations in the source term are possible. However, unless proposed industry testing of ZOI and settling yields favorable results, many or most of the remaining plants will likely require additional strainer testing, modifications, or both, to achieve closure because of the very high fiber loads at these plants. Additionally, implementation of the proposed rule would require separate analyses for breaks above and below the TBS, using different assumptions, leading to the potential need for separate demonstration tests of adequate strainer performance. Despite these additional complexities, implementation of the proposed rule for GSI-191 could benefit licensees by reducing the scope of potential modifications at some remaining plants to demonstrate adequate strainer performance for the largest LOCAs, which typically have the potential to generate the most debris and are usually the limiting breaks in licensees' sump performance analyses.

If the Commission adopts 10 CFR 50.46a, the rule would provide licensees more options and potentially lessen the burden for closing out GSI-191 issues. The less conservative assumptions required for assessment of beyond-design-basis events could result in a reduced debris source term relative to current analyses for larger LOCAs. A reduced source term could in turn result in less need for testing or insulation removal. In addition, licensees might wish to augment existing strainers with active components or credit existing nonsafety features rather than remove insulation. For example, several licensees have noted the existing ability to backflush strainers, but have indicated concerns with regard to licensing that capability. The ability to use nonsafety equipment, offsite power, and nonredundant systems for LOCAs larger than the TBS could increase the feasibility of crediting features such as backflushing.

The flexibility afforded by 10 CFR 50.46a could reduce the burden associated with equipment modifications, reanalysis, or testing programs needed to address pump net positive suction head (NPSH) concerns and in-vessel effects for breaks larger than the TBS. However, adoption of 10 CFR 50.46a would not be expected to provide an "analysis only" solution for all issues, and the extent of benefit would depend on what factors are limiting for a given plant. Benefits from use of more realistic analyses will also depend on the staff and industry establishing viable positions for beyond-design-basis accidents in challenging areas, such as ZOI and debris settlement. The potential benefits for addressing in-vessel effects might also be limited because the amount of fiber bypass that can be problematic for in-vessel effects is apparently relatively small and may still be generated by LOCAs smaller than the TBS, especially in plants with large quantities of fibrous insulation.

<u>10 CFR 50.46a Rulemaking Schedule and Currently Proposed Adoption Requirements</u>

The proposed rule has been under consideration for several years, has been vetted through several public meetings with stakeholders, and has been published for formal public comment twice. The technical basis is therefore well established. A final rule is due to the Commission for approval in December of this year.

Assuming that the Commission approves the rule, licensees could choose to adopt it immediately. A licensee could choose to adopt 10 CFR 50.46a simply for the purpose of resolving GSI-191 without making any other changes to the plant. In such a case, a licensee would need to do the following based on the current language in the proposed rule, which is subject to change before final approval:

1. Show the applicability of the supporting technical basis for the rule to its plant. This involves demonstrating that the assumptions of the expert elicitation study (NUREG-1829, "Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process," issued April 2008) are consistent with the plant design and operation. A draft regulatory guide is available for that purpose. Licensees that have been approved or have applied for license renewal need only to confirm that their aging management programs are consistent with license renewal plans or commitments.

2. Show the applicability of the staff's seismic study supporting the rule (NUREG-1903, "Seismic Considerations for the Transition Break Size," issued February 2008). A licensee would have to perform a plant-specific study if applicability is not demonstrated. However, a draft regulatory guide has been prepared for this purpose and additional evaluation will only be required if a plant cannot demonstrate that the NUREG-1903 study is representative of the plant conditions.

3. Perform a risk-informed evaluation of any proposed changes to the plant's licensing basis in accordance with the guidance of Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis." Thus, licensees would need to submit changes made to support GSI-191 resolution in a risk-informed license amendment submittal.

4. Use plant technical specifications to identify nonsafety equipment that is credited for demonstrating compliance with the ECCS acceptance criteria for LOCAs above the TBS. Additionally, establish and monitor reliability and availability goals for credited nonsafety systems.

5. Every 4 years, revisit changes made to the plant to confirm that the technical basis for 10 CFR 50.46a (steps (1), (2), and (3)) has not been invalidated.

Parts of the ECCS analyses that address the short-term LOCA response (before sump recirculation) would remain valid since existing models and analysis all meet the criteria of 10 CFR 50.46a. Thus, there would be no need to reanalyze the short-term ECCS response or make any changes to existing approved models unless a licensee wishes to make other changes (i.e., changes not related to sump recirculation) that are "enabled" by 10 CFR 50.46a. Only changes that would be enabled by 10 CFR 50.46a would require a risk-informed evaluation. "Enabled" changes are changes that would satisfy the requirements of 10 CFR 50.46a, but would not satisfy the requirements of 10 CFR 50.46. If a change can be justified on the basis of an existing 10 CFR 50.46 analysis, then a risk-informed review would not be required, even if a licensee has adopted 10 CFR 50.46a. Thus, unless a licensee chooses to take advantage of additional (other than sump recirculation) enabled changes, there would be no need for new ECCS evaluation models or additional risk-informed submittals. The licensee could continue to use already-approved ECCS models.

Comparison of the Proposed 10 CFR 50.46a to Section 6, A Limited Risk-Informed Approach Currently Available to Licensees in the 2004 Safety Evaluation for NEI 04-07

The Nuclear Energy Institute (NEI) guidance report (NEI 04-07) entitled, "Pressurized Water Reactor Sump Performance Methodology," and the accompanying NRC safety evaluation (SE) (Agencywide Documents Access and Management System Accession No. ML043280007) included a risk-informed alternate methodology in Section 6. The risk-informed alternative included the use of more realistic mechanistic assumptions for the larger, less risk-significant LOCAs, and risk calculations as necessary in the event that plant-specific changes requiring exemptions from 10 CFR 50.46, single-failure, and safety-related requirements were required. Although differences exist, the risk-informed Section 6 methodology was intended to be consistent with the proposed 10 CFR 50.46a rule at the time NEI 04-07 was issued. The 2004 staff SE on NEI 04-07 endorsed, with limitations and conditions, the method described in Section 6 of NEI 04-07. Section 6 divided the break sizes into two regions with a dividing size called an alternate break size consistent with the TBS in the proposed 10 CFR 50.46a rule. Section 6 allows a reduction in conservatism for certain design-basis assumptions for analyzing strainer performance for LOCAs on piping larger than the TBS (a nominal 14-inch diameter at many PWRs). Section 6 also allows consideration of modifications that could not be considered in a design basis analysis such as reliance on a non-safety system. Depending on the reduced level of conservatism and/or the proposed modifications, a risk-informed evaluation and exemptions from the requirements might be proposed. Based on reviews of licensees' responses to Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004, the staff has observed that few licensees (e.g., 2–3 plants) have explored the risk-informed alternate methodology described in Section 6 of the staff's SE on NEI 04-07, and no licensee has implemented the options that require risk calculations.

The staff has not solicited systematic input from licensees to discern the reasons that the risk-informed Section 6 approach was not implemented. However, the staff has received anecdotal feedback from the industry. The most notable feedback was that the staff has been unwilling to accept more realistic assessments in critical debris source term areas (e.g., ZOI and debris transport). The staff believes that more realistic assessments in these areas sufficient to support an exemption request from 10 CFR 50.46 would not be justifiable because realistic models of the phenomena in these areas do not exist and are beyond the state of the art. Significant progress has been made in understanding sump phenomena since Section 6 was written, and the staff would incorporate this improved state of knowledge in new 10 CFR 50.46a implementing guidance. But important aspects of modeling the debris source term are still beyond the current state of the art. As discussed earlier, the proposed 10 CFR 50.46a rule would potentially provide some additional flexibility in determining more realistic treatment for beyond-design-basis breaks than that which currently exists under 10 CFR 50.46. However, while not yet determined, the staff does not envision major changes to the current Section 6 approaches absent significant additional research or testing. The industry currently plans to perform additional testing in the areas of ZOI and settling. These activities may justify significant changes to realistic assessment of debris source term for beyond-design-basis breaks. However, as these tests have not yet been performed, their outcome is uncertain. Additionally, the staff has not accepted past testing in these areas for reasons such as design errors and unjustified test assumptions.

The staff has received other anecdotal feedback on why licensees have not implemented the Section 6 method. This feedback, in addition to contributing factors identified by the staff, are provided in the following table, along with a future outlook assessment of these factors under the proposed 10 CFR 50.46a rule in its current form.

Past Factors Contributing to Licensees' Not Implementing Risk-Informed Alternate Approach to GSI-191 Resolution	Future Outlook
Implementation of many significant provisions of the Section 6 methodology would require an exemption to 10 CFR 50.46 or other regulations (e.g., crediting nonsafety systems with LOCA mitigation or not considering a single failure in the analysis for breaks on piping larger than 14 inches).	Under the proposed 10 CFR 50.46a rule, licensees that adopt the rule for GSI-191 will not need exemptions for breaks above the TBS because these allowances are in the new rule.
Implementation of some provisions of the Section 6 methodology could require plant-specific license amendments.	Under the proposed 10 CFR 50.46a rule, licensees that adopt the rule for GSI-191 would need to submit license amendment requests for risk-informed licensing basis changes.
The existing Section 6 methodology is not comprehensive in providing guidance with reduced conservatism in many areas of the analysis, including ZOI, debris transport, headloss, and chemical effects. This is because sufficiently realistic models for risk-informed treatment of these areas that lead to sump clogging do not currently exist and have not been developed by the industry or NRC staff.	Under the proposed 10 CFR 50.46a rule, based on their low likelihood, breaks larger than the TBS would become beyond-design-basis breaks. Existing guidance in Section 6 could be the starting point for new 10 CFR 50.46a implementing guidance to provide reduced conservatism for other areas of the evaluation. However, large changes in current models for some phenomena will be very challenging without significant additional research or testing.

Licensees implementing the Section 6 methodology need to perform analyses for breaks above and below 14 inches in diameter. Additionally, testing to justify that risk-informed mitigation methods are reliable may be necessary. For example, a licensee may need to reference or perform testing to show that a nonsafety system credited for unclogging a clogged strainer can perform its function.	Under the proposed 10 CFR 50.46a rule, there would be no change.
Licensees initially expected to be able to address the strainer performance issue without needing to resort to risk-informed approaches. They also believed that the new strainer designs would have a large margin to accommodate potential future challenges to strainer performance.	Licensees have recognized that significant uncertainties associated with the strainer performance issue make it difficult to demonstrate adequate strainer performance with large margins using design-basis analysis methods and are expected to be more amenable to alternate resolution approaches.

Future Outlook for Section 6 after the Proposed 10 CFR 50.46a Is Approved or Disapproved

The original intent of the Section 6 guidance was to achieve consistency with the expected outcome of the 10 CFR 50.46a rulemaking process based on the form of the proposed rule in 2004, when the staff issued its SE on NEI 04-07. As such, assuming the Commission approves 10 CFR 50.46a, Section 6 will be used as a starting point for new implementing guidance for GSI-191 which will incorporate more realistic methods and will be made consistent with the final 10 CFR 50.46a rule. The staff does not intend to review requests to use Section 6 evaluations if GSI-191 specific implementing guidance for 10 CFR 50.46a is endorsed because 10 CFR 50.46a, if approved, will be the NRC's processes to risk inform the ECCS requirements. In this event, a risk-informed resolution to GSI-191 should be performed according to these requirements. As such, new implementing guidance would likely supersede the existing Section 6 approach.

Should the proposed 10 CFR 50.46a rule not be issued, the staff would need to consider the implications of the Commission's decision on the existing Section 6 approach. It might be appropriate to enhance or revise the section or to eliminate the approach entirely, depending on the Commission's views on the subject.

RISK-INFORMED VERSUS DETERMINISTIC TREATMENT

The regulation at Title 10 of the *Code of Federal Regulations* (10 CFR) 50.46(a)(1)(i) currently describes two types of deterministic evaluation models that can be used to demonstrate compliance with the emergency core cooling system (ECCS) design requirements, one of which is a bounding analysis and the other a best-estimate analysis. Both the bounding and the best-estimate analysis calculate parameters that are compared to acceptance criteria (e.g., peak cladding temperature) and provide a high level of confidence that acceptance criteria will not be exceeded. In the bounding analysis, evaluation models and correlations are justified on the basis of conservatism. Best-estimate calculations are performed with realistic models and correlations with uncertainties explicitly addressed in the calculations. The best-estimate analysis must additionally estimate the uncertainty in the calculated parameter and demonstrate that there is a high level of probability that the acceptance criteria would not be exceeded. The U.S. Nuclear Regulatory Commission (NRC) staff has determined, in Regulatory Guide 1.157, "Best-Estimate Calculations of Emergency Core Cooling System Performance," that a 95-percent probability level is acceptable to the staff for comparison of best-estimate predictions to the applicable limits.

The acceptance criterion for the design of the ECCS as it relates to sump performance is that sufficient net positive suction head (NPSH) is available at the inlet to the low-pressure injection pumps during operation in the recirculation mode. A collection of methods or "technical elements" that can be used to evaluate the loss of NPSH from debris generation, transport, and collection on the sump screens is endorsed with identified conditions and limitations in the NRC's safety evaluation (SE) of Nuclear Energy Institute (NEI) 04-07, "Pressurized Water Reactor Sump Performance Methodology."

These methods are bounding analyses for evaluating sump performance during and following design basis loss of coolant accidents. A best-estimate analysis of the probability of successful sump performance that would be necessary to support a best-estimate compliance evaluation permitted by 10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors," is presently not possible because of the complex phenomena that is not understood well enough for industry to develop, or staff to evaluate, an integrated model of debris generation, transport, and deposition on the sump screens. Such an integrated model would also need to propagate the uncertainty of the constituent input parameter distributions through all of the elements. This would be necessary to eventually support an estimate of the uncertainty in the results and permit the determination that there is a high level of probability that the acceptance criteria are not exceeded. Therefore, it will not be possible to estimate the uncertainty on the available NPSH, and a best-estimate compliance evaluation permitted by 10 CFR 50.46 is presently not possible. Similarly, a more complete understanding of the complex phenomena would be needed to develop more detailed models to support analysis via a probabilistic risk assessment. The complexities of sump performance evaluations and the lack of success in past attempts to model aspects of sump performance has led the staff to determine that a comprehensive, defensible sump performance model cannot be developed in the foreseeable future. The staff considered the option of developing a generic integrated probabilistic model for sump phenomena that could be applied in a plant-specific manner, but determined this option not to be viable for similar reasons, as discussed in Enclosure 2.

Section 6 in NEI 04-07 proposed a limited risk-informed alternative evaluation methodology for demonstrating acceptable sump performance. The alternate methodology proposed to use more realistic analysis methods and assumptions to evaluate sump performance for large breaks. The more realistic analysis did not include estimating the uncertainty in the available NPSH and was therefore not a best-estimate evaluation, as defined in 10 CFR 50.46. The staff's SE noted that the requirements of 10 CFR 50.46 are applicable and stated that licensees could request, on a plant-specific basis, exemptions from the requirements associated with demonstrating long-term core cooling capability in 10 CFR 50.46(b)(5). NEI 04-07 also proposed a risk impact calculation to be performed when changes to the existing facility design are necessary to meet the acceptance criteria using the alternate methodologies described in Section 6. The NRC staff's SE noted that exemptions from the requirements of 10 CFR 50.46(b) may be required for use of Section 6. However, no licensee has requested an exemption for the purpose of implementing the Section 6 approach for Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance." The staff and licensees have, to date, found application of risk tools for resolution of GSI-191 to be challenging and of limited use. However, there is some potential for expanding the use of these tools. At a meeting in June 2010, an NEI representative stated that additional implementation guidance is needed to enable licensees to better determine whether the Section 6 approach would be useful to plants that have not yet resolved strainer performance issues.

In addition, regarding risk informing the remaining elements of GSI-191, the agency is currently in the process of developing a risk-informed alternative to the ECCS rule, which may have implications for GSI-191. This risk-informed effort is intended to determine what relaxations in ECCS analyses are appropriate. Based on the new proposed risk-informed ECCS rulemaking, "Risk-Informed Redefinition of Large Break LOCA ECCS Requirements," at 10 CFR 50.46a, licensees would still be required to demonstrate adequate strainer performance considering the impacts of larger breaks, albeit with more realistic methods. These evaluations might still predict very large debris source terms for some plants with large amounts of fibrous insulation. Moreover, a limited risk-informed approach to addressing GSI-191 is already available to licensees via the 2004 SE previously discussed, but this approach has not been used for reasons discussed in Enclosure 4.

In summary, 10 CFR 50.46 is not a risk-informed rule, and no provisions exist in the rule to utilize risk to demonstrate compliance with the rule. As summarized above, the realistic approach can utilize probability, but only in the context of addressing the uncertainties in the parameters and the probability of not exceeding the acceptance criteria (in this case, NPSH) and not any measure of risk. Therefore, exemptions under 10 CFR 50.12, "Specific Exemptions," would be necessary to utilize a risk-informed treatment of the remaining elements. The exemption criteria in 10 CFR 50.12 that would be applicable, and the regulations from which exemptions must be sought, would depend on the specific application. However, if the Commission approves the risk-informed 10 CFR 50.46a rulemaking effort, a viable regulation would exist that would allow licensees to adopt and subsequently implement risk-informed methods without the need for exemptions. Thus, exemptions to 10 CFR 50.46 under 10 CFR 50.12 might be difficult to justify upon promulgation of 10 CFR 50.46a.

RADIATION PROTECTION AND DOSE EVALUATIONS

Radiation Protection Policy

Radiation protection, as practiced internationally and within the United States, is based on three fundamental principles, as described in International Commission on Radiological Protection (ICRP) Publication 103, "The 2007 Recommendations of the International Commission on Radiological Protection" (*Annals of the ICRP*, Volume 37, Nos. 2–4). These principles are (1) justification of the exposure; (2) optimization of protection; and (3) limitation of individual dose. The U.S. Nuclear Regulatory Commission standards for protection against ionizing radiation (Title 10 of the *Code of Federal Regulations* (10 CFR) Part 20, "Standards for Protection against Radiation") and other U. S. Nuclear Regulatory Commission (NRC) regulatory requirements embody these principles, particularly those related to optimization of protection and limitation of individual dose.

The first principle, justification, states that "any decision that alters the radiation exposure situation should do more good than harm" (ICRP Publication 103). Thus, the principle of justification would apply to the proposal and planning for changes to insulation or sump areas within a facility and would indicate that the benefits of the action should outweigh the detriments. Decisions associated with justification do not simply take radiation doses into account, but rather should encompass all of the possible benefits and detriments of the proposal. Thus, a decision may be justified by conclusions that the benefits of improved safety outweigh the detriment of occupational exposure and other detriments associated with taking the action. Rarely, in fact, does the radiation dose associated with the activity serve as the only decision criterion.

The second principle, optimization, states that "the likelihood of incurring exposure, the number of people exposed, and the magnitude of their individual doses should be kept as low as reasonably achievable, taking into account economic and societal factors" (ICRP Publication 103). Thus, once a particular exposure situation has been determined to be justified, it is also necessary to take actions to reduce exposures to as low as is reasonably achievable (ALARA). The NRC regulations at 10 CFR 20.1101(b) contain the ALARA requirement, which is amplified in several regulatory guides, such as Regulatory Guide 8.8, "Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations Will Be as Low as Is Reasonably Achievable." It should be noted that maintaining radiation exposures ALARA is not necessarily the same as minimization of exposure.

The third principle, limitation, states that "the total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits" (ICRP Publication 103). Limits for occupational exposure are contained in 10 CFR 20.1201, "Occupational Dose Limits for Adults"; 10 CFR 20.1206, "Planned Special Exposures"; 10 CFR 20.1207, "Occupational Dose Limits for Minors"; and 10 CFR 20.1208, "Dose Equivalent to an Embryo/Fetus." Exceeding an occupational exposure limit is a significant violation and subject to enforcement.

Application of these three principles first requires that the activity is justified in terms of the net benefit. Radiation dose can be, but may not always be, considered in this justification decision.

Some practices are deemed so frivolous that no amount of radiation exposure can be justified. Once the activity is justified, it must be conducted in a way that the resulting radiation exposures are maintained within the dose limits and are ALARA.

Consistent with the justification principle, the NRC's backfit policy requires the staff, in certain instances, to complete a regulatory analysis that includes a cost/benefit analysis to ensure that the costs associated with a proposed change in regulatory position are justified by the resulting benefit. This regulatory analysis is not required for backfits involving adequate protection, compliance with Commission regulations or orders, or a redefinition of the level of protection considered adequate for public health and safety or the common defense and security. However, when a regulatory analysis is required, both occupational and public dose incurred or averted are factors included in this analysis. NUREG/BR-0184, "Regulatory Analysis Technical Evaluation Handbook—Final Report," issued January 1997, provides guidance on how the monetary value of these doses are determined and factored into the analysis. In accordance with this guidance, dose is considered as a cost at the rate of $2,000 per rem.

The Commission does not have a separate "ALARA Policy" as a policy statement. However, provisions to keep planned exposures ALARA have been a formal regulatory requirement (i.e., a "shall" statement) in 10 CFR Part 20 since its revision in 1991. The Statements of Consideration published with the 1991 revised rule (Volume 56, page 23367, of the *Federal Register*) clarify that licensees are required to have a "radiation protection program that includes provisions for keeping radiation doses ALARA," and that there is no established standard as to how much collective dose is, or is not, warranted in any specific operational situation. Historically, the NRC has typically not accepted requests by reactor licensees to delete or defer safety-related activities, such as surveillance tests (required by the plant's technical specifications), based solely on ALARA (e.g., deferring a safety-related activity that would incur some amount of additional occupational dose). Licensees are required to perform those activities that ensure adequate protection of public health and safety in a manner that is ALARA.

The discussions of radiation protection policy in this enclosure and the SECY paper were coordinated with the Office of Federal and State Materials and Environmental Management Programs.

Typical Operational Doses at U.S. Pressurized-Water Reactors

Based on a review of NUREG-0713, Volume 30, "Occupational Radiation Exposure at Commercial Nuclear Power Reactors and Other Facilities," issued in 2008, the following information was obtained regarding typical operational doses incurred by industry. The 3-year average collective dose per reactor is one of the metrics that the NRC uses in the Reactor Oversight Program to evaluate the effectiveness of the licensee's ALARA program.

Based on the 207 reactor-years of operation accumulated over a 3-year period (ending December 31, 2008) at 69 pressurized-water reactors (PWRs), the average 3-year collective total effective dose equivalent (TEDE) per reactor was found to be 75 person-rem. Based on the 105 reactor-years of operation accumulated over the same period by 35 boiling-water reactors, the average 3-year collective TEDE per reactor was found to be 142 person-rem.

Analysis of Potential Doses from Insulation Replacements

Industry Estimates

A Nuclear Energy Institute letter dated April 7, 2010 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML101050354), stated that current NRC options for addressing remaining issues would require wholesale replacement of insulation systems and additional plant-specific testing. These changes will result in significant worker exposure in high-radiation areas of PWR containments, with some estimates ranging from 100 person-rem to 600 person-rem. In the April 15, 2010, Commission meeting, the industry stated that the average dose impact per plant would be 200 person-rem.

Actual Total Doses from Insulation Replacements including Hazardous Materials

The staff informally requested information from licensees that had actually performed insulation replacements in response to Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance," to determine the likely dose impact of additional modifications at the remaining high-fiber plants. The average occupational dose, based on responses received, was 18.7 person-rem per plant. The actual dose incurred at each of the plants from replacing insulation, including the scope of changes, is presented below:

- Case 1: A plant received 6 person-rem during replacement of 411 linear feet of insulation as follows:
    - 76 linear feet of Min-K insulation on large reactor coolant system piping
    - 39 linear feet of Cal-Sil insulation on 14-inch steam generator/feedwater piping in containment
    - 296 linear feet of Cal-Sil on small steam generator blowdown piping
- Case 2: A plant received 8.9 person-rem during replacement of 2,319 linear feet of Cal-Sil and Microtherm insulation located near the steam generators in the loop rooms.
- Case 3: A plant received 35.9 person-rem during replacement/jacketing repairs of 5,799 feet of Cal-Sil and Microtherm insulation. Replacements were performed at locations near the steam generators in the loop rooms. Jacketing was added or repaired in basement and annulus areas on emergency core cooling system lines, residual heat removal lines, and service water lines.
- Case 4: A plant received 4.4 person-rem during replacement of 20 linear feet of Cal-Sil insulation on a regenerative heat exchanger. Five percent of this Cal-Sil contained asbestos.

- Case 5: A plant received 21 person-rem including scaffolding for replacement of mineral wool and NUKON® with reflective metal insulation (RMI) over two outages. The scope of replacements included the following:

    - Replaced mineral wool with RMI on steam generators.
    - Replaced NUKON® with RMI on pressurizer head and spray line.
    - Replaced NUKON® from valves on pressurizer.
    - Replaced NUKON® with RMI on steam generator drains.
    - Removed mineral wool from blowdown lines.

- Case 6: A plant received a total of 4.7 person-rem during the following replacements:

    - Removed 14.3 cubic feet of fibrous insulation areas, such as a safety injection check valve enclosure and gaps in various lines at joints and hangers.

    - Removed or replaced 40–50 cubic feet of Cal-Sil. Removed Cal-Sil from inactive piping sections and replaced Cal-Sil with RMI on a section of safety injection piping in the steam generator cavities on safety injection.

    - Added banding to several hundred linear feet of Cal-Sil on over 40 small-bore piping lines, including chemical and volume control system letdown and regenerative lines, reactor coolant pump seal return lines, pressurizer spray and sample lines, primary sample lines, primary drainlines, steam generator sample lines, and safety injection lines.

- Case 7: A plant received 19.6 person-rem during replacement of 400 linear feet of piping insulation and replacement of steam generator insulation on all three steam generators from the tubesheet to the transition area.

- Case 8: A plant received 43.9 person-rem for replacement of 1,300 linear feet of piping insulation and replacement of steam generator insulation on all three steam generators from the tubesheet to the transition area.

- Case 9: A plant received 23.6 person-rem for the replacement of 975 cubic feet of Cal-Sil and 691 cubic feet of Temp Mat. Replacements were performed on the steam generators, pressurizer, and reactor vessel head. Some of this material was replaced with RMI. Asbestos insulation was present in the steam generator bays and the entire area was treated as an asbestos work area, which required tenting and other precautions.

<u>Remaining Plants That Have Hazardous Materials</u>

The NRC staff reviewed plant submittals to determine, and NEI anecdotally confirmed that approximately 18 of the 69 PWR units have some amount of asbestos insulation within a zone of influence (ZOI) for GSI-191. Almost all of the asbestos insulation reported was Cal-Sil insulation. The NRC staff notes that 11 of those 18 units have already resolved GSI-191, with the exception of in-vessel effects. Of the seven remaining units, five also reported the assumed

ZOIs used in analysis. None of these five plants credited a reduced ZOI for asbestos material. The remaining two plants did not report a ZOI assumed for the asbestos insulation. Based on the information obtained, the NRC staff notes that licensees typically assume staff-accepted, or larger, ZOIs for insulation containing asbestos. As such, these materials are less likely to be replaced. Additionally, while the presence of hazardous materials would be expected to increase doses because of the need for extra precautions, Case 9 above shows that the effects are not significantly out of line with doses received during replacement of insulation that does not contain hazardous materials. Furthermore, expected doses from insulation replacements are likely to be more sensitive to replacements in high-dose locations, as suggested by the relatively large dose for replacement of 20 linear feet of insulation on a regenerative heat exchanger in Case 4 above.

Dose Conclusions

No established standard exists for how much collective dose is, or is not, warranted in any specific operational situation. Once an activity is determined to be justified, licensees are required to conduct those activities in a manner that is ALARA. Ensuring that exposures are ALARA includes work planning and dose assessments to evaluate the need for, or effectiveness of, alternate dose mitigation strategies (i.e., additional shielding, source term reduction, use of respiratory protection); tracking and trending of the actual doses received in the execution of the work plan; and taking additional protective actions as necessary to achieve doses that are ALARA.

The staff expects that the remaining high-fiber plants would prefer to take advantage of reduced ZOIs for NUKON® using sure-hold bands rather than large insulation replacement campaigns using RMI. This would reduce expected doses as compared to actual insulation replacements. The highest reported dose incurred during actual insulation replacements, as noted above, was 44 person-rem. This collective dose equates to a cost of $88,000 in a regulatory analysis. The staff recognizes that this may not be a bounding value, since the scope of modifications needed at some plants to fully address GSI-191 could be larger than that for the limited sample of plants the staff obtained. Even if this number is not bounding, the dose cost is clearly not out of line with the expected doses from larger scope outage work performed occasionally by licensees (e.g., steam generator replacement).

Industry dose estimates range up to 600 person-rem ($1.2 million) with an average of 200 person-rem ($400,000). These values seem excessively conservative compared to the actual industry experience reported above. One reason for the apparent discrepancy could be that licensees are required to maintain doses ALARA in accordance with current regulations. This means that, after determining that insulation replacements are necessary, a licensee would be required by ALARA regulations to perform the replacements in an optimized manner to minimize incurred dose. This may mean electing to replace one insulation configuration over another within the same ZOI to minimize dose. This may also mean electing to replace insulation within the ZOI that does not contain hazardous materials (e.g., asbestos). However, it is unclear to what extent additional ALARA work planning or alternate means of GSI-191 resolution would reduce these estimated costs.

However, even if the estimates based on actual insulation replacements are too low for some plants, given the existence of hazardous materials (e.g., asbestos) that require additional protective measures, such as use of respiratory protective devices that may result in increased dose, the staff notes that justification in terms of dose is only performed for backfits in which adequate protection, compliance with agency regulations, or redefining adequate protection are not involved. The staff has not performed a regulatory analysis in this case. However, the staff believes that the data show that the cost in terms of dose for insulation replacement is within the range of large-scope work that licensees have performed in the past (e.g., steam generator replacements). Furthermore, the staff does not believe that the dose likely to be received in support of issue resolution is excessive given the safety issues discussed in the paper.