POLICY ISSUE
(Notation Vote)

July 9, 2012 SECY-12-0093

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)-SECY-10-0113, "Closure Options for Generic Safety Issue [GSI] - 191, Assessment of Debris Accumulation on Pressurized Water Reactor [PWR] Sump Performance," dated December 23, 2010 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML103570354), and requests a decision on policy issues and options for resolving GSI-191. This paper does not address any new commitments.

SUMMARY:

The staff last provided recommendations to the Commission for the resolution of GSI-191 in SECY-10-0113, "Closure Options for Generic Safety Issue - 191, Assessment of Debris Accumulation on Pressurized Water Reactor Sump Performance," dated August 26, 2010 (ADAMS Accession No. ML101820212). On September 29, 2010, the Commission held a meeting with the staff and industry representatives to discuss options to resolve GSI-191. As indicated above, the Commission issued SRM-SECY-10-0113 directing the staff to consider alternative options for resolving GSI-191 that are innovative and creative, as well as risk informed and safety conscious, while the industry completed testing in 2011.

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Since the issuance of the SRM, the staff has interacted with the industry and stakeholders to develop options for the resolution of GSI-191. The staff is currently working with the South Texas Project Nuclear Operating Company (STP) to develop a "no transition break size" analysis using the methods described in Regulatory Guide (RG) 1.174, Revision 2, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis" (ADAMS Accession No. ML100910006), for the resolution of GSI-191. STP plans to submit the analysis by December 2012 for U.S. Nuclear Regulatory Commission (NRC) review and approval. If approved, the staff plans to use STP as a pilot for other licensees choosing to use this approach. Enclosure 3 provides a more detailed description of this approach.

The staff issued a *Federal Register* (FR) notice on May 3, 2011 (76 FR 24925), to request stakeholder input on alternative approaches to resolving GSI-191, and it has held numerous public meetings to discuss the topic. The staff also interacted frequently with industry representatives as the industry completed the committed-to generic testing in 2011. Enclosure 1 discusses the interactions between the staff and industry since the issuance of SRM-SECY-10-0113.

Resolution of GSI-191 continues to be more difficult than anticipated. The industry's testing on in-vessel effects (the potential for debris to lodge in the core and restrict flow), which was generic and performed to bound all PWRs, failed to show that more than very low amounts of fiber are acceptable. The Pressurized-Water Reactor Owners Group (PWROG) submitted Topical Report (TR) WCAP-16793, Revision 2, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," in October 2011 (ADAMS Accession No. ML11292A021), which summarized the testing, and requested NRC review and approval. The staff is currently reviewing the TR and expects to issue its safety evaluation by September 2012. The thermal-hydraulics subcommittee of the Advisory Committee on Reactor Safeguards (ACRS) held a meeting on May 8 and 9, 2012, to discuss the TR with both the industry and staff. The ACRS subcommittee raised concerns that the TR lacked sufficient information to justify even the low fiber amount on a generic basis. The restrictive fiber limits will make in-vessel effects the limiting factor for many plants, which has led many licensees to plan plant-specific testing to reduce the scope of modifications (e.g., insulation modifications, installation of a bypass eliminator). The ACRS plans to issue a letter on this subject in the short term. Furthermore, the industry in-vessel effects testing did not attempt to differentiate between smaller break loss-of-coolant accidents (LOCAs) (which are more likely but are judged to be less severe) and the less-likely larger breaks (which are typically judged to be limiting for strainer performance and in-vessel effects), and did not address the potential for debris in the core to cause boric acid precipitation to occur earlier than currently predicted. These considerations have made it difficult to justify alternatives for resolving GSI-191.

Based on the interactions described above and the results of the recent industry testing, the staff developed three options that will be effective ways to resolve GSI-191. The first option is similar to Option 1 of SECY-10-0113. This option would require licensees to demonstrate compliance with Title 10 of the *Code of Federal Regulations* (10 CFR) 50.46, "Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors," through approved models and test methods. This option is the most clearly defined path for resolution of GSI-191, but will likely result in the most extensive modifications and occupational dose. The second option requires implementation of additional mitigative measures and allows additional time for licensees to resolve issues through further industry testing or use of the STP approach,

either of which may reduce the scope of modifications and occupational dose. The third option involves separating the regulatory treatment of the sump strainer and in-vessel effects, which also is expected to reduce the scope of modifications and occupational dose. The staff anticipates the first option would take two refueling outages (RFOs) to implement. For licensees choosing the deterministic approach of Option 2, the staff anticipates it would take three RFOs to complete. Licensees using risk-informed Options 2 and 3 will need to be completed with all modifications one RFO after the NRC decision on the analysis. The staff recommends that the Commission allow licensees the flexibility to choose one of the above options to resolve GSI-191 at its plant(s), subject to the conditions and schedules discussed in this paper.

Given the potential for post-LOCA debris to block flow in the emergency core cooling system (ECCS), the containment spray system (CSS), and the reactor core, the staff maintains that it is not acceptable to allow debris-generating materials to remain within containment in quantities greater than those demonstrated to provide reasonable assurance that long-term cooling will be maintained in accordance with 10 CFR 50.46(b)(5).

BACKGROUND:

GSI-191 concluded that debris could clog the containment sump strainers in PWRs, leading to the loss of net positive suction head for the ECCS and CSS 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" (ADAMS Accession No. ML042360586), dated September 13, 2004, requesting that licensees address the issues raised by GSI-191. GL 2004-02 was focused on demonstrating compliance with 10 CFR 50.46.

The staff recognizes that significant cost and occupational dose are associated with replacing or reinforcing insulation, and it acknowledges that compensatory actions and modifications made to date have reduced the risk of strainer clogging. All PWR licensees have made their sump strainers substantially larger. Some licensees removed fibrous or particulate insulation, changed their sump pH buffers to reduce chemical effects, or installed debris interceptors to reduce the amount of debris that can reach the strainers. The industry also has spent considerable effort trying to reduce the uncertainties and conservatisms in the standard models for assessing GSI-191. Licensees have made, and will continue to make modifications and develop analyses to resolve GSI-191 in accordance with the regulations. Each plant will document these actions in its updated final safety analysis report, in accordance with 10 CFR 50.71(e). However, the resolution of GSI-191 has been challenging because of a history of unexpected test results (e.g., sensitivities to debris types and time of arrival of the debris at the sump strainer or reactor core). The testing in 2011 continued this trend, and in-vessel effects will be the limiting factor for many plants. Even latent debris (which does not include accident-generated debris) can cause a reduction in core flow if conservative assumptions are made regarding the amount of latent fiber, the fiber transport, and the percent of fiber passing through the strainer.

Licensees implemented compensatory measures in response to Bulletin 2003-01, "Potential Impact of Debris Blockage on Emergency Sump Recirculation at Pressurized-Water Reactors" (ADAMS Accession No. ML031600259), dated June 9, 2003, and GL 2004-02 to address the potential for sump strainer blockage. Additional compensatory measures could be developed by licensees to specifically address in-vessel blockage. PWRs have instrumentation to monitor core water levels and temperatures following a LOCA and operating procedures to initiate hot-

leg injection, which may provide an alternate flowpath that bypasses core inlet blockage. For these reasons and others documented in GL 2004-02 that are still applicable, continued operation is justified for each of the recommended options and schedules to resolve GSI-191.

The Nuclear Energy Institute (NEI) submitted a letter on May 4, 2012 (ADAMS Accession No. ML12142A316), recommending actions for resolving GSI-191 that a licensee would select based on the amount of fiber in containment. The letter stated that all licensees would submit by December 31, 2012, a plant-specific path and schedule for resolution of GSI-191. Licensees that do not meet the deterministic criteria today either have, or will implement additional defense-in-depth measures to mitigate risk while they either continue testing or pursue a risk-informed approach. Licensees of "high fiber" plants would take measurements at the next opportunity to prepare to replace fibrous insulation, if necessary.

DISCUSSION:

Staff Recommended Options to Resolve GSI-191

All of the options discussed below will be effective in resolving GSI-191. Enclosure 2 describes the options in more detail, including pros and cons.

- *Option 1: Compliance with 10 CFR 50.46 Based on Approved Models*

  This option is similar to Option 1 presented in SECY-10-0113. Licensees will demonstrate compliance with 10 CFR 50.46 through approved models for analyses, strainer headloss testing, and in-vessel effects. This option is the best defined and will lead to the quickest resolution of GSI-191, but will likely require the most extensive plant modifications and receive the highest amount of occupational dose in comparison with other options presented in this paper. Under this option, the staff will continue to use the holistic integrated review process described in Enclosure 2.

  The staff recently approved "clean-plant" criteria that provide guidance to resolve the strainer and in-vessel issues (NRC letter to NEI dated May 2, 2012, ADAMS Accession No. ML120730181). The in-vessel guidance is based on WCAP-16793, Revision 2, which is still under staff review, and plants using the criteria will need to address any limitations placed on use of the WCAP based on the staff review and acceptance. Plants would need very low fiber amounts and strict containment cleanliness programs to use the clean-plant approach. Plants not meeting the clean-plant criteria would be required to demonstrate compliance through deterministic testing for the sump strainer performance and in-vessel effects. Some plants have installed strainer design features such as bypass eliminators that significantly reduce the amount of debris that passes through the sump strainer and reaches the core, such that the in-vessel limits can be met even with high fiber loads in containment.

  The staff proposes that two RFOs is a reasonable time to plan, design, and install modifications using methods that maintain dose as low as reasonably achievable.

- *Option 2: Mitigative Measures and Alternative Methods Approach*

  Option 2 is a graded approach in which licensees' actions and schedules are based on the amount of fibrous insulation in the plant. Importantly, licensees would implement mitigative measures for strainer blockage and in-vessel effects, whichever are not resolved, while they complete their analyses and plant modifications. Enclosure 2 discusses mitigative measures in more detail. Plants with a high fiber load are generally recognized as having higher risk of strainer and in-vessel issues than plants with relatively low fiber amounts; therefore, higher fiber plants would take measurements at the first opportunity in preparation for insulation modifications. In parallel, licensees could continue to pursue refinements to the evaluation methods (e.g., continue testing and analyses of in-vessel effects), or licensees could use the STP risk-informed approach (described in Enclosure 3), which focuses plant modifications on the most risk-significant aspects of GSI-191 for each plant. Option 2 is in general alignment with the closeout path proposed in the NEI May 4, 2012, letter. Licensees that pursue a risk-informed approach would need to inform the staff of their intent by December 31, 2012, consistent with the NEI proposal in its letter dated May 4, 2012. The staff would work with interested licensees to develop a submittal schedule and would conduct preapplication meetings to reach agreement on plant-specific testing and analyses. Licensees would submit their risk-informed analyses in a staggered schedule all within one year following the staff's decision on the STP approach, which is projected to be completed by December 2014.

  Licensees interested in following the STP approach would need to satisfy specified entry conditions on items such as the quality of the plant-specific probabilistic risk assessment. Licensees would also need to commit to develop a model of plant piping and insulation, sufficient to follow the STP approach, in their next RFO after January 1, 2013, and commit to perform any plant-specific testing needed to justify major assumptions (e.g., chemical effects or strainer headloss correlation) within two RFOs after January 1, 2013. Plants that pursue a risk-informed approach would need to be prepared to implement a deterministic approach in case the risk-informed approach is not viable. This would become evident during the plant-specific testing that would be completed within two RFOs. Since plant measurements would be available, a licensee could default to the already-established deterministic methods and complete modifications by the third RFO after January 1, 2013. If it becomes apparent that a risk-informed approach will not be successful (e.g., unexpected test results), licensees would be required to pursue a deterministic approach for resolution of GSI-191, and finish by the end of the third RFO after January 1, 2013.

  For licensees that pursue a deterministic approach under Option 2, the staff would expect all analyses, testing, and modifications to be completed by the third RFO after January 1, 2013. The additional RFO (compared to Option 1) would be used to refine methods and conduct plant-specific testing.

- *Option 3: Different Regulatory Treatment for Suction Strainer and In-Vessel Effects*

  New information since the preparation of SECY-10-0113, including insights from the STP risk-informed analysis (still preliminary), suggests that different regulatory treatment

for the containment sump and in-vessel effects may be warranted. Even though WCAP-16793, Revision 2, only supports low amounts of fiber that reach the core, the STP preliminary analysis indicates that in-vessel effects are only problematic for a small population of break sizes and locations. WCAP-16793, Revision 2, also does not consider event timing, but the STP analysis shows that timing is important. Enclosure 2 contains a more detailed explanation of Option 3.

In this option, suction strainer blockage is treated in a deterministic fashion. Blockage of sump strainers would result in a significant reduction in defense-in-depth and challenge the integrity of multiple barriers; therefore, sump strainers (the original scope of GSI-191) are handled in a conservative, deterministic fashion. However, if the ECCS and CSS pumps have adequate net positive suction head, but the core inlet becomes blocked, then the following apply:

– Containment cooling remains operable, so containment remains within its design basis and equipment remains within its environmental qualification.

– Containment spray remains operable providing fission product scrubbing.

– The reactor vessel downcomer and lower plenum remain filled and cooled for almost all PWR designs (although the core may uncover).

– Alternative flowpaths (such as hot-leg injection) are available to allow core cooling for most break locations.

Under Option 3, licensees could pursue a risk assessment of in-vessel effects. Timing is important because of the reduction in decay heat, the onset of chemical effects, and operator actions. A risk-informed approach would evaluate the timing and potential mitigative actions associated with the event, rather than assuming worst-case conditions throughout. For some plants, it may be sufficient to show that hot-leg injection is initiated before core blockage occurs. Other plants may require a more rigorous evaluation of break sizes and locations, chemical effects, and debris flowpaths, and they may need supplemental in-vessel effects tests. However, the staff anticipates that the in-vessel risk assessment will be smaller in scope than the overall STP approach discussed in Enclosure 3. The staff would seek a licensee or several licensees to pilot this approach and develop guidance for industry to follow.

For licensees that pursue Option 3, the staff would expect implementation to be consistent with Option 2 regarding the incorporation of mitigative measures. The staff would expect the deterministic strainer evaluation to be completed within two RFOs after January 1, 2013, and all analyses, testing, modifications, and NRC approval to be completed for the in-vessel evaluation on a schedule consistent with the risk-informed approach of Option 2.

On March 1, 2012, the staff provided SECY-12-0034, “Proposed Rulemaking - 10 CFR 50.46(c): Emergency Core Cooling System Performance During Loss-of-Coolant Accidents (RIN 3150-AH42)” (ADAMS Accession No. ML112520186), to the Commission for review and approval. The 10 CFR 50.46(c) proposed rule would expand the applicability of the rule, account for research findings, and address two petitions for rulemaking. The proposed rule

would also provide performance-based requirements and would not be an optional rule. GSI-191 is focused on the long-term cooling aspect of 10 CFR 50.46. The options presented in this paper are consistent with SECY-12-0034. If licensees resolve GSI-191 using deterministic methods, the in-vessel effects would be measured against performance-based criteria submitted for staff review and approval. This was the approach used by the PWROG in developing WCAP-16793, Revision 2. If licensees elect to use a risk-informed approach that would require an exemption from 10 CFR 50.46(c), the exemption would be based on meeting the criteria in RG 1.174.

Summary of Options

	Suction Strainer Resolution Method	**In-Vessel Effects Resolution Method**	**Resolution Period**
Option 1	Deterministic (Approved Models)	Deterministic (Approved Models)	2 RFOs after January 1, 2013
Option 2	Deterministic (Potential to Refine Models) OR Risk-Informed (STP) Approach	Deterministic (Plant-Specific Testing and Analyses) OR Risk-Informed (STP) Approach	3 RFOs after January 1, 2013 OR 1 RFO after NRC decision
Option 3	Deterministic (Approved Models)	Risk-Informed Assessment of In-Vessel Effects	1 RFO after NRC decision

Under Option 1, licensees would complete all work by January 1, 2017 (two RFOs after January 1, 2013, assuming a two-year cycle). Under Option 2, licensees that pursue a deterministic approach would complete all work by January 1, 2019 (three RFOs after January 1, 2013, assuming a two-year cycle). Licensees that pursue a risk-informed approach under Option 2 would complete all work by the end of 2019 (licensees would submit by December 2015, staff review is expected to exceed one year, followed by one two-year cycle to implement modifications). Under Option 3, all work related to the sump strainers would be completed by January 1, 2017, and all work related to in-vessel effects would be completed by the end of 2019.

Backfit Considerations and the Committee to Review Generic Requirements

Adequate sump performance is necessary following a LOCA to maintain long-term core cooling as required by 10 CFR 50.46(b)(5). When the staff issued GL 2004-02, it determined that the actions and information requested were necessary for the NRC to verify licensee compliance with 10 CFR 50.46(b)(5) and, therefore, fell under the compliance exception of the backfit rule (10 CFR 50.109(a)(4)(i)). The staff believes that additional information requests are needed to determine compliance with 10 CFR 50.46, and that such requests are within the scope of GL 2004-02, so the compliance backfit exception remains applicable.

Several times during the staff's consideration of GSI-191, the staff consulted with the Committee to Review Generic Requirements (CRGR) regarding GSI-191. At each consultation, the CRGR

concurred with the staff's determination that information requests were justified to determine compliance with 10 CFR 50.46. The CRGR also agreed that the compliance backfit exception applied to any actions that may be imposed on a licensee to resolve GSI-191.

Dose Considerations

In SECY-10-0113, the staff noted differences between the doses estimated by industry for insulation removal associated with GSI-191 activities and historical doses reported for similar activities. In SRM-SECY-10-0113, the Commission directed the staff to provide the best possible estimate of the occupational dose that would be realized if plants were to undertake plant modifications to remove insulation and to explain the apparent differences between staff and industry occupational dose estimates. Models for resolving GSI-191 are still being developed and licensees are still performing their evaluations; therefore, the scope of modifications has not been determined at this time. As a result, the staff is not in a position at this time to provide a sound and independent estimate of the additional total occupational dose associated with resolution of GSI-191. The industry estimates that replacing the necessary amount of the remaining insulation would result in 80 to 525 person-rem for each plant. The staff does not have a basis to believe that the industry estimates are unreasonable. Enclosure 4 further discusses this issue.

POLICY DISCUSSION:

Under the risk-informed path in Option 2, licensees would need an exemption from certain requirements of 10 CFR 50.46. The exemption would be based on meeting the guidance in RG 1.174. The proposed change would allow fibrous insulation to remain in containment. Although a fundamental principle of RG 1.174 is that the proposed change meets the current regulations, a licensee can use RG 1.174 to support an exemption request or rule change. In accordance with 10 CFR 50.12, "Specific exemptions," the staff would consult with the Commission before issuing this exemption. Industry representatives have indicated that approximately six plants may pursue this approach, so the staff does not anticipate the need for a rule change at this time.

Option 3 allows separate regulatory treatment of sump strainer issues and in-vessel effects. The policy implications for Option 3 are similar to the risk-informed path of Option 2, with two exceptions: (1) it is not clear whether a licensee would need an exemption for the reduced scope of the change and (2) STP is not explicitly piloting this approach. If Option 3 is selected, the staff requests that identified licensees be permitted to pilot the approach.

Any option selected requires a policy decision on schedule.

NEW REACTORS:

New reactor designs are being evaluated using the deterministic methods that were developed for operating reactors. To date, new reactor applicants use large area strainers and their design approach is to minimize or eliminate fibrous insulation within the zone of influence. The remaining fibrous debris source comes primarily from latent or resident debris and is controlled through containment cleanliness programs. In-vessel effects are being considered for all new reactor designs. In December 2011, the AP1000 standard design certification was amended via rulemaking. This amendment resolved GSI-191 including debris strainers and in-vessel effects.

The AP1000 passive design established well-defined limits for debris through design-specific testing and analysis of screens and fuel assemblies. The remaining new PWR applicants (U.S. EPR and US-APWR), given their limited debris source term, are expecting to resolve GSI-191 in a similar manner appropriate to active plants and those reviews are on-going.

RECOMMENDATION:

All three options presented in this paper are viable paths for resolving GSI-191. The staff recommends that the Commission allow licensees the flexibility to choose any of the options discussed to resolve GSI-191 at its plant(s), subject to the conditions and schedules discussed in this paper.

The NEI letter dated May 4, 2012, indicates that licensees will request a variety of paths to resolution of GSI-191 – all encompassed by the options described in this paper. According to NEI, and other informal discussions between the staff and industry, plants would pursue resolutions in the following manner. Of the 69 units affected by GSI-191, approximately half of licensees would currently meet the "clean plant" criteria and are expected to seek resolution under Option 1. These plants should be able to submit documentation to resolve GSI-191 much sooner than the Option 1 end date. Under Option 2, approximately one quarter of plants would seek to continue in-vessel effects testing to demonstrate that the current plant condition meets the requirements. Approximately six plants would pursue a risk-informed approach being piloted by STP. Licensees have also expressed interest in pursuing Option 3.

Upon Commission approval, the staff will ensure that each plant's GSI-191 chosen resolution option and associated implementation schedule are submitted to the NRC by December 31, 2012. The Director of the Office of Nuclear Reactor Regulations (NRR) would use the appropriate regulatory tools to ensure that safety is maintained and schedules are met as plants resolve GSI-191.

RESOURCES:

Approximately six full-time equivalents (FTEs) are included in the fiscal year (FY) 2013 President's budget. FY 2014 resources and beyond will be addressed through the agency's Planning, Budgeting, and Performance Management Process. NRR has verified that adequate resources are available within the FY 2013 and 2014 budgets to address the proposed options, including the most likely "Combination of Options."

FTE Estimates for Resolution of GSI-191

Fiscal Year	Option 1	Option 2	Option 3	Combination of Options
FY 2013	4.0 FTE	5.0 FTE	5.0 FTE	6.0 FTE
FY 2014	4.0 FTE	6.0 FTE	6.0 FTE	6.0 FTE
FY 2015	2.0 FTE	6.0 FTE	4.0 FTE	6.0 FTE
FY 2016	—	4.0 FTE	1.0 FTE	4.0 FTE

The current staff that review risk-informed license applications are fully loaded on a number of significant applications, including 10 CFR 50.48(c) (National Fire Protection Association 805), 10 CFR 50.69 pilot, and risk-managed technical specification (RITS Initiative 4B) pilot. Some of these activities are being supported with staff detailed from other offices. The staff is attempting to recruit and develop additional PRA experts to be able to support these reviews, but it is recognized that there is limited risk expertise available, both inside and outside the agency. There will also be additional time needed to qualify and train new staff assigned to these application 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/

R. W. Borchardt
Executive Director
for Operations

Enclosures:
1. Background Discussion and Technical Issues
2. Evaluation of Generic Safety Issue-191 Closure Options
3. Risk-Informed Approach to Address GSI-191, South Texas Project
4. Estimating the Dose for GSI-191

BACKGROUND DISCUSSION AND TECHNICAL ISSUES

DESCRIPTION OF DEBRIS-INDUCED CLOGGING

A fundamental function of the containment sump strainer is to support the recirculation function of the emergency core cooling system (ECCS) and containment spray system (CSS). The containment sump recirculates water that has collected at the bottom of the containment following a postulated loss-of-coolant accident (LOCA). Breaks in the reactor coolant system (RCS) piping, known as 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 decay heat following a LOCA and prevent core damage.

If a LOCA were to occur, piping thermal insulation and other materials will be dislodged by the jet emanating from the broken RCS pipe. The flow coming from the RCS break or from the CSS may transport debris (e.g., insulation) to the pool of water that would be present at the bottom of containment. Once transported to the sump pool, the debris could be drawn towards the sump strainers, which are designed to prevent debris from entering the ECCS and CSS. If this debris were to clog the strainers, reactor core and containment cooling would be lost, leading to potential core damage and containment failure.

Some debris would pass through the sump strainer (termed sump strainer "bypass") and be available to lodge in the core (known as in-vessel effects). This could result in reduced core cooling and potential core damage, even if the containment sump strainer were to perform as designed. Therefore, the evaluations for Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on PWR [Pressurized-Water Reactor] Sump Performance," have been expanded to include in-vessel effects.

HISTORICAL BACKGROUND

In 1979, as a result of evolving staff concerns related to the adequacy of 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, Technical Findings Related to Unresolved Safety Issue A-43" (Agencywide Documents and Access Management System (ADAMS) Accession No. ML112440046) 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" (ADAMS Accession No. ML031550731), 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 Revision 0 to Regulatory Guide (RG) 1.82, "Sumps for Emergency Core Cooling and Containment Spray Systems" (ADAMS Accession No. ML111680318), issued June 1974, 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 [Light-Water Reactor] 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 [boiling-water reactor] 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 over the period of 1993 to 1996 (Bulletin 93-02, Supplement 1, "Debris Plugging of Emergency Core Cooling Suction Strainers" (ADAMS Accession No. ML031190684) dated February 18, 1994; Bulletin 95-02, "Unexpected Clogging of a RHR [Residual Heat Removal] Pump Strainer While Operating in Suppression Pool Cooling Mode" (ADAMS Accession No. ML082490807), dated October 17, 1995; and Bulletin 96-03, "Potential Plugging of ECCS [Emergency Core Cooling System] Suction Strainers by Debris in BWRs" (ADAMS Accession No. ML082401219) dated May 6, 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 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 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 blockage than an equivalent amount of either type of debris alone. These research findings prompted the NRC to open GSI-191 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 recirculation operation of the ECCS and CSS. The NRC completed its review of GSI-191 in 2002 and documented the results in a parametric study that 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 2003-01, "Potential Impact of Debris Blockage on Emergency Sump Recirculation at Pressurized-Water Reactors" (ADAMS Accession No. ML031600259). (The endorsement by the Committee to Review Generic Requirements (CRGR) of this bulletin can be found in ADAMS Accession Nos. ML030830459 and ML031210035.) 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 with regulatory requirements concerning the ECCS and CSS recirculation functions, based on a mechanistic analysis. The staff asked licensees that chose not to confirm regulatory compliance to describe any interim compensatory measures that they had implemented or would implement to reduce risk until the analysis could be completed. All PWR licensees have responded to Bulletin 2003-01.

In developing Bulletin 2003-01, the staff recognized that it might be necessary for licensees 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, the NRC did not request that information, but licensees 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" (ADAMS Accession No. ML042360586) 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. (The CRGR endorsement can be found at ADAMS Accession Nos. ML040430074 and ML040840034). In addition, the staff issued substantial guidance on the subject, including a detailed safety evaluation (SE) (ADAMS Accession No. ML043280007) in December 2004 of the Nuclear Energy Institute's (NEI's) guidance document, NEI 04-07, "Pressurized Water Reactor Sump Performance Evaluation Methodology" (ADAMS Accession No. ML050550138). The SE provided a conservative "baseline" deterministic evaluation method and a more risk-informed alternative method that accounted for the extremely low probability of the largest postulated pipe breaks. (The CRGR review of the SE can be found at 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 to reduce the potential for chemical effects or installed debris interceptors to reduce the amount of debris that can reach the sump strainers. However, encouraged by the NRC to take near-term actions to improve 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 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.

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. The staff also discussed research regarding chemical effects that 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.

As the staff's knowledge increased from evaluations of licensee-sponsored tests and evaluations, as well as the chemical effects research, the staff issued supplemental review guidance in March 2008 (ADAMS Accession No. ML080230234) to address headloss testing, coatings evaluations, and chemical effects.

Temporary Instruction (TI) 2515/166, "Pressurized Water Reactor Containment Sump Blockage [NRC GL 04-02]" (ADAMS Accession No. ML060760340) was written to provide guidance to NRC inspectors to determine the adequacy of licensee actions taken in response to GL 2004-02. The TI inspection activities were to verify that the implementation of plant modifications and procedure changes were completed as committed to by each licensee and to verify that the changes were completed in accordance with 10 CFR 50.59. The TI has been completed at all operating domestic PWRs. Inspection Procedure (IP) 71111.17, "Evaluation of Changes, Tests, or Experiments and Permanent Plant Modifications," IP 71111.18, "Plant Modifications," and IP 71111.20, "Refueling and Other Outage Activities," have been revised to

include guidance to ensure that conditions that could affect sump performance will be considered during routine inspection activities.

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 resulted in a review that was unnecessarily focused on compliance versus a determination that the underlying safety issue had been satisfactorily addressed. The DPO panel found that, while the resolution of GSI-191 is focused on compliance, compliance with the regulatory requirements presumptively ensures that adequate safety is maintained. Therefore, the panel found the current approach to be appropriate. The Director of the Office of Nuclear Reactor Regulation agreed with the panel (ADAMS Accession No. ML100990069).

Prior to the Commission meeting on April 15, 2010, concerning GSI-191, 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 using methods consistent with the SE for NEI-04-07. During the April 15, 2010, Commission meeting, industry representatives expressed concern that forcing near-term issue resolution using staff-accepted methods would lead to large radiation exposures to plant staff without significant safety benefit. The Commission issued Staff Requirements Memorandum (SRM)-M100415 (ADAMS Accession No. ML101370261), dated May 17, 2010, requesting the staff to write a Notation Vote policy paper on potential approaches to bring GSI-191 to closure.

In response to SRM-M100415, the staff developed SECY-10-0113, "Closure Options for Generic Safety Issue-191, Assessment of Debris Accumulation on Pressurized Water Reactor Sump Performance" (ADAMS Accession No. ML101820296), dated August 26, 2010. That paper provided three options for closing GSI-191, addressing methods for complying with 10 CFR 50.46. The paper also discussed the timeframes for plant modifications. During the Commission meeting on September 29, 2010, industry representatives again expressed their concerns about forcing near-term resolution, particularly with the understanding that in-vessel effects could be limiting. The industry representatives noted that industry and staff had reached agreement on the additional testing and analyses needed to bring GSI-191 to closure. In SRM-SECY-10-0113 (ADAMS Accession No. ML103570354) dated December 23, 2010, the Commission directed the staff, in part, to consider all options, including a risk-informed approach, while the industry completed testing in 2011 and to submit a SECY paper identifying proposed policy options for resolving GSI-191. This paper responds to SRM-SECY-10-0113.

TECHNICAL ISSUES

The staff knew at the time that the GL and SE were issued that certain aspects of plant post-LOCA behavior 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 or debris deposited in the reactor core. Downstream effects refer to the potential for materials that bypass the ECCS strainer to impact downstream components (e.g., valves, pumps, and the reactor core).

From vendor testing, it became clear that the results in terms of strainer headloss 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 resulting headloss. 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 most limiting sequence or a sequence that was demonstrated to be realistic. The staff's evaluation of the strainer performance and test practices took various forms, including plant-specific audits, reviews of vendor test protocols, staff observation of testing, and detailed reviews of licensee supplemental responses to the GL. To clarify expectations for licensee GL responses that were due at the end of 2007, the staff issued a content guide for GL 2004-02. Despite issuance of the content guide, many licensees' written responses to the GL did not provide the information necessary for the staff to confirm that testing and evaluation methods were acceptable. This resulted in the staff issuing a large number of requests for additional information. Because of the complex nature of GSI-191 issues, the staff performed detailed reviews in each of the technical areas of the problem. The detailed review process led some licensees and other industry stakeholders to express frustration that the staff had 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 developed the integrated review process 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 that does not meet all of the deterministic criteria 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 approximately two-thirds of the PWRs.

Refinements to Methodologies

The staff has been and continues to be receptive to refinements in methodologies. For example, the staff accepted a significant reduction in the "standard assumptions" (found in the staff's SE on NEI-04-07) for the amount of fibrous debris generated by long-term erosion of the larger, less transportable pieces of fibrous insulation, based on industry testing.

The staff also accepted several refinements regarding chemical effects. The staff allowed licensees to demonstrate that chemical effects would be delayed for their plant-specific conditions, which significantly improves the predicted margin because strainer headloss remains low until the available net positive suction head (NPSH) is increased by higher subcooling. Delayed chemical effects can also provide time for licensees to throttle ECCS flow so that the required NPSH is decreased. Furthermore, the staff allowed licensees to conduct strainer headloss tests in simulated plant-specific environments instead of testing by adding the pre-mixed WCAP-16530-NP precipitate originally developed by industry. Some licensees have also performed tests by introducing chemical species at their projected release rate over time, which is more representative of plant conditions.

The staff also permitted refinements to the zone of influence (ZOI), the area around the break where the jet generates transportable debris. The staff has allowed licensees to take credit for smaller ZOIs where it was demonstrated that breaks would have limited separation and offset resulting from piping restraints. These ZOI refinements can have significant effects on the amount of debris generated from breaks that qualify for such treatment. The staff also has been

open to new ZOI testing, but the testing conducted by several licensees was determined to be flawed (see section on ZOI). Several licensees are still pursuing ZOI testing to reduce the amount of debris assumed to be generated following a pipe break (see section on recent developments).

As another example, latent debris amounts can be important for some low fiber plants. In many cases, the staff has accepted that plants have less than the standard assumption for latent debris (found in the staff's SE on NEI-04-07) in the plant and that they have adequate controls in place to ensure that latent debris will not become a significant factor in the operation of the ECCS system.

In conclusion, the staff has accepted several refinements. The staff will continue to accept refinements proposed by industry if they are adequately justified and can be completed in a timeframe commensurate with the Commission decision in this paper. However, there are many instances in which the staff has not accepted past testing, resulting in continued delays in resolving GSI-191. The following sections discuss three examples of such instances.

Zone of Influence

During its reviews of plant responses to GL 2004-02, the staff identified that a number of licensees had used ZOI values significantly smaller than the guidance in the staff's SE to NEI-04-07. The small ZOIs were based on jet impingement testing conducted by Westinghouse. The values were judged by the staff to be significantly smaller than would be expected, and the staff issued a number of requests for additional information about the testing. From staff questions, the industry identified several locations in the test loop in which the inside diameter of the piping was significantly smaller than the jet nozzle. The small diameter locations (choke points) upstream of the jet nozzle were postulated to result in a much weaker jet than the tests assumed. The Pressurized-Water Reactor Owners Group (PWROG) performed confirmatory testing in January 2010 that revealed that the jet pressures were much lower than assumed in the ZOI testing reports. Therefore, the staff did not accept the ZOI volumes determined by this test program, and licensees that referenced them had to recalculate debris loads based on accepted ZOI sizing.

Debris Settling

Most strainer headloss testing used test protocols that ensure (through agitation of the fluid in the test tank) that the debris analyzed to reach the strainers is collected on the strainer surfaces. The staff considers this methodology appropriate. However, some licensees ran the strainer headloss tests in a flume designed to simulate containment pool flow conditions in order to credit debris settlement. Results from completed tests have shown significantly reduced transport of debris to the strainer, but licensees did not demonstrate that the debris settling was prototypical. Licensees and test vendors were not able to demonstrate that test flow conditions (e.g., velocity and turbulence), debris-to-debris and debris-to-wall interactions, and methods for preparing debris and adding it to the test flume resulted in realistic or conservative debris transport. Therefore, the staff has not accepted the test results.

In-Vessel Effects

In-vessel effects is the last area to be addressed by industry, even though the guidance has been under development for several years. The PWROG initially addressed in-vessel effects through a series of calculations. However, prompted by comments made by the Advisory Committee on Reactor Safeguards in 2008, the staff requested testing to supplement the analyses. This resulted in a substantial industry test program. Early testing found that fuel assembly headloss was influenced unexpectedly by flow rate and debris combinations. Further testing was conducted to gain a better understanding of these phenomena, and this testing indicated significantly greater core differential pressure for one vendor's fuel as compared to another's. This led the staff to request more testing to determine whether the differences were caused by fuel design differences or the fact that testing had been conducted at different facilities.

The PWROG is addressing in-vessel effects generically through a topical report that is currently under staff review. The in-vessel limits proposed by the PWROG are designed to bound all plants. The limits are very low and are likely limiting for most plants with respect to the amount of fibrous material in containment. Even plants that have acceptable strainer results may need further modifications to achieve acceptable in-vessel results. The industry is currently developing methods to show that higher in-vessel debris limits are acceptable. Testing at higher fiber levels revealed that fiber beds build up at the core inlet and in grid spacers. To date industry has not addressed how higher fibrous debris amounts may affect the timing of boric acid precipitation at higher fiber levels.

To properly address in-vessel effects, the impact of chemical, particulate, and fibrous buildup in the core needs to be evaluated. To demonstrate adequate post-LOCA long-term cooling, one must ensure that sufficient coolant injection reaches the core to (1) match core boil off to preclude core uncovery and heatup, and (2) prevention of boric acid precipitation in the core, which can block the coolant channels and inhibit core cooling. The buildup of fibrous material at the core inlet and lower spacer grid locations may inhibit mixing of the boric acid within the core region or between the core region and the lower plenum region of the vessel, causing earlier boron precipitation. The timing of boron precipitation establishes key operator actions intended to prevent boron precipitation. In the current analyses, precipitation timing is based on uninhibited mixing of boric acid within the core and with the lower plenum. Interruption of this mixing could invalidate the operator action timing in the emergency operator procedures to control precipitation. In order to more fully address long term core cooling, licensees need to show that buildup of chemicals, particulates, and fibrous material in the core will not prevent adequate water from entering the core, and to show that operator actions adequately prevent boron precipitation.

RECENT DEVELOPMENTS

Developments since the issuance of SRM-SECY-10-0113 can generally be categorized in three areas: (1) technical developments (e.g., the testing completed in 2011), (2) developments in the South Texas Project Nuclear Operating Company (STP) pilot program, and (3) developments related to alternative approaches.

Technical Developments

As noted in SRM-SECY-10-0113, the industry was to perform analysis and testing in 2011 important to the closeout of GSI-191. Enclosure 1 to SECY-10-0113 provides a detailed description of the technical issues related to ZOI, debris settlement testing, and in-vessel effects, as well as the problems that industry had encountered in addressing these issues. The industry has performed testing or analysis in these three areas, and the staff has now either completed its review or is in the process of reviewing the results.

Zone of Influence

The PWROG has performed additional ZOI testing that resolves the previous test issues. This includes testing that did not involve an upstream choke location, thus ensuring that the jet pressures were as expected for the plant conditions. The ZOI calculational methodology used for the recent round of testing has not been previously evaluated. Initial staff impressions are that the methodology may be acceptable. The testing included instrumented tests that allow a better understanding of jet behavior, a jet model to validate that ZOI test thermodynamic conditions were as expected, and target tests to determine ZOIs for various insulation systems. The staff has reviewed the jet model and observed some of the instrumented tests. However, it has not received a topical report providing a full description of the ZOI refinements. It is unclear when a final determination of acceptance of the new methodology will be available.

Debris Settling

After numerous discussions with vendors and licensees, the staff has agreed to a generic procedure that can be used to perform testing that allows settling, including a resolution of the issues described above. The procedure requires complex calculations using computational fluid dynamics models and comparisons between the plant and the test flume. The procedures also include hold points that the staff must review if the plant-specific implementation of the procedure does not meet certain criteria. Up to this point, no plant has tested using this procedure, so it is not clear whether it will provide a successful methodology. The industry testing that credits settling is behind the schedule proposed by industry when SRM-SECY-10-0113 was issued.

In-Vessel Effects

At the time SECY-10-0113 was written, several questions existed about the in-vessel effects testing, which had shown unexpected variations in results between fuel types. The PWROG completed testing to answer these questions. The PWROG determined that the fuel types in the test program respond similarly and differences in test results were mostly attributable to test facility differences. The testing completed during the test program provides part of the basis for the latest revision to the fuel test topical report. The PWROG submitted the revised topical report (Revision 2 to WCAP-16793, “Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid”) in October 2011. The topical report is currently under staff review. The debris limits based on the generic testing are very low, such that in-vessel effects are expected to be the limiting factor for most plants with respect to the amount of fiber in containment.

The industry plans to perform additional testing and evaluations in an attempt to allow some licensees to increase the limits based on plant-specific parameters. The PWROG provided the staff a white paper for information in November 2011. The methodologies described in the white paper were similar to the generic in-vessel effects testing, but using plant-specific flows and driving heads (or flows and driving heads that bound groups of plants instead of all PWRs) to recover margin. Any additional testing will be completed much later than was originally anticipated, delaying licensees' plans for resolution of GSI-191.

The staff's most significant feedback was that the proposed testing did not consider boric acid precipitation. The staff had previously agreed to keep questions of debris blockage and boric acid separate, and the PWROG had separate programs to address each issue. However, information from the in-vessel effects testing showed that, at least at higher fiber amounts, debris beds within the core could result in early boric acid precipitation. Therefore, the staff informed the PWROG that it would need to address boric acid precipitation as part of any plant-specific in-vessel effects testing attempting to raise the acceptable debris limits.

The PWROG reviewed the questions that its boric acid program was attempting to address and developed a path to answer those questions as they relate to debris. The staff held a conference call on February 21, 2012, expressing general agreement with the approach and providing feedback on specific items. The staff met with the PWROG again on March 7, 2012, to discuss the test plans regarding the combined effects of debris and boric acid. The PWROG planned testing that would bound all licensees and demonstrate acceptable core cooling until hot-side injection was initiated. The staff had numerous questions about the accuracy of the scaling in the proposed testing. The staff's position is that the modeling of flow rates and turbulence in the lower plenum need to be well defined for the test results to be prototypical. Since the meeting, the PWROG has continued to develop its test plans. The PWROG plans to complete the testing by June 2013.

Development of South Texas Project Risk-Informed Approach

Since SRM-SECY-10-0113 was issued, the staff has closely followed STP's efforts to develop a risk-informed method for evaluating GSI-191. STP is comparing the risk, measured in core damage frequency (CDF) and large early release frequency (LERF), between the current condition of STP and the postulated condition with STP as a "clean plant." In a sense, this is determining the GSI-191 contribution to CDF and LERF. Enclosure 3 discusses this approach in more detail.

The staff held 12 public meetings with STP to discuss the details of its approach. The staff also visited the plant in November 2011 and attended an STP technical meeting (which was also attended by other licensees that are interested in the approach) in April 2012. The staff has been providing feedback on sensitivities and critical assumptions, both in the meetings and in a letter dated May 4, 2012 (ADAMS Accession No. ML121080006), which STP is factoring into the evaluation. For example, at the staff's prompting, STP is conducting plant-specific testing to validate the chemical effects and the strainer headloss models used in their evaluations.

The staff has been following STP closely to understand how the risk analyses are performed, to assess the viability of a risk-informed approach for the rest of the industry, and to gain insights into areas of conservatism and alternative methods for closing GSI-191. Insights from STP led the staff to recommend Option 2 of this paper, which permits interested licensees to use a

risk-informed approach. Insights from STP also led the staff to develop specific conditions other licensees would need to meet to follow STP's approach. Based on STP's preapplication activities, the staff expects that a licensee that chooses to use a risk-informed approach will be able to identify, early in the process, whether the approach will be successful or whether significant modifications (e.g., insulation replacement) will be needed. Option 2 is structured such that licensees would be in a good position to fall back to a deterministic approach with no significant delay in the modifications if the risk-informed approach will not be successful. This is an important aspect of Option 2.

Insights from STP also led the staff to develop Option 3, which permits in-vessel effects to be addressed in a risk-informed manner. STP's evaluation highlighted the importance of event timing and the importance of hot-side injection, which provides a flowpath around any core inlet blockage (although this may not be the case for all plants). It also indicates that the limiting cases modeled and tested by the PRWOG (and that led to the 15 gram in-vessel limit) are unlikely because, for the majority of break sizes and locations, ECCS injection flow is expected to make it to the core even in the event of core inlet blockage. Questions remain about boric acid precipitation, but these questions would be addressed in a risk assessment of in-vessel effects.

Efforts to Identify Alternative Resolution Paths

The staff consulted industry and other stakeholders with the intent of developing alternative solutions, as directed by SRM-SECY-10-0113. The first public meeting was with NEI on January 27, 2011. In that meeting, industry presented its testing plans for ZOI and in-vessel effects, discussed the need for additional guidance for operability determinations, and presented the approach being developed by STP. Industry and staff laid out general plans for future meetings and agreed to further develop the actions.

The staff issued a *Federal Register* (FR) notice (76 FR 24925) on May 3, 2011, which requested public comment on innovative and creative options to close GSI-191 for the staff's consideration. Industry provided comments in two consolidated letters, one from NEI (ADAMS Accession No. ML11189A080) and one from Westinghouse (ADAMS Accession No. ML11188A125). The NEI letter included three attachments covering (1) regulatory frameworks, (2) operability determinations, and (3) recommendations for relaxations in the conservative modeling. NEI noted that the recommendations provided by the letter were not comprehensive and were not ready for implementation, but were intended to promote discussions of potential methods to risk inform the resolution of GSI-191. The Westinghouse letter did not provide alternative options, but endorsed those provided by NEI.

The regulatory frameworks discussed by the NEI letter were varying degrees of risk informing the GSI-191 issue. The potential methods range from the existing deterministic approach to a fully risk-informed approach being developed by STP. Intermediate approaches included the use of a transition break size (TBS). For breaks smaller than the TBS, the issue would be addressed deterministically using existing guidance. For breaks larger than the TBS, the licensee could use a more realistic evaluation, credit operator actions, and defense-in-depth, and design-basis rules would not apply. The staff had already issued a methodology for using the TBS approach as part of its SE on NEI 04-07. The NEI letter stated that the TBS approach in the staff's SE to NEI 04-07 had not been fully utilized because the conservative modeling assumptions approved by the staff SE had not been adequately relaxed.

The operability determinations discussed in the NEI letter relate to the industry's concern that discoveries of nonconforming conditions in the plant (e.g., finding material that could contribute to ECCS strainer or in-vessel blockage that was not considered in the plant evaluations) will result in the determination that the ECCS is inoperable. The NEI letter expressed the position that conservatisms associated with the currently installed strainers should be credited if an emergent condition associated with strainer operability is discovered. The letter also stated that it may be appropriate to develop a risk-informed technical specification for sump strainers if the risk of continued operation in a degraded condition is below an established threshold. The staff is open to consideration of such an effort and is awaiting industry action on this issue. (The staff proposed that Option 3 of this paper could be used for operability determinations.)

Regarding the recommended relaxations in the deterministic methods contained in the NEI letter, in general the proposals were already in use by licensees, were industry works in progress, or were general ideas that were not fully developed. The staff had already reviewed, but not accepted, some of the recommendations. Therefore, the staff concluded that the response to the FR notice provided little in the way of innovative or creative suggestions that would readily assist in the near-term closure of GSI-191.

The staff met with NEI on September 21, 2011, to discuss its response to the FR notice in more detail. Industry representatives agreed to further develop those recommended relaxations that were perceived to provide the most benefit and that were most likely to receive near-term staff approval, based on the staff's feedback at the meeting. However, by the time of the meeting, it had become apparent that in-vessel effects would be the limiting factor for most plants with respect to the amount of fiber in containment. The perception was that refinements to limiting assumptions, even when combined, would not help a plant meet the very low fiber limits for in-vessel effects. In summary, in-vessel effects significantly restricted the alternatives for resolving GSI-191.

Following the September 2011 meeting, the industry (NEI and the PWROG) further developed several of the options and relaxations and provided white papers to the staff either for review or for information. Those white papers are discussed in more detail under the pertinent technical issues sections in this paper.

Staff Consideration of Alternative That Credits Leak Before Break for In-Vessel Effects

SECY-10-0113 contained considerable discussion about using leak before break (LBB) for GSI-191 evaluations and concluded that LBB should not be used for sump strainer issues. In Option 3 of the current SECY, the staff proposed to separate the manner in which in-vessel effects and strainer clogging are addressed. LBB is one means considered by the staff for addressing in-vessel effects. The staff does not recommend this approach.

The staff position in SECY-10-0113 was that LBB should not be applied to GSI-191 sump strainer evaluations: LBB may be applied to local dynamic effects but not to global dynamic effects. The staff considered debris generation within GSI-191 to have global dynamic effects because of the potential to render the containment sump unable to fulfill its safety functions. That is, the containment systems, ECCS, and equipment qualifications are related to global effects; therefore, as described in the Statements of Consideration (SOCs) accompanying the final rule modifying General Design Criterion 4, "Environmental and dynamic effects design basis," of Appendix A to 10 CFR Part 50, LBB was not applicable. The SOCs state:

> 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 found that while the application of LBB to the containment sump evaluations may have alleviated the need for licensees to modify containment sumps or remove fibrous pipe insulation, it could threaten successful strainer performance. The staff did not find this reduction of defense-in-depth to be acceptable.

In the present case, the staff finds that applying LBB only to in-vessel effects continues to result in a decrease in defense-in-depth, however, the extent of that decrease is reduced. Licensees would still be required to modify containment sumps and remove sufficient fibrous insulation to demonstrate post-LOCA sump strainer performance is acceptable, such that ECCS and CSS would remain operable. Potential in-vessel blockage would not render containment cooling or pressure control inoperable, fission product scrubbing (via CSS) would still be available, and sufficient ECCS flow would likely reach the core for most break sizes and locations (e.g., via ECCS hot-side injection if it is initiated early enough). However, in-vessel effects could obstruct the normal flow paths from the ECCS to the core, and thus would fall under “affecting emergency core cooling systems” as discussed in the SOCs.

If LBB were applied to in-vessel effects, in-vessel evaluations would only consider latent debris and debris generated from breaks in nonqualified piping. Debris from breaks in LBB-qualified piping could be treated as beyond design basis, meaning the debris would be treated as a severe accident for which licensees would be expected to prepare prevention and mitigation strategies, accordingly.

However, this approach may not result in a significant reduction in the scope of modifications and associated occupational exposure needed to resolve GSI-191, latent debris would still need to be addressed, and there is no clear increase in safety to counter the potential reduction in defense-in-depth that this approach would entail. Furthermore, no licensee has expressed interest in this approach. Therefore, the staff does not recommend this approach.

EVALUATION OF GENERIC SAFETY ISSUE-191 CLOSURE OPTIONS

Option 1: Demonstrate Compliance with Title 10 of the *Code of Federal Regulations* (10 CFR), 50.46, "Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors," Based on Approved Models (Maintain the current holistic integrated resolution process).

Description: The U.S. Nuclear Regulatory Commission (NRC) staff would continue its holistic integrated review process for remaining licensee analyses and testing related to Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on PWR [Pressurized-Water Reactor] Sump Performance." The review process 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 uncertainties in the various review areas, the licensee has demonstrated adequate strainer and fuel performance and, therefore, compliance with the regulations.

This option includes staff review of proposed approaches that will be reviewed in the near term (e.g., reduced zones of influence (ZOIs) and settling credit during strainer testing). The deterministic integrated review method has proven effective in closing the sump strainer issue for approximately two-thirds of the PWRs; however, the in-vessel effects issue is still open for almost all licensees.

As part of this approach, the review team would evaluate in-vessel effects based on the generic testing performed by the Pressurized Water Reactor Owners' Group (PWROG) and documented in topical report WCAP-16793, Revision 2, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid" (Agencywide Documents Access and Management System (ADAMS) Accession No. ML11292A021), issued October 2011. The staff expects to issue its safety evaluation (SE) on WCAP-16793, Revision 2, in summer 2012. The generic testing showed that the in-vessel debris limits are very low—15 grams per assembly—such that plants would need to have very low fiber levels in containment or employ methods to filter the water to meet them.

By letter (ADAMS Accession No. ML120730181) dated May 2, 2012, the staff approved "clean-plant" criteria that licensees can use to close GSI-191. The clean-plant criteria relies on WCAP-16793, Revision 2, which is still under staff review. Licensees that use the clean-plant approach would need to satisfy any conditions and limitations on the topical report. Licensees using this approach would likely need to have very little fibrous insulation in containment and strict containment cleanliness programs. Alternatively, plants would rely on an acceptable strainer headloss test, using approved approaches, and demonstrate that they meet the 15-gram in-vessel limit. Some plants have sump strainer design features known as bypass eliminators that significantly reduce the amount of fiber that reaches the core, such that the 15-gram limit can be met.

Once the staff issues its SE on WCAP-16793, Revision 2, all methods will be in place to allow licensees to close GSI-191 in a deterministic fashion. The reduced ZOI and the strainer testing that allows settling credit (described in Enclosure 1), both of which will be reviewed in the near term, would potentially reduce the extent of modifications needed to resolve GSI-191.

Pros:

- 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 will complete its review of ZOI and settling credit in time to support this option. This may reduce the scope of plant modifications.
- This option utilizes current resources already budgeted.
- This option represents a demonstrably successful process which has led to resolution of sump strainer performance issues for approximately two-thirds of PWRs.

Cons:

- Continuance of this approach would likely lead to replacement or modification (e.g., reinforcement) of substantial amounts of problematic insulation at approximately 15 or so affected units, resulting in significant occupational dose.
- If insulation replacements are selected, replacement insulation may not have the same performance characteristics.
- Under this approach, it is difficult to justify nonconforming conditions in the plant (e.g., discovery of materials that were not included in the plant evaluation).

If this option is selected, closeout could be accomplished in two refueling outages. Two refueling outages is a reasonable amount of time to plan the modifications using established (or soon to be reviewed) guidance and install the modifications in a fashion that keeps occupational doses as low as reasonably achievable. This schedule provides the earliest closeout of GSI-191 for all plants; however, it would likely result in the most extensive plant modifications and the highest resulting occupational exposure.

The staff considered, but does not recommend, an alternative schedule in which the Commission chooses a separate schedule for smaller versus larger breaks. The rationale for this distinction would be based on the differing risk for sump performance posed by smaller breaks versus larger breaks. Smaller break loss-of-coolant accidents (LOCAs) are orders of magnitude more likely than larger break LOCAs. Testing has shown that a relatively small amount of debris of the right type can lead to high headloss across a strainer. The thickness of a filtering debris bed that could lead to such losses is on the order of 1/8 inch or less. Additionally, recent industry testing indicates that in-vessel effects may be problematic with even small amounts of debris. Even though the generic in-vessel effects testing only modeled large-break LOCAs, extrapolation of the results to smaller breaks would indicate that even a relatively small break could result in blockage at the core inlet. Therefore, given the very small probability of the largest pipe breaks, smaller breaks are potentially of more significant concern,

depending on the plant. Hence, the staff believes it would be reasonable to expect a near-term resolution for smaller breaks, but additional time (e.g., one additional cycle) could be allotted for larger breaks based on their lower probability. In practice, this would likely result in a delay in the replacement of fibrous insulation that is only impacted by the largest breaks in the large-bore reactor coolant system piping. Affected plants would need to clarify which modifications are for smaller breaks versus larger breaks. The staff would review the distinction and carry the affected plants in a "partially resolved" status for another cycle. The staff does not recommend allowing modifications for larger LOCAs to be further delayed under Option 1.

Regarding in-vessel effects, the staff expects to issue the SE on the topical report in September 2012. However, the industry considers the topical report to be overly conservative. It is likely that some licensees, having resolved suction strainer performance issues, will find that further modifications are needed to address in-vessel effects. As a result, the staff expects that many licensees will request variations of this option. The industry has already indicated (in a letter (ADAMS Accession No. ML12142A316) from the Nuclear Energy Institute (NEI) dated May 4, 2012) that many licensees will seek further refinement of the deterministic methodologies, and approximately six licensees will pursue a risk-informed method. The staff will need to evaluate variations from Option 1 on a case-by-case basis.

Resource Estimates

Resources to support evaluation of remaining PWR licensee submittals, including staff evaluation of the three technical issues that will be addressed in the near term, are 4 full-time equivalents (FTEs) in fiscal year (FY) 2013 and FY 2014, and 2 FTEs in FY 2015. Within the planned activity (PA) code 114-149BA, "Other Licensing Tasks" (from which GSI-191 draws its plant-specific resources), the Office of Nuclear Reactor Regulation (NRR) is currently budgeted for approximately 12 FTE in FY 2013 and FY 2014. FY 2015 resources will be addressed through the agency's planning, budgeting and performance management (PBPM) process.

Resource Estimate for Evaluating Industry-Proposed 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. The industry vendors that perform these tests have provided test protocol revisions that address the staff's concerns regarding debris preparation and addition for future tests. The staff has also reached an agreement with vendors on the significant issues associated with realistic modeling of flows and debris transport to the strainer during the test. However, to date vendors have not provided an example that incorporates these methods in a manner that is acceptable to the staff. It remains uncertain whether the revised methodology being developed by the test vendors will ultimately result in a successful testing approach.

Resource Estimate for Evaluating Industry-Proposed Testing to Justify Reduced ZOIs

The PWROG has completed field work on a project to perform testing combined with numerical modeling to determine realistic jet impingement damage thresholds for insulation systems. The staff has performed preliminary evaluations of some of this work, but is awaiting a topical report that fully describes the methodology. Additional testing could be performed, but the industry has not provided the staff with firm plans for further testing. The staff's review of this work

typically takes 1 year or more. It is still unclear whether the results will support significantly reduced ZOIs for many materials, but the ZOIs are likely to be reduced for reinforced systems (e.g., double banded) that have not been tested yet. If reinforced configurations are significantly more resistant to damage from jet impingement, licensees may choose to modify their insulation systems instead of removing insulation.

Total Resources for Option 1

Description	FY 2013	FY 2014	FY 2015
	FTE	FTE	FTE
Evaluation of remaining PWR submittals and additional regulatory measures as needed	3.0	4.0	2.0
Evaluation of industry ZOI testing	0.5	—	—
Evaluation of industry settling testing	0.3	—	—
Evaluation of in-vessel refinements	0.2	—	—
Total Resources	4.0	4.0	2.0

Option 2: Mitigative Measures and Alternative Methods Approach

Description: Option 2 is a graded approach in which the licensee's actions, and the schedule for those actions, are based on the amount of fibrous insulation in the plant. Licensees would implement defense-in-depth measures to mitigate the residual risk from those issues that have not been resolved. This option is in general alignment with the proposal by NEI in its letter dated May 4, 2012. Under this option, licensees either have or will implement mitigative measures while they completed testing, analysis, and modifications to resolve GSI-191.

Plants with high fiber loads are generally recognized as being at higher risk of strainer blockage and core flow blockage than plants with relatively low fiber amounts, even if this is not the case under all conditions. Plants with high fiber amounts would begin preparation for insulation replacement at the first available opportunity (after submitting their resolution path). As an example provided by NEI, licensees of high-fiber plants would generally take measurements during the first refueling outage after January 1, 2013, in preparation for insulation removal.

The NEI letter categorized plants into three categories based on fiber amount and provided the number of plants in each group. NEI's approach can be summarized as follows:

- Plants with Substantial Fibrous Insulation
  - Licensees would take measurements at the first opportunity (following the submittal) to prepare for insulation modifications.

  - Licensees would identify the resolution path and schedule, using either of the following approaches:

    - A deterministic approach: This approach is similar to Option 1 of this paper, except licensees may pursue additional modeling refinements as time permits.

    - A risk-informed approach: This approach is being piloted by the South Texas Project Nuclear Operating Company (STP). Enclosure 3 of this paper provides further information on this approach.

  - Licensees would identify defense-in-depth measures that mitigate the potential effects of debris during the time required to complete the remaining actions.

- Plants with Low to Medium Fibrous Insulation

  - Licensees would identify the resolution path and schedule, similar to above.

  - Licensees would identify defense-in-depth measures that mitigate the potential effects of debris during the time required to complete the remaining actions.

- Plants with Minimal Insulation

  - Licensees would inform the staff of resolution status. These plants are expected to already meet deterministic criteria for closing GSI-191.

NEI has proposed a submittal date of December 31, 2012, for all licensees to identify the plant-specific GSI-191 resolution path and schedule. The submittals will include a summary of actions already taken to minimize the impact of debris blockage. For plants that have not demonstrated compliance by deterministic methods, the submittals will include defense-in-depth measures that have been or will be taken to mitigate the effects of debris while analyses and testing are completed. Most licensees implemented mitigative measures for suction strainer clogging following Bulletin 2003-01, “Potential Impact of Debris Blockage on Emergency Sump Recirculation at Pressurized-Water Reactors” (ADAMS Accession No. ML031600259) dated June 9, 2003, and Generic Letter (GL) 2004-02, “Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors” (ADAMS Accession No. ML042360580) dated September 13, 2004. The staff would expect these measures to be in place while suction strainer performance is resolved, if applicable, and the licensee to implement additional mitigative measures for in-vessel effects. Such measures could include operator training and enhanced procedures to monitor reactor water level and core exit temperatures and, if core inlet blockage is indicated, a change in the injection lineup (e.g., initiate hot-side injection or change the hot-side injection point). Hot-side injection provides a coolant flowpath that bypasses the core inlet which may become blocked by debris. For some plants, operators could control containment sump temperature to delay the onset of chemical effects until hot-leg injection is initiated. Other measures may also be available.

For licensees that pursue a deterministic approach, NEI proposed that all actions would be completed within three refueling outages after January 1, 2013. Some licensees are likely to close GSI-191 using existing methods or the clean-plant criteria. For those licensees, Option 2 is similar to Option 1. Other licensees will continue to refine the deterministic evaluation models, particularly related to in-vessel effects, to reduce the scope of modifications to the plant. These licensees would also complete the modifications in three refueling outages.

For licensees that pursue a risk-informed approach, which is being developed by STP, NEI proposed that licensees will submit their analyses 6 months to 1 year following issuance of the staff's SE for STP, which is projected to be completed by December 2014. There is a long lead time for the extensive testing and analyses that is required to use a risk-informed approach. The staff would expect licensees to commit to performing any testing needed to verify important assumptions within two refueling outages (after January 1, 2013), so licensees would have a strong indication of whether this approach will be successful for their plant significantly in advance of their submittal date. The staff will conduct periodic preapplication meetings with licensees that pursue a risk-informed approach. Licensees would be expected to pursue a deterministic approach if the risk-informed approach is determined not to be viable for their plant. Therefore, if a licensee initiates a risk-informed approach and determines that it will not be successful, the licensee could complete all modifications within three refueling outages, similar to a plant that uses a deterministic approach.

Pros:

- Licensees incorporate defense-in-depth measures to mitigate the residual risk of strainer or in-vessel issues that have not been resolved, as applicable.
- Plants that meet the clean-plant criteria would close GSI-191 in the near term.
- This option permits licensees to pursue a risk-informed approach, piloted by STP, in which any needed plant modifications would focus on the areas of greatest risk.
- This option allows licensees to pursue new approaches or refinements to existing approaches that could reduce the scope (and dose) of modifications.
- This option aligns with industry's proposed actions for closing GSI-191.

Cons:

- The industry has a history of pursuing refinements that are either not approved by the staff or for which the improvements are minor. Thus, new approaches that would remove or reduce the need for additional modifications may never materialize.
- Plants with the highest fiber loads take the longest to reach resolution of GSI-191.
- This approach requires more staff resources than for Option 1, but those resources are within the budgeted resources for FY 2013 and 2014.

Resource Estimates

Resource Estimate for Review of Deterministic and Risk-Informed Approach

Baseline resources are similar to Option 1 and are based on plant-specific reviews of licensee's final supplements to GL 2004-02. Additional resources are estimated based on the number of licensees that are expected to pursue plant-specific in-vessel effects testing or a risk-informed approach, or both, as discussed in NEI's letter dated May 4, 2012.

Resource Estimate for Evaluating Licensee Site Specific In-Vessel Evaluations

The staff expects that several licensees will attempt to justify in-vessel debris limits beyond those currently approved by the staff by using minor changes to the methodology in the PWROG topical report. The PWROG has developed several alternatives for use by licensees, but the staff has not approved them. Depending on the methods chosen, staff review time will vary.

Within the PA code 114-149BA, "Other Licensing Tasks," (from which GSI-191 draws its plant-specific resources), NRR is currently budgeted for approximately 12 FTE in FY 2013 and FY 2014. FY 2015 and FY 2016 resources will be addressed through the PBPM process.

Total Resources for Option 2

Fiscal Year	Option 1 Baseline*	Risk Informed**	Testing	Total
	FTE	FTE	FTE	FTE
FY 2013	3.0	1.8	0.2	5.0
FY 2014	3.0	2.5	0.5	6.0
FY 2015	1.0	5.0	—	6.0
FY 2016	—	4.0	—	4.0

*Option 1 baseline is prorated because some licensees opt for a risk-informed approach.
**Half of the resources require risk expertise.

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.

The current staff that review risk-informed license applications are fully loaded on a number of significant applications, including 10 CFR 50.48(c) (National Fire Protection Association (NFPA) 805), 10 CFR 50.69 pilot, and risk-managed technical specification (RITS Initiative 4B) pilot. Some of these activities are being supported with staff detailed from other offices. The staff is attempting to recruit additional PRA experts to be able to support these reviews, but it is recognized that there is limited risk expertise available, both inside and outside the agency. There will also be additional time needed to qualify and train new staff assigned to these application reviews.

Option 3: Different Regulatory Treatment for Suction Strainer and In-Vessel Effects

Description: Option 3 permits the separate regulatory treatment of the sump strainer and in-vessel effects, based on the different consequences. Blockage of the containment sump strainers and in-vessel blockage may both lead to core damage, but blockage of the containment sump strainers would also affect the containment barrier and other mitigation capabilities, representing a significant reduction in defense-in-depth.

In SECY-10-0113, the staff recommended against separate regulatory treatment for in-vessel effects because it was viewed as delaying additional needed modifications (e.g., replacement of fibrous insulation with less problematic materials). The concern was that separating the issues would result in one set of modifications to resolve the sump clogging issue and a second to resolve in-vessel effects, which could increase the overall dose for resolving GSI-191.

If the sump strainer is blocked, flow from the emergency core cooling system (ECCS) into the core would be interrupted, reactor vessel inventory would be lost (with possible vessel failure), containment cooling and pressure control would be lost, and containment spray would be unavailable to scrub fission products. Blockage of the sump strainers does not preserve the balance among the three layers of defense-in-depth or preserve the multiple fission product barriers. Sump strainer blockage results in the following:

- a significant reduction in the effectiveness of two of the three layers—accident prevention (preventing core damage and containment heat removal) and mitigating accidents (removing fission products with containment sprays), and

- the creation of conditions that degrade the remaining fission product barriers (causing core damage and increasing the likelihood of containment failure).

Hundreds of thousands of gallons of water would remain in lower containment from the injection phase, but little or no flow would be available for recirculation to the reactor coolant system for long-term cooling. In addition, little or no flow would be available for containment pressure and temperature control or for fission product scrubbing.

Postulated in-vessel effects do not impact flow through the ECCS pumps or the containment spray system (CSS). Hot-leg injection would remain available, which may provide an alternate path to cool the core such that fuel damage might not occur. The reactor vessel downcomer and lower plenum would remain filled (for most plant designs), ensuring that the vessel shell remains cooled. Containment cooling and containment spray would remain fully operable throughout the accident, ensuring that the containment barrier would not be challenged even if fuel damage did occur. Equipment inside containment would remain within its environmental qualification.

Under Option 3, the NRC would maintain defense-in-depth for strainers by requiring strainer operability to be demonstrated using conservative deterministic methods.

Under Option 3, in-vessel effects would be treated in a risk-informed manner. The STP initiative is providing important insights into in-vessel effects. Hot-leg injection provides an alternative path for ECCS flow to reach the core. The timing and location of hot-leg injection are major

considerations in responding to in-vessel blockage, and changes to the operation of hot-leg injection could be made, if needed, to address in-vessel effects. The timing of the onset of chemical effects is also important, especially if the chemical effects do not occur until after hot-leg injection is initiated. Break size and break location are important because, for the majority of break sizes and locations, ECCS injection will still reach the core even if the core inlet is blocked.

It should be noted that flow rates necessary to remove decay heat decrease sharply after a reactor scram. At the earliest initiation of recirculation (following a design-basis double-ended guillotine break LOCA), the flow rate needed to remove decay heat is approximately 500 gallons per minutes (gpm) for a 3,800 megawatt thermal unit. This drops to 200 gpm within hours after the accident and continues to decrease thereafter. While ECCS injection flow rates vary by design, typical values far exceed the flow required for decay heat removal.

Under this option, licensees would quantify the risk of in-vessel blockage using the methods and criteria found in Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis" (ADAMS Accession No. ML100910006) considering event timing and operator actions. The staff anticipates that this approach would be less extensive and require fewer resources than the STP approach because only in-vessel effects are treated in a risk-informed manner. Licensees could maintain defense-in-depth by reducing problematic materials in specified ZOIs, if needed; enhance detection of in-vessel effects; and strengthen mitigative actions, such as procedures to ensure timely implementation of hot-leg injection. Defense-in-depth would be within the scope of the assessment process. This approach may not require an exemption, depending on a plant's design features. For example, plants with multiple hot-leg injection paths may be able to mitigate breaks in any location of the reactor coolant system, provided hot-leg injection has adequate flow rate and is initiated in time. Other plants may show that the risk of in-vessel blockage is sufficiently small to support an exemption.

The staff would seek one or more volunteers to pilot this process and develop the necessary technical bases and guidance. This approach could be implemented under the constraints and timelines of Option 2, such that the scope of GSI-191 modifications is reduced, or this approach could be developed later either for margin recovery or to support operability evaluations for nonconforming conditions. NEI has stated that licensees need methods to evaluate nonconforming conditions in the plant (e.g., operability evaluations). In its May 4, 2012, letter, NEI mentions a risk-informed approach. To date, the industry has not offered any specific proposals. The staff expects that any development of guidance for nonconforming conditions would be in parallel with licensee's efforts to close GSI-191.

Pros:

- This option maintains defense-in-depth by requiring a deterministic evaluation of sump strainer performance.

- This option allows a more realistic assessment of in-vessel blockage and a consideration of the associated risk.

- This option may reduce the scope of modifications and associated occupational exposure.

- The scenario timelines and risk assessments required by this option would establish a framework for evaluating nonconforming conditions.

Cons:

- Licensees with large amounts of fibrous insulation may still be unable to bring the issue to closure under this option.

- This approach requires more staff resources than for Option 1, but those resources are within the budgeted resources for FY 2013 and 2014.

- This approach has not been developed or piloted yet. Therefore, it would take time and resources to develop.

Resource Estimates

Resource Estimate for Review of Deterministic and Risk-Informed Approach

Baseline resources are similar to Option 1 and are based on plant-specific reviews of a licensee's final supplements to GL 2004-02. Additional resources are estimated based on the number of licensees that are expected to pursue plant-specific in-vessel effects testing or a risk-informed approach, or both, as discussed in NEI's letter dated May 4, 2012.

Within the PA code 114-149BA, "Other Licensing Tasks," (from which GSI-191 draws its plant-specific resources), NRR is currently budgeted for approximately 12 FTE in FY 2013 and FY 2014. FY 2015 and FY 2016 resources will be addressed through the PBPM process.

Total Resources for Option 3

Fiscal Year	Option 1 Baseline*	Risk-Informed**	Total
	FTE	FTE	FTE
FY 2013	3.0	2.0	5.0
FY 2014	3.0	3.0	6.0
FY 2015	1.0	3.0	4.0
FY 2016	—	1.0	1.0

*Option 1 baseline is prorated because some licensees opt for risk-informed approach.
**Half of the resources require risk expertise.

The current staff that review risk-informed applications are fully loaded on a number of significant applications, including NFPA 805, the 10 CFR 50.69 pilot, and the risk-managed technical specification (Initiative 4B) pilot. Some of these activities are being supported with staff detailed from other offices, which will end at the close of the fiscal year. The risk review

branch is in the process of recruiting additional capability to support these activities, but it is recognized that limited risk expertise is available, both inside and outside the agency.

Risk-Informed Approaches

Risk-informed Options 2 and 3 are consistent with the risk management goal of NUREG-2150, "A Proposed Risk Management Regulatory Framework" (ADAMS Accession No. ML12109A277) issued April 2012, and will ensure the following:

- appropriate barriers, controls, and personnel to prevent, contain, and mitigate exposure to radioactive materials, according to the hazard present, the relevant scenarios, and the associated uncertainties, and

- maintenance of acceptably low risks resulting from the failure of some or all of the established barriers and controls, including human errors.

The two risk-informed options are consistent with Alternative 1 of Appendix H to NUREG-2150.

RISK-INFORMED APPROACH TO ADDRESS GENERIC SAFETY ISSUE-191

SOUTH TEXAS PROJECT

Transition Break Size Approach

On December 23, 2010, the U.S. Nuclear Regulatory Commission (NRC, or Commission) issued Staff Requirements Memorandum (SRM) SECY-10-0113, "Closure Options for Generic Safety Issue [GSI]-191, Assessment of Debris Accumulation on Pressurized-Water Reactor [PWR] Sump Performance" (Agencywide Documents Access and Management System (ADAMS) Accession No. ML103570354). Option 2 of that SRM focused on development of additional guidance to support a risk-informed approach that would rely on the impending proposed rulemaking for Title 10 of the *Code of Federal Regulations* (10 CFR) Section 50.46a, "Acceptance criteria for reactor coolant system venting systems," or Section 6 of Nuclear Energy Institute (NEI) 04-07, "Pressurized Water Reactor Sump Performance Evaluation Methodology." Both of these approaches reduce the loss-of-coolant accident (LOCA) break area that must be treated as a design-basis accident (DBA) through use of a transition break size (TBS). The approaches classify LOCAs smaller than the TBS as design-basis accidents, and LOCAs larger than the TBS as beyond design-basis accidents. The TBS in 10 CFR 50.46a was selected to equal the cross-sectional flow area of the inside diameter of the largest piping attached to the reactor coolant system (RCS).

The Commission approved the staff's request to withdraw the draft final rule for 10 CFR 50.46a. The staff may resubmit the rule after responding to the Commission's direction to disposition Recommendation 1 of the Near-Term Task Force review of insights from the Fukushima Dai-ichi accident. The staff expects to respond to the Commission in February 2013.

Section 6 of NEI 04-07 is still available for licensee use, and implementation of the TBS approach for GSI-191 could benefit licensees by reducing the scope of potential modifications at some remaining plants. The largest LOCAs typically have the potential to generate the most debris and are usually the limiting breaks in licensees' sump performance analyses. However, the staff has not received any requests to use the TBS approach. One reason for the seeming lack of interest may be that this approach would require separate analyses for breaks above and below the TBS using different assumptions. This would potentially require separate demonstration tests for the suction strainer. In addition, the potential benefits from using this approach may be limited because the amount of fiber that may be problematic for in-vessel effects can still be generated by LOCAs smaller than the TBS, especially in plants with large quantities of fibrous insulation. Further, the TBS approach would most likely require an exemption from 10 CFR 50.46, due to the staff's withdrawal of the draft final rule.

South Texas Project Nuclear Operating Company Approach

Because no licensee has notified the staff of intent to pilot the TBS approach, the staff has focused on the Commission's direction (from the December 23, 2010, SRM) to fully explore the policy and technical issues of how the application of a "no-transition-break-size" approach might work. The Commission referred to a December 9, 2010, letter from South Texas Project Nuclear Operating Company (STP) that stated its intent to pursue a risk-informed approach to address GSI-191. One of the main objectives of the risk-informed approach is to estimate the difference in risk (delta risk) if some or all fibrous insulation were to remain installed at the plant.

These risk estimates would be used in combination with the guidance of Regulatory Guide (RG) 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis," to provide a basis for GSI-191 resolution. STP has stated that the risk-informed approach would be used to target those plant modifications with the highest risk significance. It is expected that resolution of GSI-191 using this approach will require an exemption from certain requirements in 10 CFR 50.46 (if the analyses are approved by the staff).

The STP approach does not consider a TBS. The STP approach attempts to characterize the physical behavior of debris generation and transport over a full range of plausible conditions. Some aspects of GSI-191 have limited data support; thus uncertainty characterization in the form of cumulative distribution functions is an important part of the description of the 20 parameters modeled as part of the initial quantification.

The STP approach uses the software platform called Containment Accident Stochastic Analysis (CASA) Grande to compile a spectrum of time-dependent results for many thousands of postulated accident sequences to estimate the risk of flow blockage leading to core damage during recirculation scenarios. CASA Grande can process uncertainty distributions on any number of input parameters. CASA Grande evaluates multiple sizes of breaks at every weld in containment, and it always includes the double-ended guillotine break condition for every weld. Nominal times to drain the refueling water storage tank (RWST) and reach recirculation are presently used for each LOCA size category, but break-size specific times based on thermal hydraulic calculations may soon be interfaced to improve fidelity of the accident time histories. STP plans to model up to 50 parameters in the future. As the complexity of the model grows, so do the staff resources needed to perform the review. This review has the potential to be one of the most resource-intensive risk-informed reviews undertaken by the staff. The review may require resources similar to those used for the pilot for National Fire Protection Association 805, "Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants."

Discussions with STP have revealed the need for experimental testing to support some of the statistical distributions used in the evaluation, especially in the area of chemical effects and head loss models. The staff's past experience in these areas is that testing to demonstrate physical models or assumptions has often produced unexpected results. Head loss is a function of the type and quantity of chemical and non-chemical debris, along with the filtering debris bed characteristics. Determining the best estimate and distributions of these parameters is challenging since the debris bed constituents, properties, and chemical effects depend on additional factors such as break location, debris transport, and temperature. In addition, testing is not able to fully simulate the post-LOCA environment. The ability to accurately model head loss, including any chemical effects, represents a key concern with this risk-informed approach. Therefore, developing a defensible technical basis with the upcoming testing in 2012 will be a critical licensee action.

Detailed review of the physical model and assumptions will be necessary because of the heavy reliance on them. STP cannot adequately model chemical effects in the probabilistic risk assessment (PRA) until it justifies its assumptions with plant-specific testing that is scheduled for 2012. The current model makes assumptions that the staff does not accept as accurate or conservative. For example, the staff does not accept the use of the NUREG/CR-6224, "Parametric Study of the Potential for BWR [Boiling Water Reactor] ECCS [Emergency Core

Cooling System] Strainer Blockage Due to LOCA Generated Debris," correlation, coupled with a chemical bump up factor, to calculate strainer head loss. The staff does not accept the strainer bypass correlation used in the initial quantification due to insufficient data. The staff does not accept the current assumption that strainer blockage will not occur if the debris bed is less than 1/8th-inch; the staff currently accepts a 1/16th-inch debris bed for this assumption. The staff does not accept the assumption that chemical effects would not be a factor for in-vessel effects in the event of a cold-side break. Also, STP has not addressed the potential effects of debris on the timing of boric acid precipitation.

STP is currently conducting two major test programs, each of which has subcategories of tests. The first test program aims to validate the head loss correlation currently being used by STP. The second is a chemical effects program intended to determine realistic chemical effects for STP under varying post-LOCA scenarios. These test programs are interrelated. Head loss tests, to validate the STP head loss model, are being performed in a vertical loop. These tests will have to model multiple potential debris load combinations to accurately predict the strainer head losses that could occur due to debris. The chemical effects test program consists of multiple short- and long-term tests to determine the potential interactions that chemical precipitates could have with debris deposited on the emergency core cooling system strainer or in the core. After the chemical effects and strainer tests are completed, STP will need to model the interaction between debris and chemicals. Because of the potential combinations of debris that can reach the strainer and core and the potential variability of the chemicals that may be produced in the post-LOCA environment, the integration of the results of the test programs into a realistic prediction of strainer and in-vessel head losses will be complex.

Uncertainty becomes more important when dealing with complex phenomena. One way to address uncertainties is with defense-in-depth and safety margins. Although STP has not explicitly addressed defense-in-depth measures in support of its proposed resolution of GSI-191, NEI submitted a letter dated March 5, 2012 (ADAMS Accession No. ML120730661), addressing defense-in-depth. NEI stated in the letter that to ensure the availability of adequate defense-in-depth measures, it is important that PWRs maintain capabilities to detect and mitigate inadequate flow through recirculation strainer(s) and the reactor core. NEI provided a listing of potential defense-in-depth measures such as: (1) reducing flow through the strainer(s), (2) monitoring differential flow across the strainer, differential water level in the sump, pump distress, core exit thermocouples, and reactor water level indication, (3) refilling or realignment of the RWST for injection flow, (4) using injection flow from alternate sources, and (5) transfer to hot leg injection or combined hot leg/cold leg injection flow paths. STP has described similar capabilities and modeled them in the PRA, but has not explicitly identified them as defense-in-depth measures in support of GSI-191 resolution. The staff expects STP to include a description of such features that are modeled in the PRA or credited for addressing uncertainties in the license amendment request (LAR). In addition, appropriate regulatory controls, including possibly license conditions, will need to be included in the LAR to support the assumptions in the PRA and the defense-in-depth guidance in RG 1.174.

STP's preliminary quantification results are in Region 3, "Very Small Changes," of RG 1.174, which means the staff would consider the proposal to leave in place certain amounts of fibrous insulation. Key risk insights from the preliminary analyses and initial quantification are that blockage of the strainers sufficient to cause loss of net positive suction head is not predicted because of the decrease in containment temperature by the time the debris arrives. The dominant mechanism leading to fuel damage for medium and large LOCAs is in-vessel effects,

not sump strainer blockage. In determining the amount of debris that reaches the core, STP's model shows that approach velocity at the strainer is as important to risk as, or more important than, break size or size of the zone of influence. Fluid approach velocity at STP has been greatly reduced by the addition of larger strainers at STP. Approach velocity is reduced further during smaller breaks. Switch over to hot leg injection can mitigate in-vessel effects, including boron precipitation. These risk insights show the importance of procedures and training to initiate hot leg injection, reducing injection flow to that needed, and procedures and training to refill and/or realign the RWST.

Validation of these risk insights is contingent on additional work by STP. For example, the initial quantification assumes high debris amounts for in-vessel effects. STP plans to justify these assumptions through proposed testing that it will perform in 2012. If the in-vessel debris limit is less than STP assumed in the initial quantification, STP would need to further plant modifications, such as selective insulation removal and/or installation of bypass eliminators.

Generic Applicability of the STP Approach

A licensee could use the guidance in RG 1.174 to support a proposed licensing basis change related to a proposed exemption. The STP alternative approach will most likely require an exemption from the long-term cooling requirements in 10 CFR 50.46. In accordance with 10 CFR 50.12, "Specific exemptions," the staff would inform the Commission before issuing such an exemption. The staff would plan to follow up the exemption with a proposed rulemaking unless the number of licensees applying this approach was ten or fewer. Industry has indicated that this approach may be pursued by six plants.

As discussed in Enclosure 2, licensees interested in pursuing this option must inform the staff of their intent by December 31, 2012 (consistent with the NEI proposal in its letter dated May 4, 2012). The staff would work with these licensees to develop submittal schedules and conduct preapplication meetings to reach agreement on plant-specific testing and analysis. Licensees would submit their risk-informed analyses in a staggered schedule all within 1 year following the staff's approval of the STP approach (staff-projected completion December 2014). These licensees would need a PRA that meets RG 1.200, Revision 2, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities," and that has been acceptably peer reviewed. For those supporting requirements not meeting Capability Category II, the licensee would have to provide sufficient information to demonstrate the acceptability of those supporting requirements to meet the STP approach. Alternatively, the licensee could have a focused-scope peer review performed on the required Capability Categories. The licensee would also have to commit to develop a model of plant piping and insulation, sufficient to follow the STP approach, in its next refueling outage after the December 31, 2012, letter (e.g., the first refueling outage (RFO) after January 1, 2013), and commit to perform any plant-specific testing needed to justify major assumptions (e.g., chemical effects or strainer head loss correlation) within two RFOs after January 1, 2013. If it becomes apparent that a risk-informed approach will not be successful (e.g., unexpected test results), licensees would be required to pursue a deterministic approach by the end of the third RFO after January 1, 2013.

The staff resources required to review the STP approach are still uncertain but appear to be significant. The staff would need to review the licensee's bases for approximately 20 probability distributions involving break size, zone of influence, debris generation, transport, strainer

bypass, and chemical effects. In addition, the staff will have to review the results from the chemical effects test program, testing for strainer head loss, and possibly testing for in-vessel effects. The staff anticipates performing some verification of thermal-hydraulic codes for modeling RCS and containment behavior, evaluating the effects of boric acid precipitation, and reviewing human actions credited in the analyses. The staff has included resource estimates in the body of the paper and Enclosure 2.

In summary, the staff considers the STP approach to be viable and informative. Key elements such as event timing are evaluated for the range of accident conditions, resulting in a more thorough understanding of the sensitivities and uncertainties of GSI-191. A licensee would be better able to identify those modifications with the most impact on safety and/or focus its efforts on the appropriate defense-in-depth measures. However, this approach requires significant additional evaluation and/or testing compared to the deterministic methods to demonstrate that leaving existing fibrous insulation in place meets the risk acceptance guidelines of RG 1.174. As a result, success with this method will not be assured for several years.

ESTIMATING THE DOSE FOR GENERIC SAFETY ISSUE-191 INSULATION REMOVAL

In Staff Requirements Memorandum (SRM)-SECY-10-0113, "Closure Options for Generic Safety Issue [GSI]-191, Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance," dated December 23, 2010 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML103570354), the U.S. Nuclear Regulatory Commission staff noted significant differences between the industry-estimated doses for insulation removal associated with GSI-191 activities and reported historical doses for similar activities. As stated in SECY-10-0113, the staff conducted a limited survey of nine licensees who have performed significant insulation replacements associated with steam generator replacement and activities associated with GSI-191. Results of this survey showed an average total reported dose of 19 person-rem. In contrast, during an April 15, 2010, Commission meeting, industry provided the highest estimated dose of future insulation replacements provided at 600 person-rem, with an average dose of 200 person-rem.

At the September 29, 2010, public Commission meeting, industry representatives provided additional information, stating that two high-fiber units (but with a low source term) had recently substantially completed GSI-191 insulation replacement and had experienced 37 person-rem and 76 person-rem. The estimate given for another two-unit plant with considerable work remaining was 36 person-rem to 162 person-rem. The staff did not take issue with the estimates for those units. The staff is sensitive to the dose impacts of this type of work, and supports alternative approaches that can resolve the safety concerns with less radiation exposure.

In SRM-SECY-10-0113, the Commission gave the following direction:

> On the subject of occupational dose, the staff should provide the Commission with the best possible estimate of the occupational dose that would be realized if the remaining plants were to undertake plant modifications to remove insulation. Staff should also provide better understanding of the differences between staff and industry estimates.

At this time, the staff is unable to provide a sound and independent estimate of the additional total occupational dose associated with insulation removal to close out GSI-191. The dose values cited by the staff in SECY-10-0113 were historical doses reported by licensees for specific tasks generally associated with closure of containment sump issues of GSI-191. The staff has not yet determined the impact of in-vessel effects and the scope of related modifications.

Among the difficulties in providing a broader dose estimate for GSI-191 insulation removal activities are the following:

- Final scope remains uncertain (e.g., additional modifications may be necessary);
- Installation decisions (e.g., insulation banding versus replacement) affect job dose;
- Radiation fields vary by unit and by location at a unit;
- Unexpected contamination levels can slow work, increasing job dose; and
- Hazardous materials may necessitate additional handling steps within radiation areas.

Additionally, units that have already replaced all insulation necessary to demonstrate operability of the containment sump (thus not among “the remaining plants” in the SRM) may be required to replace additional insulation to resolve in-vessel concerns, incurring additional radiation exposure to workers.

The industry recently provided updated dose estimates (see letter from the Nuclear Energy Institute (NEI) dated March 30, 2012 (ADAMS Accession No. ML12095A319)), based on additional experience gained since the September 29, 2010, Commission meeting. While noting estimating difficulties similar to those identified above, the NEI letter summarizes the issue as follows:

> Dose estimates for replacing insulation on a steam generator and associated piping on a unit basis ranged from as low as 17 person-rem to as high as 276 person-rem. The most typical estimate was in range of 50-70 person-rem. Actual dose for this scope of work ranged from 21 to 58 person-rem. Dose estimates were also provided for replacing “All” affected insulation on a per unit basis, and those estimates ranged from 80 to 525 person-rem.

As noted above, actual doses tend to be lower than estimated; however, given the uncertainties in scope and site-specific factors such as source term and hazardous materials, the staff does not have a basis to believe that the industry estimates are unreasonable.