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.