UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

May 17, 2017

Mr. Victor McCree
Executive Director for Operations
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: SAFETY EVALUATION OF LICENSE AMENDMENT REQUEST BY SOUTH TEXAS PROJECT NUCLEAR OPERATING COMPANY TO ADOPT A RISK-INFORMED RESOLUTION OF GENERIC SAFETY ISSUE-191

Dear Mr. McCree:

During the 643rd meeting of the Advisory Committee on Reactor Safeguards, May 4-5, 2017, we reviewed the draft safety evaluation for the South Texas Project Nuclear Operating Company (STPNOC) license amendment request (LAR) to adopt a risk-informed resolution to Generic Safety Issue-191 (GSI-191), "Assessment of Debris Accumulation on PWR Sump Performance," as its licensing basis analysis for the South Texas Project (STP) Units 1 and 2, and close Generic Letter (GL) 2004-02. Our Thermal-Hydraulics Phenomena Subcommittee also reviewed this matter during meetings on May 8-9, 2012, September 3, 2014, March 18, 2015, April 5, 2017, and April 18, 201. During these meetings, we had the benefit of discussions with STPNOC and the NRC staff. We also had the benefit of the referenced documents.

CONCLUSIONS

1. The STPNOC proposed change to its licensing basis as described in its LAR is acceptable.

2. The STPNOC proposed changes to the technical specifications are acceptable, and there are no changes to the radiological source term as previously approved for STP Units 1 and 2.

3. There is reasonable assurance that the health and safety of the public will not be affected by operation of STP Units 1 and 2 in the proposed manner.

4. The staff should ensure that future application of this methodology benefit from more systematic implementation of the risk assessment process.

BACKGROUND

In the event of a loss-of-coolant accident (LOCA), the emergency core cooling system (ECCS) provides water to the reactor core to remove decay heat and the containment spray system (CSS) injects water into the containment atmosphere to condense steam and reduce pressure.

Water is supplied from the refueling water storage tank until a low level is reached, and then ECCS and CSS pumps recirculate this water by taking suction from containment sumps through sump strainers and piping back to the pumps.

During a LOCA, two-phase water jets coming from a pipe break can dislodge and fragment thermal insulation and other materials near the pipe. Water flow transports this debris to the containment recirculation sump. Debris could then be drawn towards the sump strainers, which are designed to prevent debris from entering the CSS and the ECCS pumps. If this debris clogs the strainers, the pump net positive suction head may not be satisfied and the ECCS or CSS pumps could fail. It is also possible that some debris would pass through the sump strainers and accumulate in the reactor core. This could reduce core cooling and possibly lead to core damage.

In 1996, the staff established GSI-191 to address the effects of debris accumulation on pressurized water reactor (PWR) sump performance during design-basis accidents. Resolution of GSI-191 involves two distinct, but related safety concerns: (1) potential clogging of the sump strainers that fails ECCS or CSS pumps and (2) potential clogging of flow channels within the reactor core by debris passing through the sump strainers (in-vessel effects). Clogging at either the strainers or in-core flow channels can result in loss of long-term cooling. In September 2004, the staff issued GL 2004-02 to holders of operating licenses for PWRs. In GL 2004-02, the staff requested that licensees: (1) perform an evaluation of the ECCS and CSS recirculation phase; (2) consider the effect of debris circulating with water through the ECCS and the CSS after a LOCA caused by a high-energy pipe break; and (3) if needed, take additional action to ensure system functionality and inform NRC of their plans.

In the Staff Requirements Memorandum in response to SECY-10-113, the Commission directed the staff to consider a risk-informed approach as an option for resolution of GSI-191. The staff developed three options for resolution, as documented in SECY-12-0093, with a risk-informed approach as one possible option.

STPNOC submitted LARs for STP Units 1 and 2 as the pilot licensee to use the risk-informed methodology as generally outlined in SECY-12-0093. The LAR changes the licensing basis to allow STPNOC to use a risk-informed approach to resolve the concerns addressed in GSI-191 and GL 2004-02. The LAR amended the technical specifications to add a required action and completion time specific to the effects of sump debris. The licensee also requested exemptions from ECCS requirements in certain sections in Title 10 of the *Code of Federal Regulations* (10 CFR) 50.46 and 10 CFR Part 50 Appendix A, General Design Criterion (GDC) 35, “Emergency core cooling;” GDC 38, “Containment heat removal;” and GDC 41, “Containment atmosphere cleanup.” The licensee noted that the exemptions are necessary to support STPNOC’s risk-informed approach in addressing GSI-191 and responding to GL 2004-02 since the staff had hitherto only accepted deterministic analysis to show compliance with 10 CFR 50.46.

DISCUSSION

<u>Risk-Over-Deterministic (RoverD) Methodology</u>

STPNOC developed the RoverD methodology to analyze the effects of debris generated during LOCA events using plant-specific testing to support deterministic and risk-informed analyses.

The methodology uses STPNOC test data to establish a threshold amount of fine fiber debris above which ECCS and CSS function may be lost. It estimates the incremental risk increase attributable to debris loadings that exceed this value and compares it to the risk guidelines in Regulatory Guide (RG) 1.174.

The STPNOC testing used NRC-approved methods to determine the strainer debris load above which pump functions may be lost. This is represented as the 'deterministic empirical limit.' This debris loading used a variable amount of fine fibers in the tests with bounding amounts of other types of debris including particulates and chemical precipitates. The RoverD method then used a calculation platform (CASA Grande) to examine various break sizes, orientations, and locations to identify the amount of fine fibers generated and transported for each scenario. The results were then compared to this empirical limit to determine if the scenario is predicted to have debris at the strainer that is less than this threshold (ECCS and CSS function is maintained) or if it exceeds this amount and must be categorized as a risk-informed scenario (ECCS and CSS function failed). For the subset of break scenarios that exceed the threshold, the RoverD methodology is used to calculate the increase in risk. The changes in the core damage frequency (ΔCDF), and the large early release frequency (ΔLERF) were then compared to the acceptance guidelines in RG 1.174.

Technical Evaluation of Sump Strainers

The staff performed its integrated review considering the five key principles of risk-informed decisionmaking set forth in RG 1.174:

- Proposed change meets the current regulations, unless it explicitly relates to a requested exemption or rule change: The staff determined that special circumstances exist to grant the exemption and that this exemption would not result in a violation of the Atomic Energy Act of 1954, as amended.

- Proposed change is consistent with the defense-in-depth philosophy: The staff reviewed the licensee's actions and programs relied upon to maintain adequate defense-in-depth in accordance with the key factors of RG 1.174. The staff concluded that the licensee has adequately addressed these factors of the defense-in-depth philosophy and that the licensee has taken additional actions that provide the needed defense-in-depth.

- Proposed change maintains sufficient safety margins: The licensee identified margins and conservatisms in the design, analysis, construction, and operation of the plant to show that the proposed methodology change (i.e., a risk-informed approach) will maintain sufficient safety margins.

- Proposed change impact is monitored using performance measurement strategies: The licensee stated that condition reports would be written to document any adverse conditions identified during containment inspections or containment emergency sumps and strainers surveillances. The staff review concluded that the licensee's monitoring program is acceptable because it is consistent with the guidance in RG 1.174.

- Proposed change that results in an increase in CDF or risk should be small and consistent with the Safety Goal Policy Statement: The staff reviewed the licensee's base probabilistic risk assessment model, including the calculated total risk values (CDF, LERF) for each unit, and the risk-informed assessment of debris effects.

Sump Strainer Debris Testing

Tests were performed to determine the head loss induced by debris accumulation on the sump strainers. The staff considered these tests to be acceptable because they used bounding amounts of particulate debris and chemical precipitates and were performed in accordance with NRC guidance. The strainer testing provided an acceptance criterion for the amount of fine fiber that can arrive at the strainer and still result in acceptable head losses. Pipe breaks that generate and transport less than 192 lbs. of fine fiber result in acceptable strainer performance. Conversely, any break that generates and transports more fine fiber is assumed to lead to core damage and increase CDF over the base case. The failure mode of the strainer was the development of a thin fiber bed fully saturated with particulate debris. It is thus unlikely that any combination of less fiber and particulate could produce greater head loss.

The criterion of 192 lbs. of fiber was for cases with operation of two or three trains of ECCS and CSS pumps. In their baseline analyses, STPNOC assumed that half that amount of fiber would result in failure when only one train is available. The CSS pumps would be the first affected since they have the limiting net positive suction head margin. However, STP Units 1 and 2 have containment fan coolers that can provide sufficient containment cooling if the CSS is unavailable.

Pipe Break Analysis and Strainer Failure

STPNOC postulated pipe breaks at every weld location in the system and calculated the amount of fine fiber that that would be generated and transported to the sump strainer. Both partial breaks and full double-ended breaks were considered. All orientations of partial breaks were considered. These calculations were done in accordance with NRC guidance and used conservative estimates of model parameters, such as the zone of influence (ZOI). Insulation and coatings were considered damaged if within the ZOI, even if located in the shadow of other steel equipment such as a pump.

For 2- or 3-train operation, out of 628 welds where a LOCA could occur, breaks at 45 welds could potentially produce more than 192 lbs. of fine fiber. The smallest break that can exceed 192 lbs. was calculated to be a 12.8 inch break (pressurizer surge line). Not all breaks larger than this size produced more than 192 lbs. of fiber. At each location, the break had to be large enough and have enough fiber insulation within the ZOI. It was also assumed that all larger breaks at that location would produce enough fiber debris to exceed the limit. For 1-train operation, the smallest break that produces enough fiber to exceed the deterministic limit was calculated as 9.3 inches. There are 95 welds which could potentially produce more than this limit. STPNOC estimated that 99.96% of the time, two or three trains will be available and the other 0.04% of the time only a single train is available.

To assign frequencies to LOCAs that exceeded the deterministic limit, STPNOC used information from NUREG-1829, which provides exceedance frequencies for discrete break sizes, i.e., the frequency of having a specified break at a given size or larger. STPNOC's approach assumed that the frequency of all breaks of a certain size was the same whether they are full double-ended guillotine breaks or partial breaks of a larger pipe. This approach also assumed that all welds are equally susceptible to degradation. Most NUREG-1829 experts expected that the smallest diameter piping system or subcomponent that could support a particular LOCA size or category was the dominant LOCA frequency contributor; however, this weld was only a qualitative expectation. The allocation of the NUREG-1829 frequencies to individual welds was a major source of uncertainty in the RoverD approach. The licensee addressed this using a sensitivity study where all of the breaks were allocated to double-ended guillotine breaks.

The staff addressed this uncertainty by performing a bounding calculation. The staff assumed that all breaks greater than the smallest break computed to produce enough fine fibers to exceed the deterministic limit would lead to core damage. This is conservative for many of these postulated breaks because there would not be enough fiber insulation in the ZOI to produce fine fibers in excess of the limit. The staff's confirmatory calculation resulted in ΔCDF and ΔLERF values well within the acceptable range of RG 1.174.

<u>Technical Evaluation of In-Vessel Debris Effects</u>

On November 21, 2007, the staff issued, "Revised Content Guide for Generic Letter 2004-02 Supplemental Responses," for guidance to licensees preparing supplemental responses to GL 2004-02. This guide provided information to licensees on how to evaluate the effects of debris carried downstream of the containment sump strainer and into the reactor vessel, in order to show that the in-vessel effects evaluation is consistent with, or bounded by, industry guidance (WCAP-16793), as modified and approved by the staff. In WCAP-16793, the acceptance criteria for long-term core cooling (LTCC) following core quench and reflooding are:

- The maximum clad temperature shall not exceed 800°F following core quench and reflood.

- The thickness of the cladding oxide and the deposits of material on the fuel shall not exceed 0.05 inch in any fuel region.

The RoverD methodology for debris that would pass through the sump strainers and accumulate in the reactor core was developed in a similar fashion to that for the sump strainer analysis method. If the amount of downstream debris transported to the vessel was less than a limit of 15 grams per fuel assembly, then prototypical test data from WCAP-16793 indicated that LTCC was assured.

For cold leg breaks most of the ECCS flow bypasses the core with little debris deposited in the core. For these breaks, the licensee determined that the maximum amount of fiber that could reach the core is less than seven grams per fuel assembly. The results in WCAP-16793 show that adequate flow would reach the fuel and the core would be cooled.

All hot leg breaks generate and transport more than 15 grams of debris per fuel assembly. The licensee assumed that LTCC is not possible for hot leg breaks larger than 16 inches, and those breaks were assigned directly to core damage. For hot leg breaks smaller than 16 inches, a deterministic analysis was performed to determine if LTCC was maintained, assuming flow into the bottom of the core was completely blocked. Finally, if a large-break LOCA event

(>16 inches) occurred, LTCC was assumed not to be possible and was considered as part of the increase in CDF. The licensee identified the following six bypass flow paths, which were conservatively ignored in the deterministic analysis making the STPNOC analysis bounding:

- Thimble tube flow through the fuel rods
- Core former-to-fuel gap flows
- LOCA holes flow between the barrel-baffle region and the core
- Barrel-baffle flow between the bottom of the core and top of the core
- Cold-leg to hot-leg leakage flow
- Upper head spray nozzle flow

The licensee used the RELAP5-3D computer code to evaluate core cooling. In this situation with the core inlet blocked, water flow reached the top of the core by backflow up the downcomer, through the steam generators, and into the intact hot legs. STPNOC's analysis showed that sufficient water was available to flow down through the top of the fuel assemblies and maintain the clad temperatures well below 800°F, even with conservative counter-current flow limits considered in the two-phase flow process.

Although the RELAP5 series of codes is widely used, RELAP5-3D has not been accepted by the staff as an evaluation model for LOCAs. Rather than review it formally as acceptable for general licensing analysis of LOCAs, a more limited review focused on its capability to analyze this LTCC process. The staff found the RELAP5-3D model acceptable for this application.

STPNOC referenced a LOCA Deposition Model (LOCADM) analysis in WCAP-16793, which demonstrated the total thickness of the deposit due to clad oxidation, and debris buildup did not exceed the prescribed limit of 0.05 inch. This analysis assumes that any debris, which passes through the strainers and into the vessel is completely dissolved, transported into the core, and then precipitates onto the fuel rod at the boiling front. STPNOC considered this to be a bounding analysis. It was not clear to the staff, however, that this LOCADM analysis was applicable to STP, as it appeared to assume a much lower fiber loading than could be justified for STP. Therefore, the licensee supplemented its response and provided additional details on the specific STP analysis performed. The analysis performed with LOCADM found that more than 91 grams per assembly of fibrous debris was needed to bypass sump strainers, completely dissolve, and precipitate on the fuel rods producing a 0.05 inch layer. The maximum amount that could bypass the strainer in the scenarios considered in the deterministic analysis was much less than half this amount.

Because the licensee performed an analysis that conservatively assumed a larger quantity of fiber per fuel assembly than would be expected for the scenarios under consideration, and because the analysis confirmed that the thickness of clad oxide and deposits of material will be less than 0.05 inch, the staff determined that this criterion was satisfied.

<u>Future Applications of this Methodology</u>

The pioneering effort by STPNOC and the staff will be adapted by other licensees. Lessons have been learned in this first-of-a-kind effort. It is possible now to apply the risk-informed approach in a more systematic manner. Risk assessment should be structured to provide clear answers to three questions: what can happen, how likely is it, and what are the consequences.

To answer the first question, a consistent approach could have examined all physical configurations. At a high level, with a three train system, there are seven possible flow path operating configurations: one with all three trains operating, three with only two trains operating, and three with only one train operating. The plant-specific probabilistic risk assessment would then provide the answer to the second question, accounting for design features and operating practices that affect the conditional probability of each configuration. Consideration of all configurations is important because no abbreviated approach can be conservative for all issues or ensure that there are no important asymmetries among the trains.

For this application, the third question becomes, *what minimum pipe break size will generate an unacceptable amount of fine fiber debris?* The answer to that question depends on the system operating configuration, the strainer head loss in that configuration, the physical arrangement of the three sumps, and the corresponding debris generation, transport, and deposition analyses. Considering the STP sump configuration, the analyses to answer this question may identify a different minimum break size for each operating configuration.

Absent this systematic process, STP needed to perform supplementary assessments to justify that there is adequate margin in their risk estimates to account for single-train and dual-train operating configurations that are different from the configuration used for their baseline analyses. The staff should ensure that future applications of this simplified risk-informed methodology contain consistent examinations of system operating configurations, the likelihood of each configuration, and the frequency of generating unacceptable amounts of debris for that configuration.

SUMMARY

We find the STPNOC methodology to be an innovative way to combine deterministic analysis with risk-informed concepts. The STPNOC proposed change to its licensing basis as described in its LAR is acceptable because it satisfies the key principles of risk-informed decisionmaking as described in RG 1.174. STPNOC proposed changes to the technical specifications are acceptable and there are no changes to the radiological source term as previously approved for STP. There is reasonable assurance that the health and safety of the public will not be affected by STP operation in the proposed manner.

Member Matthew Sunseri did not participate in the deliberations on this matter.

Sincerely,

/RA/

Dennis C. Bley
Chairman

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