March 24, 2016

Mr. Jerald G. Head
Senior Vice President, Regulatory Affairs
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SUBJECT: REQUEST FOR ADDITIONAL INFORMATION REGARDING REVIEW OF LICENSING TOPICAL REPORT NEDE-33005P AND NEDO-33005, "TRACG APPLICATION FOR EMERGENCY CORE COOLING SYSTEMS/ LOSS-OF-COOLANT ACCIDENT ANALYSES FOR BWR/2-6" (TAC NO. ME5405)

Dear Mr. Head:

By letter dated January 27, 2011, GE Hitachi Nuclear Energy Americas LLC, submitted for U.S. Nuclear Regulatory Commission (NRC) staff review Topical Reports NEDE-33005P and NEDO-33005, "Licensing Topical Report TRACG Application for Emergency Core Cooling Systems / Loss-of-Coolant-Accident Analyses for BWR/2-6" (Agencywide Documents Access and Management System Accession No. ML110280323).

Upon review of the information provided, the NRC staff has determined that additional information is needed to complete the review. Enclosed with this letter is a non-proprietary Request for Additional Information (RAI). On March 2, 2016, James Harrison, GEH Vice President, Fuels Licensing, Regulatory Affairs, and I agreed that the NRC staff will receive your response to the enclosed RAI questions within 30 days of receipt of this letter.

If you have any questions regarding the enclosed RAI questions, please contact me at (301) 415-1002.

Sincerely,

/RA/

Joseph A. Golla, Project Manager
Licensing Processes Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 710

Enclosure:
As stated

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ADAMS Accession No.: ML16062A061; *concurred via e-mail **NRR-106**

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OFFICE OF NUCLEAR REACTOR REGULATION

REQUEST FOR ADDITIONAL INFORMATION

REVIEW OF TOPICAL REPORT NEDE-33005P AND NEDO-33005, "LICENSING TOPICAL REPORT TRACG APPLICATION FOR EMERGENCY CORE COOLING SYSTEMS / LOSS-OF-COOLANT ACCIDENT ANALYSES FOR BWR/2-6" (TAC NO. MF0743)

RAI 99) Statistical Meaning of Limiting Results (Follow-on to RAI 66)

In response to request for additional information (RAI) 66, General Electric-Hitachi (GEH, the vendor) reviewed the applicable regulations and regulatory guidance (Agencywide Documents Access and Management System (ADAMS) Accession No. ML14281A014). Following the review, GEH provided its rationale regarding the adequacy of both statistical approaches outlined in licensing topical repot (LTR) NEDE-33005P, "TRACG Application for Emergency Core Cooling Systems/Loss-of-Coolant Accident Analyses for BWR/2-6," Section 7.1 (ADAMS Accession No. ML110280321). The following key concepts summarize the NRC staff understanding of the response:

- The applicable regulations do not include specific quantiles and confidence limits, and the available regulatory guidance specifies 95%-probability coverage.
- Consideration of joint statistical coverage is not required to demonstrate compliance with the applicable acceptance criteria.
- The normally distributed, one-sided upper tolerance limit (OSUTL) approach, as applied to 59 cases, is reasonably consistent with the approach delineated in Regulatory Position 4.4 of Regulatory Guide (RG) 1.157, "Best-Estimate Calculations of Emergency Core Cooling System Performance" (ADAMS Accession No. ML003739584).
- When considering the order statistic-based approach, GEH methodology exceeds the minimum required for tri-variate, joint 95% confidence.

Specific discussion is provided in the following sections; a request for additional information follows.

Application of a 95/95 Upper Tolerance Limit

Regarding an acceptable evaluation model, 10 CFR 50.46(a)(1)(i) states, in part:

> This uncertainty must be accounted for, so that, when the calculated ECCS [emergency core cooling system] cooling performance is compared to the criteria set forth in paragraph (b) of this section, there is a high level of probability that the criteria would not be exceeded.

In accordance with various policy documents, the NRC position is established that results should be expressed "at the 95% probability limit," as stated in Regulatory Position 4.4, "Statistical Treatment of Overall Calculational Uncertainty," of RG 1.157. The RG indicates that

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uncertainty may be estimated using normally distributed results and a 95% probability limit, or a conservative application of two standard deviations to the mean. [1] The RG also states that other techniques to quantify uncertainty "may require the use of confidence levels."

Appendix A to SECY 83-472, "Emergency Core Cooling System Analysis Methods," provides a brief discussion of the Commission's philosophy in applying 95% probability level in licensing decisions regarding 10 CFR 50.46 compliance. The following passage is especially informative, regarding the origination and application of a 95% acceptance criterion to 10 CFR 50.46(b) acceptance criteria:

> Ninety five percent was selected for a number of reasons. Primary was its historical significance in regulatory matters involving thermal-hydraulic performance. Many parameters, most notably the departure from nucleate boiling ratio (DNBR) were proposed by the industry and accepted by the NRC to be conservatively established at the 95 percent probability level.

The noted example is provided in Standard Review Plan (SRP) Chapter 4.4, "Thermal and Hydraulic Design" (ADAMS Accession No. ML070550060). In fuel system thermal-hydraulic review guidance, the NRC staff introduces the concept of acceptable confidence, stating, in part, that "One criterion provides assurance that there be at least a 95-percent probability at the 95-percent confidence level that the hot fuel rod in the core does not experience a DNB or transition condition during normal operation or AOOs [anticipated operational occurrences]."

In its reviews of Best-Estimate or Realistic ECCS evaluation models, the NRC staff has applied the same acceptance criterion. On the matter of statistical confidence in results, the 95% confidence level is considered acceptable. The accession number referenced in RAI 66 provides one example of NRC staff correspondence documenting this position; however, the practice is applied reasonably consistently in best-estimate ECCS evaluation model reviews (ADAMS Accession No. ML062150349).

Use of a Tolerance Interval

One statistical approach proposed by GEH identifies a normally distributed OSUTL. That is, the high probability statement leads to the conclusion that one is 95% confident that 95% of the actual population will fall below the specified value. This approach is in attempt to comply to rule language in 10 CFR 50.46(a)(1)(i), that includes the requirement that ECCS cooling performance "…must be calculated for a number of postulated loss-of-coolant accidents of

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[1] The recommendation in RG 1.157 that the probability limit can be estimated using two standard deviations was likely based on consideration of the response surface technique discussed in NUREG/CR-5249, "Quantifying Reactor Safety Margins: Application of the Code Scaling, Applicability, and Uncertainty Evaluation Methodology to a Large-Break, Loss-of-Coolant Accident" (ADAMS Accession No. ML030380473). As documented, the technique relied on 50000 Monte Carlo trials, and practically, response surface and similar statistical methods employed thousands to tens of thousands of cases. At these high numbers of statistical trials, adding two standard deviations to the mean is conservative relative to a statistically based, 95^{th} percentile result with 95% confidence. It appears unlikely that the RG authors envisioned the comparatively low number of sample cases executed in concert with an order statistics-based method that subsequently became the state of the art.

different sizes, locations, and other properties sufficient to provide assurance that the most severe postulated loss-of-coolant accidents are calculated," and that the results ensure "there is a high level of probability that the criteria [in 10 CFR 50.46(b)] would not be exceeded."

Despite that GEH proposes to remove reference to a "95/95" limit, the selection of the z-value, according to Table R66-1 of the LTR, appears to relate to a 95% confidence limit for 95% coverage, given normally distributed parameters. Removal of the confidence limit renders the selection of a z-value arbitrary. If the sample size is always 59 cases, and the z-value remains greater than two, then the approach conforms to RG 1.157 because the upper tolerance limits exceeds two times the standard deviation of the sample. However, the use of a larger sample without a specified confidence level could lead to the selection of a z-value less than two. The confidence associated with such a value would require justification.

Joint Coverage

The NRC staff acknowledges that the language in RG 1.157 states, in part, that "explicit consideration of the probability of exceeding the other criteria [aside from peak cladding temperature] may not be required if it can be demonstrated that meeting the temperature criterion at the 95% probability level ensures with an equal or greater probability that the other criteria will not be exceeded." Generically, this demonstration is impractical because cladding oxidation and embrittlement are functions not only of the cladding temperature, but also the integral time at temperature. The results of the transient analyses are thus also important in ensuring that the cladding oxidation criteria are satisfied as well as the temperature criterion. For a longer transient, cladding oxidation could prove to be more limiting that the cladding temperature.

In the statistical combination of overall uncertainty, adherence to each of the criteria should be considered as separate events. The confidence in the results should be considered insofar as they provide simultaneous coverage of the population (i.e., $PCT < PCT^{95}$, $MLO < MLO^{95}$, and $CWO < CWO^{95}$). The specified confidence level should ensure that all three attributes are satisfied simultaneously. Thus, the NRC staff disagrees with GEH's assertion that 10 CFR 50.46 and RG 1.157 contain no requirement for "joint" upper tolerance limits. This is because the regulation specifies that all criteria must be satisfied; exceeding any is not acceptable.

Order Statistics Based Approach

If results cannot be confirmed to be normally distributed, the sample size is selected as to provide high-confidence coverage that the sampled parameters can be rank ordered. Based on the sample size, a specifically ranked result can be used as an estimate of the upper tolerance limit. GEH contends that using the highest-ranked results from three samples consisting of 59 cases, each executed at a different limiting break size, provides higher-confidence assurance of statistical coverage than an approach based on a sample size adequate to provide 95% confidence for tri-variate, 95% coverage.

A. For the normally distributed OSUTL approach, explain what measures will be taken to ensure that the specified confidence levels ensure coverage of each parameter simultaneously.
B. For the order statistics approach, clarify whether GEH will generate independent samples for analysis of each break size.
C. Explain whether the sample size is a fixed aspect of the methodology.

RAI 100) <u>Limitation on Cathcart-Pawel Cladding Oxidation</u>

Background

The requirements in 10 CFR 50.46(b) impose a limit on peak fuel cladding temperature of 2200 °F, and a limit on cladding oxidation of 0.17 times the total cladding thickness before oxidation. The oxidation limit is usually considered as a percentage, and more recently, has been expressed as equivalent cladding reacted (ECR) (i.e., 17% ECR). The Atomic Energy Commission's deliberation over the 17% ECR acceptance criterion is discussed in detail in the 1973 Opinion of the Commission regarding acceptance criteria for emergency core cooling systems (ECCS) for light-water-cooled nuclear power reactors (6 AEC 1085).

In its proceedings, the AEC noted that the "limits specified in these criteria will assure that some ductility would remain in the zircaloy cladding as it goes through the quenching process". The values were selected because experimental data indicated that cladding ductility is influenced not only by oxidation alone, but also by the temperature at which the oxidation occurs. The AEC received recommendations from fuel vendors, the AEC staff, and the public, regarding the selection of an appropriate oxidation limit. The AEC's consideration included not only the total oxidation, but also the thickness of brittle oxidation and zirconium layers in the cladding, and the ratio of the thickness of the brittle layers to the remaining ductile layers. Noting wide agreement on the value of 17%, ECR as a threshold above which cladding generally exhibited brittle behavior, the AEC settled in this value as the cladding oxidation limit.

The experimental studies supporting this limit evaluated cladding ductile performance and correlated it to the thicknesses of the differing layers (i.e., oxide, brittle zirconium, ductile zirconium), rather than to a measured ECR. The percentage values were calculated, based on the test conditions, using the Baker-Just correlation. Thus, the AEC also noted that "the Regulatory Staff in their concluding statement compared various measures of oxidation (page 90) and concluded that a 17% total oxidation limit is satisfactory, [emphasis added] *if calculated by the Baker-Just equation*." (6 AEC 1097)

Realistic ECCS Research and Additional Cladding Oxidation Correlations

Upon revision in 1988 to 10 CFR 50.46 to allow more realistic emergency core cooling performance calculations, the state of the art for cladding oxidation calculations had evolved. In addition to Baker Just, Chapter 6.13 of NUREG-1230, "Compendium of ECCS Research for Realistic LOCA [loss-of-coolant accident] Analysis," reviews Cathcart-Pawel alongside two additional oxidation rate equations (ADAMS Accession No. ML053490333).

The NUREG, as well as RG 1.157 recommend the use of Cathcart-Pawel based on its superior accuracy when compared to Baker-Just. However, as noted in Research Information Letter (RIL) 02-02, Attachment 2, the original and confirmatory ring compression tests on which the 17% ECR criterion was based relied on an ECR value calculated using Baker-Just (ADAMS Accession No. ML021720709). As noted on Page 9 of RIL 02-02, Attachment 2, “had the Cathcart-Pawel correlation – which did not exist at that time – been used, the cladding oxidation limit would have been about 13%. Therefore, the Baker-Just correlation must be used when comparing results with the old 17% limit.”

Safety Implication

The use of a 17% limit on ECR, when applied to cladding oxidation values calculated using the Cathcart-Pawel correlation, does not provide the same level of assurance of cladding ductility as the same limit, when applied to a result calculated using the Baker-Just correlation.

Implications of 10 CFR 50.46c Research

In 2008, the NRC published NUREG/CR-6967, “Cladding Embrittlement During Postulated Loss-of-Coolant Accidents” (ADAMS Accession No. ML082130389). The report identifies newly identified cladding embrittlement mechanisms, and provides a more detailed evaluation of expected post-LOCA cladding behavior. The NUREG also used more rigorous testing methods than the work that formed the basis for the original ECCS rule (e.g., Hobson and Rittenhouse). The NUREG documents, in part, is the basis for the draft performance-based rule at 10 CFR 50.46c. An accompanying RG, RG 1.224, “Establishing Analytical Limits for Zirconium-Alloy Cladding Material,” provides an acceptable limit to ensure ductile cladding behavior for existing zirconium alloy cladding, and also provides methods acceptable to the NRC staff to establish new analytical limits for post-quench cladding ductility (ADAMS Accession No. ML15281A192). Most notably, the analytical limit for zirconium alloy fuels in RG 1.224 reduces the acceptable value of ECR calculated using the Cathcart-Pawel correlation as a function of hydrogen pickup, a phenomenon that occurs through the in-reactor design life of the fuel.

These documents, NUREG/CR-6967 and RG 1.224, can be used as a basis to apply new, performance-based limits for post-LOCA cladding ductility, once 10 CFR 50.46c is promulgated. However, for application within the existing prescriptive regulations and acceptance criteria at 10 CFR 50.46, it is more appropriate to apply the ECR value that is equivalent to 17% ECR, as stated in the 1973 Opinion of the Commission, “if calculated by the Baker-Just equation.” This value, using the Cathcart-Pawel correlation, is roughly equivalent to 13%.

Request

In its present reviews of ECCS evaluation models, the NRC staff is imposing a review condition specifying that the ECR results calculated using the Cathcart-Pawel correlation will be considered acceptable in conformance with 10 CFR 50.46(b)(2), if the ECR value is less than 13%, which is equivalent to 17% ECR, if calculated using the Baker-Just equation. This condition will be considered temporary, and may be removed upon the NRC’s adoption of a more performance-based regulatory framework with respect to ECCS performance.

In the unlikely event that the Commission chooses not to promulgate 10 CFR 50.46c, the NRC staff will consider further action to ensure that users of currently approved, realistic or best estimate ECCS evaluation models are using acceptance criteria that provide appropriate assurance of post-LOCA cladding ductility as set forth in 10 CFR 50.46(b)(2), in consideration of the Opinion of the Commission published in 1973.

In light of the staff's limitation, please provide the following information:

A. Explain whether GEH will continue to calculate cladding oxidation as discussed in NEDE-33006P.
B. If an alternative approach to calculate cladding oxidation is proposed, summarize that approach.
C. Explain how TRACG-LOCA accounts for pre-transient cladding oxidation.