ENCLOSURE 2

MFN 16-020

Response to Round 3 Requests for Additional Information 99 and 100
and Revised Set 1 RAI 33 Response

Non-Proprietary Information – Class I (Public)

IMPORTANT NOTICE

This is a non-proprietary version of Enclosure 1, from which the proprietary information has been removed. Portions of the enclosure that have been removed are indicated by an open and closed bracket as shown here [[ ]].

SNPB RAI-33

Please provide the following information related to PIRT item C18 (cladding perforation):

a. A summary of or reference for the tests that includes the number of tests, the type(s) of cladding tested, and the heatup rates used.

b. The basis for applying the empirical data used to estimate clad rupture stresses to current-generation fuels.

c. The basis for the assumption of normality for the upper and lower 95 percent groups used to determine the rupture stress.

d. Explanation of the origin of and justification for the assumed uncertainty of the built-in fuel rod internal pressure curves and the normality of the multiplier on rod pressure.

e. Relative to the high-temperature phase change of zirconium, please clarify the statement on page 2-11 of the TR that phase change of in-core materials is not modeled.

RAI-33 Response

a. A summary of the cladding hoop stress versus perforation temperature testing used in defining the model and model uncertainty can be found in Reference R33-1. The figures in the Reference R33-1 enclosed report shows the comparison of high temperature test data to the rupture stress model. All of the tests presented are for heat-up rates [[

]]. In Reference R33-1, selected data from Reference R33-2 is compared with General Electric (GE) proprietary data for low heat-up rates. Note that ruptures occur at lower hoop stresses when the heat-up rates are lower so that is why the data for the higher heat-up rates in Reference R33-2 are not included. Figure 5 of Reference R33-1 aggregates data points from Figures 1, 2, and 4 of the same reference. Figure R33-1 has been reconstructed from the same data in order to provide a legend to indicate the origins of the data. The relevant NUREG-0630 (Reference R33-2) data that has heat rates of [[ ]] are also depicted with open blue markers in Figure R33-1. [[

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b. The clad rupture stress model is assessed using hoop stresses, as described by the method in Section 3.1 of Reference R33-2. By employing this method of converting differential pressure data to hoop stress data, design-specific dimensional effects are eliminated. This allows the clad rupture stress model to be extended beyond the 7x7 and 8x8 fuel from the test programs to current-generation fuel product lines. Additionally, the data in Figure 1 of Reference R33-1 show that the differences between 7x7 and 8x8 fuel rod data extracted from NEDM-20350-3 (Reference R33-3) are insignificant compared to the scatter in the data, confirming that dimensional effects have been eliminated. This fact is also depicted by comparison of the red triangles (8x8) with the red squares (7x7) in Figure R33-1.

c. The clad rupture stress uncertainty model was developed using temperature-dependent rupture stress data from GE material testing programs. Relevant low heat-up rate data from NUREG-0630 (Reference R33-2) has been shown for comparison. The uncertainty model [[

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d. The Linear Heat Generation Rate (LHGR)- and exposure-dependent values of the nominal fuel rod internal pressure used in TRACG Loss-of-Coolant Accident (LOCA) analyses are calculated based on the Nuclear Regulatory Commission (NRC)-approved PRIME model [[ ]] The calculation method qualified previously for GESTR (Reference R33-4) has been replaced by PRIME thermal-mechanical analyses (References R33-5 and R33-6). [[ ]] The key driver of rod perforation uncertainty is the uncertainty in the temperature-dependent rupture stress. The rod internal pressure is less important. PRIME nominal rod internal pressure as used in LOCA calculations is [[ ]] shown in Figure 5.2 of Reference R33-6. Updated data provided in Figure 2-8 of Reference R33-7 is replicated here as Figure R33-3. [[

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e. Clarifications to the entries in Columns 2 and 3 in Section 3.3.2 of Table 2.5-1 on page 2-11 of the LTR are proposed in view of the additional details and clarification provided below.

The entry in Column 2 labeled *GEH Process* will be modified to read:

> Material properties for zircaloy account for the alpha and beta phases. The Zr-H_2O reaction to produce ZrO_2 is modeled. Melting of UO_2 is precluded by the GE SAFDL applied for AOO transients and this bounds all LOCA calculations provided the 2,200°F limit on PCT is satisfied. Eutectic formations are not significant provided the 2,200°F limit on PCT is satisfied.

The entry in Column 3 under *Evaluation* will be modified to read:

The phenomena necessary for BWR LOCA are modeled.

Cladding hoop stresses are modeled in TRACG for the purpose of tracking geometric changes due to rod perforation and to account for the resulting oxidation of the cladding. Additionally, material properties for the cladding and fuel take into account transient temperature effects. Specifically, the zircaloy cladding properties account for the physical differences associated with the alpha and beta phases of zircaloy. The contact pressure between the UO_2 pellet and cladding inside surface is specifically modeled and is strongly influenced by uncertainty in parameters that affect the temperature of the fuel pellet and its thermal expansion. If the 10 CFR 50.46(b) acceptance criteria for Emergency Core Cooling Systems (ECCS) are met, the chemical effects of eutectic formation will have no adverse effect on the fuel and can be ignored in cladding response calculations within the range of post-LOCA conditions. Proposed additional requirements from 10 CFR 50.46(c) related to post-quench ductility and break away oxidation are expected to be addressed by material testing that will be used to stipulate a time limit at a prescribed temperature that must not be exceeded in the LOCA calculations. Assessment relative to the new criteria is independent of the TRACG modeling and application methodology and can be achieved by comparing the calculated PCT trace to the required limit once the new rules are finalized.

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Figure R33-1. Rupture Stress Model Compared to Data

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Figure R33-2. Example of Half-Normal Distribution Generation Based on Experimental Data

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Figure R33-3. PRIME Predicted versus Measured Fuel Rod Internal Pressure (Nominal)

References

R33-1. Letter from R. H. Buchholz (GE) to L. S. Rubenstein (NRC), "General Electric Fuel Clad Swelling and Rupture Model," MFN-097-81, May 15, 1981.

R33-2. NUREG-0630, "Cladding Swelling and Rupture Models for LOCA Analysis," April 1980.

R33-3. General Electric Company, "Fuel Development Development Authorization Programs 1974 Third Quarterly Report," NEDM-20350-3, December 1974.

R33-4. General Electric Company, "The GESTR-LOCA and SAFER Models for the Evaluation of the Loss-of-Coolant Accident, Volume I: GESTR-LOCA – A Model for the Prediction of Fuel Rod Thermal Performance," NEDE-23785-1-PA, Revision 1, October 1984.

R33-5. Global Nuclear Fuel, "The PRIME Model for Analysis of Fuel Rod Thermal - Mechanical Performance Part 3 – Application Methodology," NEDC-33258P-A, Revision 1, September 2010.

R33-6. Global Nuclear Fuel, "The PRIME Model for Analysis of Fuel Rod Thermal - Mechanical Performance Part 2 – Qualification," NEDC-33257P-A, Revision 1, September 2010.

R33-7. Letter from Brian R. Moore (GNF) to Document Control Desk, "NEDC-33257P Supplement 1, 'The PRIME Model for Analysis of Fuel Rod Thermal-Mechanical Performance 2015 5-Year Update," MFN 15-060, August 7, 2015.

LTR Impact

Entries in Columns 2 and 3 in Section 3.3.2 of Table 2.5-1 on page 2-11 of the LTR will be revised.

The entry in Column 2 labeled *GEH Process* will be modified to read:

> Material properties for zircaloy account for the alpha and beta phases. The Zr-H_2O reaction to produce ZrO_2 is modeled. Melting of UO_2 is precluded by the GE SAFDL applied for AOO transients and this bounds all LOCA calculations provided the 2,200°F limit on PCT is satisfied. Eutectic formations are not significant provided the 2,200°F limit on PCT is satisfied.

The entry in Column 3 under *Evaluation* will be modified to read:

> The phenomena necessary for BWR LOCA are modeled.

LTR Section 5.1.3.24 will be replaced to read as indicated below. In addition, Figure 5.1-16 will be deleted and its deletion indicated in the LIST OF FIGURES.

5.1.3.24 C18 – Fuel Cladding Strain /Perforation (H)

The key drivers governing strain-induced fuel rod perforation are the temperature-dependent clad rupture stress and the rod internal pressure. Based on material properties, the rupture stress and its associated uncertainty is modeled in TRACG as three curves corresponding to best-estimate, lower 95%, and upper 95% rupture stress curves as functions of cladding temperature (Figure 5.1-15). At each temperature, the upper and lower 95% bounds are used to define half-normal PDFs above and below the nominal rupture stress, respectively. This is done on the basis that the upper and lower 95% points are removed by 1.645σ from the nominal value.

The instantaneous clad hoop stress is directly related to the fuel rod internal pressure. Nominal fuel rod internal pressures are calculated in TRACG as described in Section 7.5.3.1 of Reference [1] using parameters calculated by PRIME [76] and passed to TRACG [[

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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 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."

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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

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 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

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to the mean is conservative relative to a statistically based, 95th 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.

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-99 Response

A. For the very same reasons the staff noted under the Joint Coverage section of the request for additional information (RAI), GEH concurs that simultaneous demonstration that equivalent cladding reacted (ECR) and peak cladding temperature (PCT) acceptance criteria are jointly satisfied with some probability and confidence level is "impractical because cladding oxidation and embrittlement are functions not only of the cladding temperature, but also the integral time at temperature." Generically one should expect the PCT upper tolerance limit (UTL) to occur at a location and time that is different from the ECR UTL. For these same reasons, there should be no expectation that the distribution used to determine the ECR UTL be normal when the distribution used to determine the PCT UTL is normal or vice versa. This is the reason that the UTL values are determined independently for each parameter. GEH also agrees that all three criteria must be met so that for all cases and at all times the UTLs for PCT, maximum local oxidation (MLO) and core-wide oxidation (CWO) are always less than or equal to their respective Nuclear Regulatory Commission (NRC)-established limits as required by 10 CFR 50.46. It is in this way that the GEH methodology satisfies the requirement that all regulatory criteria are simultaneously met.

   The GEH process does not directly sample PCT, local oxidation (MLO) and/or CWO from pre-generated response surfaces as noted in Footnote 1 of this RAI. Instead, a random sampling of the inputs, model parameters, and plant parameters from their respective uncertainty distributions is used for each trial to create multiple loss-of-coolant accident (LOCA) transient simulations. Each simulated LOCA transient trial yields a sample value for each of the three attributes PCT, MLO, and CWO that incorporates the combination of the input uncertainties. Upon completion of the N trials, the N values for each attribute are individually evaluated to determine the UTL for that attribute. This approach is consistent with the code scaling applicability and uncertainty (CSAU) process outlined in Regulatory Guide (RG) 1.157 (Reference R99-1) which provides very little guidance on how uncertainties are to be combined. RG 1.157 clearly pre-dates the wide-spread application of order statistics and thus could not have anticipated such a technique for combining a very large number of uncertain parameters that cannot be practically addressed using the response-surface approach. Prior to the use of order statistics, the approach was to generate multi-dimensional response surfaces and then create a very large number of samples from these response surfaces. The creation of a large number of samples does not imply increased analysis fidelity because statistics determined from these large sample sizes is limited by the fidelity of the response surfaces used to produce the samples, and these response surfaces, for practical reasons, are limited by the number of dimensions they can accommodate.

   As indicated above, upon completion of the N trials, the N values for each attribute are individually evaluated to determine the one-sided upper tolerance limit (OSUTL) for that attribute. If the distribution of the N values for a particular attribute is determined to be appropriately modeled as a normal distribution, then the OSUTL is determined as the mean plus Z standard deviations where Z=2.024 corresponding to 95% probability at 95% confidence for the individual attribute for the case where N=59 trials. If the N trials for the attribute are not normally distributed, then the highest rank is used to define the OSUTL for that attribute.

B. In the response to RAI-66, GEH pointed out that, in comparison to the cited methodology in which the break size is sampled along with uncertainty parameters, in the proposed TRACG LOCA methodology, the equivalent number of runs that correspond to at least three different limiting break sizes would be 177 because each one of them is a set of 59. This assertion is not a way to sample the break size; it was only offered to point out the contrast. In light of further discussions with the staff, GEH has committed to [[

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Additionally, in concurrence with this commitment, it would be prudent to update the position given in Section 9.1 of the licensing topical report (LTR) where [[

]] is addressed.

C. In Chapter 7 of the LTR, how a larger sample size could be utilized was explained. However, in practice, the methodology uses [[

]] The concern raised in the RAI is that the value for Z=2.024 corresponding to 95% probability and 95% confidence in an individual attribute that is normally distributed with N=59 trials could be reduced if N is increased. GEH understands and agrees with the recommendation in RG 1.157 regarding two standard deviations as an appropriate minimum. [[

]] In the RAI-66 response, the avoidance of particular reference to 95/95 was based on a different understanding that was reached from discussions with the staff that pertains to joint probability and confidences not specification of OSUTL for individual attributes.

References

R99-1. Regulatory Guide 1.157, "Best-Estimate Calculations of Emergency Core Cooling System Performance," May 1989.

LTR Impact

Changes in Chapter 7 are as follows:

The heading of Section 7.2 will be changed to read: "Approach for Combining Uncertainties"

Bullet 2 in Section 7.3.1 will be changed as follows:

- Perform a set of 59 trials (TRACG calculations) in each of which the statistically characterized model and input parameters are randomly selected from their underlying PDFs. ~~The number of trials is at least 59 and can be increased to raise the confidence level of the desired statistical bound for the output quantities that are compared with design limits.~~

It should be noted that there are other corrections that were necessitated by an editorial mistake made in the compilation of Revision 0 of the LTR and other changes that emerged from the responses to RAIs 65, 91, and 92. These changes will be made as part of Revision 1 of the LTR.

Changes will be made to the 4th paragraph of Section 9.1:

The purpose of the uncertainty analysis, the following step, is to quantify the uncertainties associated with the analysis. For jet pump plant LOCA analysis, [[

]] For the external pump plant LOCA analysis, [[

]] The break spectrum studies combined with sensitivities to the uncertainty contributors presented in this LTR indicate that intermediate breaks are more limiting for jet pump design, whereas the double-ended guillotine is the limiting case for external pump design plants. Although the limiting break size is expected to differ on a plant-specific basis, the overall trends in break spectrum are expected to be similar for the similar designs. Each LOCA analysis will include plant-specific break spectrum calculations.

RAI 100 Limitation on Cathcart-Pawel Cladding Oxidation

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.

RAI-100 Response

A. GEH expects to continue to calculate cladding oxidation using the Cathcart-Pawel correlation as discussed in NEDE-33005P and will apply the acceptance criterion that the Nuclear Regulatory Commission (NRC) staff stipulates (Approach 1). The choice of approach is up to the licensee for which the LOCA analyses are being performed. The TRACG LOCA methodology currently under review by the NRC staff is capable of and appropriate for demonstrating compliance with the equivalent cladding reacted (ECR) acceptance criterion specified for the oxidation rate correlation being applied to calculate local ECR.

B. An alternate calculational approach (Approach 2) is to use the Baker-Just correlation together with its stipulated acceptance criterion. Another alternate approach (Approach 3) is to use the Cathcart-Pawel correlation consistent with the acceptance criteria associated with the proposed 10 CFR 50.46c performance-based limits (Reference R100-1). The licensing process needed for an early adoption of the third approach has not been completely defined by the NRC so some risk by the licensee is encountered should they choose this third option.

C. Pre-transient oxide on the cladding exterior together with its uncertainty is calculated as described in Section 5.1.3.33 of the LTR (NEDE-33005P). Pre-transient oxide on the interior cladding surface is set to zero. In all modeling approaches, the initial oxide amount on the cladding surface(s) serves as the starting point for the metal-water reaction which adds to the oxide during the transient. In all modeling approaches, increased oxidation on the interior surface is modeled if rod perforation is predicted.

Reference

R100-1 U.S. NRC 10 CFR Parts 50 and 52 Proposed Rule, "Performance-Based Emergency Core Cooling Systems Cladding Acceptance Criteria," RIN 3150-AH42, March 6, 2014. (ADAMS Accession No. ML12283A174).

LTR Impact

None.