UNITED STATES
NUCLEAR REGULATORY COMMISSION
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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION
REVIEW OF FUEL THERMAL PERFORMANCE CODE

VERMONT YANKEE NUCLEAR POWER CORPORATION
VERMONT YANKEE NUCLEAR POWER STATION
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1. INTRODUCTION

By letters dated May 18, 1981 (Ref. 1) and July 27, 1981 (Ref. 2), the Yankee Atomic Electric Company submitted two proprietary licensing reports, YAEC-1249P (Ref. 3) and YAEC-1265P (Ref. 4), describing the fuel thermal performance code, FROSSTEY, and by letter dated February 5, 1985, submitted nonproprietary versions of the above reports (identified as YAEC-1249 and YAEC-1265). Although the FROSSTEY code was submitted in support of the Vermont Yankee Cycle 9 and Cycle 10 (Refs. 5-6) reload applications, the submittal stated that the code is also intended for use in future safety analyses of the Yankee Rowe, Maine Yankee and Seabrook facilities. Our generic review of the FROSSTEY code, described in the following sections, marks the first occasion in which a fuel performance code has been developed and submitted for NRC review without support from a major fuel vendor.

2. BACKGROUND

The FROSSTEY (Fuel ROd Steady State Thermal Effects) code is based on the GAPCON-THERMAL-2 code (Ref. 7) developed by Battelle Pacific Northwest Laboratory (PNL) for the Nuclear Regulatory Commission. Because our evaluation of the FROSSTEY code is based, in part, upon a technical review by the same contractor (PNL), our contractual arrangements have included a routine conflict-of-interest determination. Our conclusion that Battelle's objectivity has not been compromised in this review is based on a number of considerations, including: (1) NRC's GAPCON-THERMAL-2 code was placed in the public domain through the National Energy Software Center; (2) Yankee Atomic's currently approved fuel performance code, GAPEXX (Ref. 8), is based on a common predecessor to the NRC code called GAPCON-THERMAL (Ref. 9); (3) differences between FROSSTEY and GAPCON-THERMAL-2, as described in Appendix D of YAEC-1249P, are significant; and (4) where similar models (e.g., fuel thermal conductivity) are used in both FROSSTEY and GAPCON-THERMAL-2, these models are the same for virtually all fuel performance codes used in the industry.

Input to this review from Battelle has consisted of (1) PNL interrogatories (Ref. 10) included in staff questions (Ref. 11) to the licensee; (2) a preliminary technical evaluation (Ref. 12) based only on the subject topical reports (Refs. 3-4); and (3) a final technical evaluation (Ref. 13) based on the topical reports as well as licensee's responses (Refs. 14-15) to staff questions.

3. PREVIOUS APPLICATIONS OF FROSSTEY

As stated in the introduction, the FROSSTEY code was previously applied in the safety analysis of Vermont Yankee Cycle 9 and 10 reloads (Refs. 5-6). In those applications, the code was used to calculate (a) incipient fuel centerline melt limits, (b) 1 percent cladding strain limits, (c) core-average gap conductance and core-average fuel temperature for initializing non-LOCA (loss-of-coolant accident) transient analyses, and (d) average gap conductance and average fuel temperature of the peak bundle for initializing hot channel calculations. Previous analyses provided by General Electric were used for the remainder of the fuel thermal and mechanical analysis, including LOCA initial conditions.

The power level at which incipient fuel centerline melting and one percent cladding strain occur decreases with increasing burnup and gadolinia concentration. However, the power level at which these limits are reached (approximately 20 kW/ft) is less limiting (i.e., higher) than other fuel design limits (e.g., the 13.4 kW/ft PLHGR limit). For this reason, and because of the similarity between the licensee's results and those previously calculated by General Electric, these two applications of FROSSTEY (fuel centerline melt and one percent cladding strain limits) were previously found acceptable (Ref. 16)

Core-average gap conductance and core-average fuel temperatures used for the Cycle 9 and 10 transient analyses were also calculated by the licensee in a conservative manner (in this case, by using low values of gap conductance and

high average fuel temperatures). We recognize that the averaging technique (for core-average conditions) tends to eliminate many local uncertainties such as variations in the extent of fuel densification. In general, these limiting, core-average conditions tend to occur early-in-life as a result of fuel densification effects. Peak bundle (hot channel) gap conductance, on the other hand, is conservative if a high value is used. This condition tends to occur late-in-life because of cladding creepdown and fuel swelling effects. As discussed in our Cycle 9 evaluation, the use of FROSSTEY to determine both core-average and hot channel conditions was accepted on the basis of comparisons between FROSSTEY and the NRC audit code, GAPCON-THERMAL-2. It should also be noted that the hot channel calculations were accepted, even though they rely on analysis at higher burnups, because the licensee relied on a bounding value of hot channel gap conductance (based on previous GE analyses) and utilized FROSSTEY calculations only to confirm the applicability of the bounding value.

The FROSSTEY code is also used in other areas of plant safety analysis such as establishing the Doppler coefficient contribution to the overall power defect. For steady-state boiling water reactor (BWR - e.g., Vermont Yankee) analysis, a large error in fuel temperature may lead to a large error in the Doppler reactivity. However, the Doppler coefficient contribution is not critical. The LOCA analysis, on the other hand, is used to determine reactor operating limits. The use of FROSSTEY in LOCA analysis is discussed in Section 4.2.

4. EVALUATION OF FROSSTEY

As discussed in Reference 13, we have concluded that the FROSSTEY code is acceptable for providing best-estimate fuel temperature, gap conductance, fission gas release and rod internal pressure predictions at low-to-intermediate burnups. Due to the lack of high burnup data in the licensee's submittal and the underprediction of additional data supplied by the staff, we are unable to conclude that the code predictions are adequate for the analysis of conditions at higher burnup.

In addition, we have been unable to determine if the code is appropriate for providing initial conditions (even at low burnup) for the analysis of the loss-of-coolant accident. Because the loss-of-coolant accident analysis is used to determine plant operating conditions (e.g., MAPLHGR limits), we have traditionally required sufficient conservatism in the fuel stored energy calculation (a FROSSTEY output parameter) to bound the inherent uncertainties in the code prediction. A discussion of each of these two restrictions (high burnup and LOCA analysis) is provided in the following sections.

4.1 HIGH BURNUP ANALYSIS

The high temperature fission gas release model in FROSSTEY is based on the Beyer-Hann model (Ref. 17) with a correction for burnup enhanced release. Of those data used to derive the Beyer-Hann model, only a few were taken at burnups above 10 GWd/MtU and none were taken at burnups above 20 GWd/MtU. Recognizing the importance of fission gas release at higher burnups and the need for accurate fuel performance predictions at burnups of up to 50 GWd/MtU, we requested that the licensee confirm FROSSTEY's predictive ability at high burnup with additional data from Riso (Refs. 18-19) and Zorita (Ref. 20) reactors. As discussed in the licensee's responses (Ref. 14), all of these additional data were underpredicted. Thus, we have been unable to conclude that the FROSSTEY code is adequate at high burnup and, at this time, cannot accept the results of this code as a basis for determining conditions which are limiting at end-of-life (e.g., fuel rod internal pressure limits). This restriction does not apply to types of analysis previously reviewed and approved for Vermont Yankee (see Section 3 above).

Because the licensee has not yet utilized the FROSSTEY code to determine end-of-life rod pressures or other limiting conditions at higher burnups, this restriction is (for the moment) moot. In the interest of eliminating the restriction, it should be pointed out that the issue of high burnup fission gas release was resolved in our review of another recent fuel performance code (Ref. 21) on the basis of additional high burnup data (Ref. 22). In that case, the applicant demonstrated that the submitted code was

(on the average) sufficiently close to a best-estimate predictor of the high burnup data. Vermont Yankee may wish to pursue a similar course of action or continue to rely on the fuel vendor for these calculations.

4.2 LOCA INITIAL CONDITIONS

As stated above, we have concluded that the FROSSTEY code is essentially a best-estimate predictor of fuel thermal conditions at low and moderate burnups. Required and acceptable features of the code when used in the analysis of the loss-of-coolant accident are described in 10 CFR 50, Appendix K.

> The steady-state temperature distribution and stored energy in the fuel before the hypothetical accident shall be calculated for the burn-up that yields the highest calculated cladding temperature (or, optionally, the highest calculated stored energy). To accomplish this, the thermal conductivity of the UO_2 shall be evaluated as a function of burn-up and temperature, taking into consideration differences in initial density, and the thermal conductance of the gap between the UO_2 and the cladding shall be evaluated as a function of the burn-up, taking into consideration fuel densification and expansion, the composition and pressure of the gases within the fuel rod, the initial cold gap dimension with its tolerances, and cladding creep. (Ref. 23)

Although the regulations specify tolerances on initial gap size, fuel stored energy codes have traditionally shown a level of conservatism based upon other uncertainties as well (e.g., the fuel densification assumptions in Regulatory Guide 1.126 - Ref. 24). Our reviews of other fuel performance codes (Ref. 25) have assessed this level of conservatism on the basis of comparison with the NRC audit code (with conservative options) and on the basis of statistical examination of predicted and measured fuel centerline temperature data.

In response to our request for information on FROSSTEY code conservatism (Question 6 of Reference 11), the licensee has stated that "application methodologies are devised such that variable input parameters to the code (i.e., power levels, distributions, and exposures) are chosen to provide a conservative output value" (Ref. 14). Although conservatisms introduced through the choice of power level, power distribution and exposure form an important part of the overall margin in LOCA analysis, these parameters have not, in the past, been specifically used to account for uncertainties in the stored energy calculation. Based on information submitted by the licensee, we have been unable to determine the magnitude of these predictive uncertainties or how they are accounted for in the proposed LOCA analysis.

Because the licensee has not yet utilized the FROSSTEY code to determine LOCA initial conditions, this restriction is also (for the moment) moot. It should be pointed out that there are two significantly different methods of resolving this issue: (1) Demonstrate that the conservatisms specifically employed in the FROSSTEY analysis (above and beyond those associated with power level, power distribution and exposure) are sufficient to account for the predictive uncertainties in the code; or (2) Demonstrate that the conservatisms employed in the overall LOCA analysis are sufficient to account for the overall predictive uncertainties for the event. The second approach has recently been proposed by General Electric (Ref. 21) and has been accepted by the NRC. In either case, it is necessary that the licensee quantify the predictive undertainties in the FROSSTEY code, preferably on the basis of a statistical examination of the experimental data already submitted.

5. THE LICENSEE'S PROFICIENCY IN USING THE CODE

The licensee's analysis of confirmatory data (Refs. 18-20) supplied by the staff would ordinarily be sufficient to demonstrate a proficiency in using the FROSSTEY code for plant safety analysis (Generic Letter 83-11 (Ref. 26) requires that such a determination be made). As pointed out in Section 4.1, however, the licensee's analytical results underpredict the measured values for all of these data. Rather than base a proficiency determination exclusively

on these underpredictions, we note that the licensee's predictions of low-to-moderate burnup fuel centerline thermocouple data (Ref. 27-30) supplied by the staff are much more reasonable. Based upon these predictions, and upon the technical content of the YAEC-1249P and YAEC-1265P, we conclude that the intent of Generic Letter 83-11 has been met.

With regard to demonstrating the licensee's proficiency in using the FROSSTEY code, two additional factors should be mentioned. First, the licensee's reanalysis (Ref. 15) of Rod JBY097 from Maine Yankee Core 1 appears to be the only credible analysis of this rod from anyone in the nuclear industry, including the Electric Power Research Institute (Ref. 31). Second, we note that one of the authors of YAEC-1249P and YAEC-1265P (Schultz) has published a doctoral thesis on the subject of fuel performance analysis (Ref. 32). In our opinion, neither one of these observations are necessary to conclude that the licensee's agent (Yankee Atomic Electric Company) has demonstrated a depth of understanding and expertise in fuel performance analysis. However, they do provide substantial credibility to the FROSSTEY methodology in spite of the fact that the code was developed and submitted without support from a major fuel vendor.

6. CONCLUSIONS

We have reviewed the Yankee Electric Power Company reports YAEC-1249P and YAEC-1265P and have concluded that the FROSSTEY methodology described therein is acceptable for reference in plant safety analysis. However, because of the lack of high burnup data in the licensee's submittal and the underprediction of additional data suppplied by the staff, we restrict our approval to the analysis of conditions which are not limiting at end-of-life. This restriction applies to the analysis of fuel rod internal pressure limits, but not to the analysis of these conditions previously approved for Vermont Yankee (i.e., one percent cladding strain, fuel centerline melt, and hot channel conditions) for non-LOCA transient and accident analysis.

As discussed in Section 4.2, we also do not accept the use of FROSSTEY to determine initial conditions (even at low burnup) for the analysis of the loss-of-coolant accident.

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