CEN-220(B)-NP

SUPPLEMENTAL INFORMATION ON FATES3
STORED ENERGY CONSERVATISM

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COMBUSTION ENGINEERING, INC.

LEGAL NOTICE

Supplemental Information on FATES3

Stored Energy Conservatism

OBJECTIVE

The objective of providing supplementary information is to assist the NRC staff in assessing the degree of conservatism in FATES3 computed fuel temperatures at linear heat rates and burnups associated with the ECCS analysis. Although Calvert Cliffs 1 Cycle 6 is used as a reference, the information is generically applicable to FATES3.

SUMMARY AND CONCLUSIONS

An examination of FATES3 bias and uncertainty in predicting fuel temperatures and conservatisms introduced in the initial conditions for LOCA analysis has been made. It is quantitatively shown that sufficient conservatism has been included using the NRC suggested margin requirement of ensuring that 95% of the specified experimental data base would be overpredicted with a confidence level of 95%. [

] Therefore, no additional conservatism is warranted beyond that already included in the application of FATES3 in ECCS analysis.

INTRODUCTION

A new version of the C-E steady-state fuel performance code, FATES3, was developed and submitted for review as Ref. 1. This new version is intended to be the fuel evaluation model for licensing applications and reflects significant improvements in fission gas release modeling and in internal void volume and gas pressure modeling. It is intended to be applicable to extended burnup fuel. NRC questions related to the application of FATES3 in licensing analyses were addressed in Ref. 2. However, NRC questions about the degree of conservatism in the stored energy for the Calvert Cliffs 1 Cycle 6 ECCS analysis remained, as summarized in Ref. 3, and further discussed in Ref. 5, where it has been noted to be an open issue. This was adequately addressed for Calvert Cliffs 1 Cycle 6 by the supplementary ECCS analysis of Ref. 4 as noted in the NRC's evaluation report, Ref. 5.

TEMPERATURE BIAS OF FATES3

The FATES3 code predicted fuel centerline temperatures were compared in Ref. 1 with thermocouple data from well characterized fuel rods irradiated in the Halden test reactor. This centerline temperature comparison was shown in Figure 9-4 of Ref. 1 and is reproduced here as Figure 1. [ ] Reproducing the statistical evaluation of Ref. 3 results in a mean [ ] and a standard deviation [ ] Therefore, the centerline temperature margin required to satisfy the NRC requirement of a one-sided probability of 95% at a confidence level of 95% [ ]

However, in light of using this data to quantify conservatism required in the application of FATES3, it is reasonable to exclude certain data points which are shown as solid symbols in Figure 1. [ ] Two of the rods in HPR 80 (IFA-11 Rod HBB and IFA-21 Rod HCD) were initially power ramped at beginning of life, irradiated at high power levels to about 5,000 MWD/MTU, reduced in power, and then re-ramped to about 12 kw/ft. FATES3 predicts significant fission gas release for these two HPR 80 rods and, consequently, overpredicts fuel temperatures. The rods did not experience significant fission gas release as indicated by measured temperatures. Unpressurized fuel rod designs can, however, experience the fission gas release burst phenomenon, and these rods may, in reality, have been quite close to the release burst. These data points at 5,000 MWD/MTU burnup should be excluded from the data base for determination of code bias. [ ] IFA-418 rods were prepressurized [ ] and HPR 80 rods were unpressurized. Therefore, the data represent a good range in all important variables. Detailed characterization of this data is provided in Table 1.

Reproducing the statistical evaluation of Ref. 3 for this modified data set results in a mean [ ] and a standard deviation [ ] The centerline temperature margin is computed, using the NRC method, to be [ ] Details of the modified data set are provided in Table 2.

Sources of discrepancy between predicted and measured centerline temperatures are generally unknown. The ratio of the temperature difference (predicted minus measured) for volumetric average temperature to centerline temperature can vary from less than 0.5 to greater than 0.5, depending on the individual sources. Therefore, C-E concludes that a reasonable overall conversion factor for volumetric average temperature for the experimental centerline data is approximately 0.5 as used in Ref. 3. Using this ratio gives a margin requirement on volumetric average fuel temperature, enveloping 95% of the data at 95% confidence level, of

where [ ]

FIGURE 1

Comparison of Predicted and Measured Fuel Centerline Temperature Using FATES3 with Best Estimate Input

PREDICTED FUEL CENTERLINE TEMPERATURE, °F

MEASURED FUEL CENTERLINE TEMPERATURE, °F

TABLE 1
Test Rod Identification

Data Set	Rod	Range in LHGR, kw/ft	Rod Burnup, MWD/MTUx10^{-3}	Fuel-Clad Diametral Gap, mils	Fill Gas Composition and Pressure, psi	Enrichment, %
IFA 418						
IFA 428						
IFA 11	HBA	6→15	0	1.9	He @ 14.7	5
	HBB[2]	6→15	5	2.0	"	5
	HBC	6→15	0	6.5	"	5
21	HCA	6→14	0	1.9	"	5
	HCC	"	0	6.6	"	5
	HCD[2]	6→14	5	2.3	"	5

[2] Data from second ramp at 5,000 MWD/MTU excluded in Table 2.

TABLE 2
Test Rod Temperature Data

Data Point	Data Source	Rod	Thermo-Couple Location	Local Burnup, MWT/MTU	Local LHGR, kw/ft	Measured Temperature, °F	FATES3 Temperature Overprediction, °F

TABLE 2, continued

Data Point	Data Source	Rod	Thermo-Couple Location	Local Burnup, MWT/MTU	Local LHGR, kw/ft	Measured Temperature, °F	FATES3 Temperature Overprediction, °F

TABLE 2, continued

Data Point	Data Source	Rod	Thermo-Couple Location	Local Burnup, MWT/MTU	Local LHGR, kw/ft	Measured Temperature, °F	FATES3 Temperature Overprediction, °F

TABLE 2, continued

Data Point	Data Source	Rod	Thermo-Couple Location	Local Burnup, MWT/MTU	Local LHGR, kw/ft	Measured Temperature, °F	FATES3 Temperature Overprediction, °F

TABLE 2, continued

Data Point	Data Source	Rod	Thermo-Couple Location	Local Burnup, MWT/MTU	Local LHGR, kw/ft	Measured Temperature, °F	FATES3 Temperature Overprediction, °F
	IFA-11	HBA		0	6.10	1110	
				1	9.14	1530	
				2	12.19	2010	
				3	15.48	2530	
		HBB		0	6.10	1160	
				1	9.14	1600	
				2	12.19	2120	
				3	15.24	2640	

TABLE 2, continued

Data Point	Data Source	Rod	Thermo-Couple Location	Local Burnup, MWT/MTU	Local LHGR, kw/ft	Measured Temperature, °F	FATES3 Temperature Overprediction, °F
	IFA-11	HBC		0	6.10	1330	
				1	9.14	1880	
				2	12.19	2390	
				3	15.00	2750	
	IFA-21	HCA		0	6.10	1130	
				1	9.14	1580	
				2	12.19	2050	
				3	14.54	2370	
		HCC		0	6.10	1340	
				1	9.14	1870	
				2	12.19	2390	
				3	14.11	2610	
		HCD		0	6.10	1180	
				1	9.14	1630	
				2	12.19	2160	
				3	14.32	2550	

BIAS AND SCATTER TRENDS WITH GAP SIZE, LINEAR HEAT RATE, AND BURNUP

[ ] in the data with respect to gap size, as shown in Figure 2. For example, [ ] Also, the 6 IFA-11 and -21 rods range in gap size from 1.9 to 6.6 mils [ ]

The data (less the excluded points) have been plotted as a function of linear heat rate and burnup in Figures 3 and 4, respectively. [ ]

If only the data points at high linear heat rates as suggested by the NRC, say >14 kw/ft, are considered in order to evaluate bias and scatter near the Calvert Cliffs 1 LOCA limit, one calculates for centerline temperature a mean [ ] a standard deviation [ ] and a margin requirement (using the NRC method of Ref. 3) [ ] In terms of volumetric average temperature,

[ ]

[ ] A summary is provided in the following table.

	All Data	Data>14 kw/ft
Centerline Temperature, °F		
Average Temperature, °F		

FIGURE 2
Temperature Difference vs. As-Fabricated Diametral Gap

Temperature Difference (Predicted-Measured), °F

As-Fabricated Fuel/Clad Cold Gap, mils

FIGURE 3

Temperature Difference vs. Linear Heat Generation Rate

Temperature Difference (Predicted-Measured)°F

Linear Heat Generation Rate, kw/ft

FIGURE 4

Temperature Difference vs. Local Burnup

Temperature Difference (Predicted-Measured), ^{o}F

Local Burnup, MWD/KgU

CONSERVATISM ADDITIONALLY INTRODUCED INTO THE STORED ENERGY FOR ECCS ANALYSIS

The procedure for introducing conservatism into the stored energy for ECCS analysis is described in detail in Ref. 2. A summary of these sources of conservatism is provided in Table 3. [ ] Many of the sources listed in Table 3 accumulate significant conservatism with burnup and will not be evaluated here since limiting conditions for LOCA occur near beginning of life. At or near beginning of life sources of conservatism include [ ] Effect [ ] and treatment of these parameters is given in Table 4. As noted, the combined total of these [ ] on volumetric average fuel temperature. A plot of the absolute value of the fuel average temperature as a function of burnup to (4,000 MWD/MTU) is given in Figure 5. A nominal value of [ ] was used in the generation of this figure. The overall stored energy conservatism is significantly greater than that required when considering the margin requirement as a whole or the margin requirement near the LOCA limit as demonstrated in the following table:

	Overall	**At LOCA Limit**
[		]

Therefore, it is concluded that no additional conservatism is warranted beyond that already included in the application of FATES3 in the ECCS analysis.

FIGURE 5

Effect of Conservatisms on Fuel Average Temperature

FUEL AVERAGE TEMPERATURE, °F

ROD AVERAGE BURNUP, MWD/MTU

TABLE 3

CONSERVATISMS IN LOCA STORED ENERGY

a

a

a

a

TABLE 4

FATES3 Input Bias for Calvert Cliffs 1 Cycle 6

Item	Cycle 6 Value	Normal Value	Difference in Fuel Average Temperature

FATES3 AND GAPCON-THERMAL 2 COMPARISON

NRC audit calculations of fuel average temperature for Calvert Cliffs 1 Cycle 6 using GAPCON-THERMAL-2 (G-T-2) is provided by Ref. 3 and is reproduced here as Figure 6. As noted in Ref. 3, the peak temperature predicted by G-T-2 is approximately 214°F higher than FATES3. A detailed comparison of code submodels and results has been made which lead to the conclusion that G-T-2 calculation is more conservative than the FATES3 calculation near 0 MWD/MTU burnup, but that the FATES3 calculation is still conservative by the amounts quantified in previous sections of this report. Discussion of the comparison is provided below, and a summary of the components of the G-T-2 and FATES3 temperature differences is offered in Table 5 for NRC consideration.

Flux depression - Flux depression used in FATES3 resulted in a greater local power density shift toward the pellet surface than in G-T-2. This gives higher fuel centerline and fuel average temperature [ ] in G-T-2.

Clad conductivity - A small difference in clad conductivity results in a higher clad temperature gradient in G-T-2 than in FATES3. The elevated temperature on the clad inner diameter is amplified somewhat by the feedback effects of a decreasing fuel conductivity to a total difference of [ ]

Fuel pellet relocation - Fuel pellet relocation does not occur in the G-T-2 calculation until after 50 MWD/MTU burnup. This is the point where temperatures start to decrease as shown in Figure 6. Relocation in FATES3 is [ ] The absence of any relocation in G-T-2 results in a major difference in fuel average temperature. G-T-2 is approximately [ ] higher than FATES3 due to this parameter alone. Due to the fact that the maximum temperature occurs in FATES3 at about 3,000 MWD/MTU, some burnup dependent relocation has occurred and is, of course, a component of the [ ] difference.

Fuel densification - [ ] However, because the maximum temperature occurs in FATES3 at about 3,000 MWD/MTU burnup, significantly more densification has occurred than in G-T-2. FATES3 temperatures are, therefore, approximately [ ] higher than G-T-2. The combined effect of densification and relocation is shown in Table 5 and is [ ] (G-T-2 is higher than FATES3 overall).

Clad creepdown - It appeared that the major difference in clad creep is due to the elasped time to accumulate 3,000 MWD/MTU in FATES3. As shown in Table 5, this is equivalent to approximately [ ] G-T-2 is higher because essentially no creepdown has occurred.

Thermal expansion - Differences in fuel pellet thermal expansion exist. Although both codes utilize a partially cracked fuel pellet, the thermal expansion of the uncracked portion is treated differently, the assumed location of the crack radius is slightly different, and the coefficient of expansion slightly different. A minor difference in thermal expansion of the clad also exists. A net result is estimated to be approximately [ ] higher average fuel temperature in G-T-2 than in FATES3.

Energy deposition - Energy deposition in the clad in FATES3 is 1% of the linear heat rate as defined in Ref. 2. The G-T-2 calculation neglected this energy deposition. This difference is estimated to increase the FATES3 temperature by approximately [ ] over that of G-T-2.

FIGURE 6

NRC Audit Comparison to FATES3

Source: Ref. 3

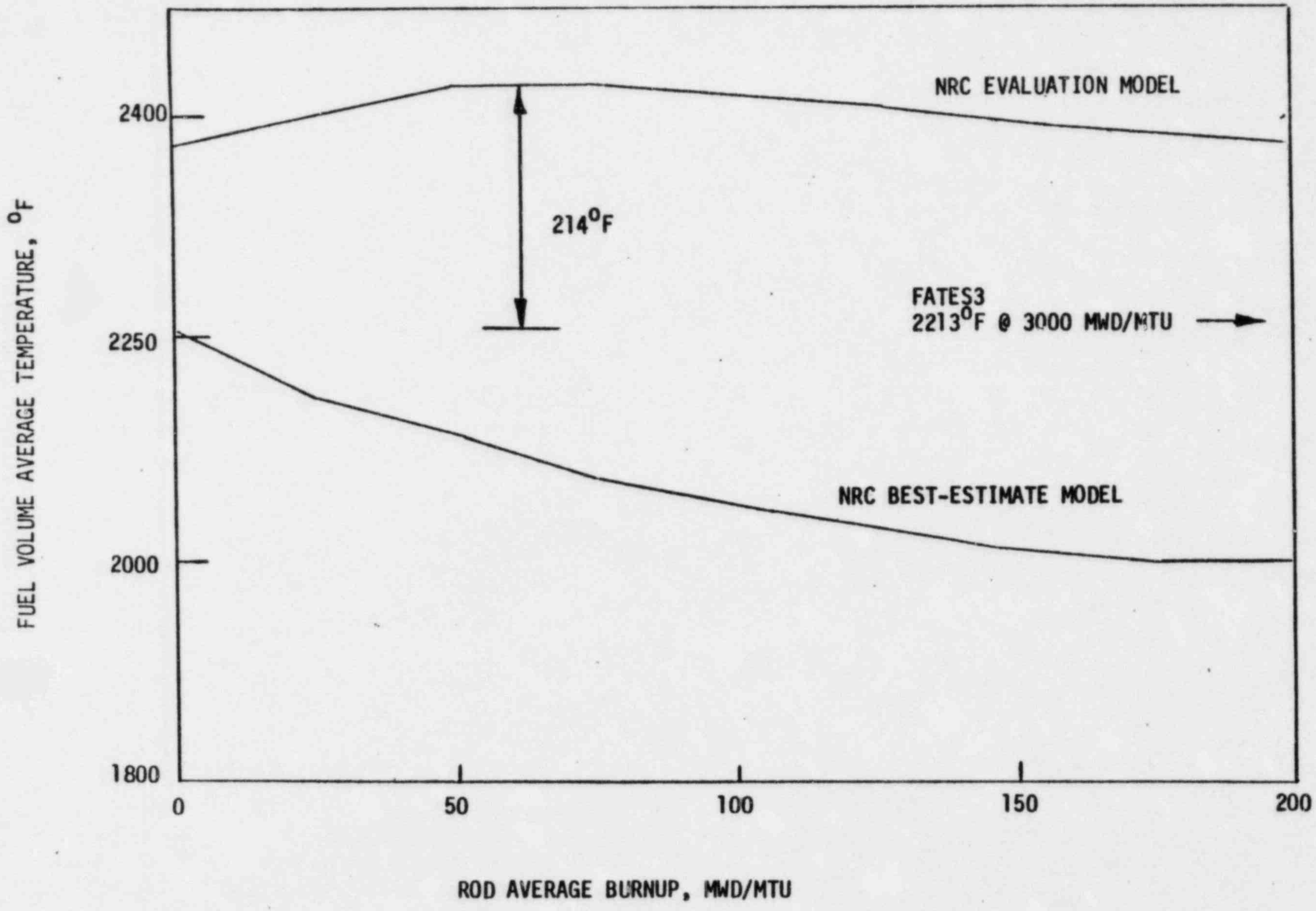

TABLE 5

SUMMARY OF GAPCON VS. FATES3

TEMPERATURE DIFFERENCES

NRC REPORTED DIFFERENCE + 214°F

SOURCE

- o FLUX DEPRESSION IN PELLET
- o CLAD CONDUCTIVITY
- o RELOCATION
- o DENSIFICATION | TOTAL
- o CLAD CREEPDOWN
- o THERMAL EXPANSION
- o NRC AUDIT LHGR DIFFERENCE

NOTE: TEMPERATURE DIFFERENCES ARE APPROXIMATE AND NEGLECT FEEDBACK OF COLLECTIVE APPLICATION

REFERENCES

1. CEN-161-(B)-P, "Improvements to Fuel Evaluation Model", Combustion Engineering, Inc., July, 1981.

2. CEN-193-(B)-P, Supplement 2-P, "Partial Response to NRC Questions on CEN-161-(B)-P, Improvements to Fuel Evaluation Model", Combustion Engineering, Inc., March 21, 1982.

3. NRC Memorandum, John C. Voglewede to Carl H. Berlinger, "Viewgraphs for Meeting on FATES-3 Code", May 14, 1982.

4. C-E Letter BG&E-9676-703, P. W. Kruse to W. J. Lippold, "Calvert Cliffs 1 Cycle 6 Supplement ECCS Calculatin", May 19, 1982.

5. Safety Evaluation by the Office of Nuclear Reactor Regulation Supporting Amendment No.71 to Facility Operating License No. DPR-53 Calvert Cliffs Nuclear Power Plant Unit No. 1 Docket No. 50-317.