COMBUSTION ENGINEERING, INC.

Report No.

1-NP to LD-83-20

Response to NRC Questions for CESSAR-F Statistical Combination of Uncertainty in Thermal Margin Analysis for System 80

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Question 1:

Previous thermal margin analysis using the combination of system parameter uncertainties approach has shown the most adverse set of state parameters (excluding axial shape index) to be at their minimum values (Combustion Engineering 1980a, 1980b). Explain why the sensitivity calculations performed for the System 80 plants no longer show the most adverse state parameters at their minimum values.

Response

Uncertainties in the core inlet flow distribution were not treated statistically in the present analysis, but were treated in a deterministic manner as described in Section 3.3 of Reference 1. Because of this fact, the most adverse state parameters are different from those of previous analyses (see References 2 and 3). As explained in responses to questions on previous statistical combination of system parameter uncertainties analyses (Ref. 4), MDNBR [ ] than to perturbations in other system parameters. Thus, when [ ]

The effect [ ] is shown in Table 1-1. These data serve an illustrative purpose only, in demonstrating the effect of including a hypothetical [ ] The data in Table 1-1 demonstrate that, [ ] than the set of state parameters used in System 80 analysis. Hence, the most adverse set of parameters for System 80 differs from those found in previous analyses because [ ] in the System 80 analysis.

REFERENCES

1. Enclosure 1-P to Letter LD-82-054 from A. E. Scherer (CE) to D. G. Eisenhut (NRC), "Statistical Combination of Uncertainties", May, 1982.
May, 1982.

2. CEN-139(A)-P, "Statistical Combination of Uncertainties", November, 1980.

3. CEN-124(B)-P, "Statistical Combination of Uncertainties, Part 2", January, 1980.

4. "Responses to Second Round Question on the Statistical Combination of Uncertainties - Reports CEN-139(A)-P, CEN-124(B)-P Part 2", April, 1981, response to question 2b.

Table 1-1

Effect of in Determining the Most Adverse State Parameters

					MDNBR		
Description	Pressure (psia)	Temp. (°F)	Flow (%)	ASI	System* Parameters Adversely Perturbed	System* Parameters Advantageously Perturbed	MDNBR (%)

Question 2:

Describe more fully the data base used in determining the mean and standard deviation given for the enthalpy rise factor described in Section 3.5.

Response

Derivation of the enthalpy rise factor is done in accordance with standard C-E quality assurance procedures as reviewed and approved by NRC in Reference 1. Input involves 100% recording of the pellet lots used in each rod of each assembly. Within pellet lots, NRC approved sampling procedures are used to determine the U_{235} loading. The enthalpy rise factor in every channel is determined by taking the ratio of the as-built value of U_{235} loading in that channel to the nominal value. The enthalpy rise factor is calculated for each subchannel in all the assemblies of a fuel batch. The factors are then collected in a histogram for each specific type of channel and for SCU, the histogram for the channel type in which MDNBR occurs is inserted to the SIGMA Monte Carlo Code as described in Reference 2.

As-built data for System 80 fuel are not yet available. However, a survey of enthalpy rise factors computed for other 16x16 fuel demonstrates that the mean and standard deviation used in the System 80 SCU analysis are bounding. Since tolerances and fuel fabrication procedures are the same for 16x16 fuel, these values are expected to bound actual as-built data for System 80. When as-built data for Arizona Unit 1 Cycle 1 fuel become available, the enthalpy rise factor will be calculated and verified to be conservative relative to the values used in the System 80 SCU analysis.

References

1. CENPD-210-A Rev. 3, "Quality Assurance Program", November, 1977.

2. CEN-139(A)-P, "Statistical Combination of Uncertainties", November, 1980.

Question 3:

Describe the procedure used in determining the mean and standard deviation for the engineering heat flux factor described in Section 3.6.

Response

Variations in local heat flux for a fuel rod are dependent upon changes in pellet diameter, pellet density, pellet enrichment and clad diameter. Local heat flux is related to these parameters by the following equation:

$$q'' = \frac{K D_p^2 \rho_p n}{D_c}$$

K = constant of proportionality

D_p = fuel pellet diameter

ρ_p = fuel pellet density

n = U_{235} enrichment

D_c = fuel rod clad outside diameter

The overall standard deviation on local heat flux is evaluated by taking the root sum square of the standard deviations of each of the measured parameters in this equation. Partial derivatives on heat flux with respect to each parameter are determined from the above equation and included in the root sum square technique to account for the proper weighting of each standard deviation.

The standard deviations for pellet enrichment and clad outside diameter are evaluated using as-built data. Fuel pellet diameter is inspected on a go no-go basis to be within the drawing tolerance. Thus, pellet diameter tolerance is used to describe the statistical variation of pellet diameter. The fuel pellet density standard deviation is determined from fuel pellet specifications. The engineering factor on local heat flux is determined for each nominal enrichment by adding the overall 2 sigma deviation (95 probability/95 confidence level) to the mean as-built rod heat flux and dividing this sum by the nominal rod heat flux. Based on all enrichments examined, the mean and standard deviation corresponding to the largest engineering factor are chosen for use in the SCU analysis.

The mean and standard deviation for the engineering heat flux factor given in Section 3.6 was calculated on the basis of manufacturing tolerances on pellet density, pellet enrichment, pellet diameter and clad diameter. These values are based

entirely on the information provided on the certified drawings and fuel pellet specifications for conservatism. When as-built data for pellet enrichment and clad outside diameter are available for Arizona Unit 1 Cycle 1, the heat flux factor will be calculated and verified to be conservative relative to the values used in the System 80 SCU analysis.

Question 4: (Section 3.8)

Describe more fully the data base used in determining the mean and standard deviation for systematic gap width described in Section 3.8

Response:

The mean and standard deviation of the systematic gap width used in the System 80 system parameter component of the Statistical Combination of Uncertainties (SCU) analysis were based on as-built data for 16x16 fuel assemblies from the ANO-2 Cycle 1 core. These data were described previously in Reference 1, and were obtained as part of a joint CE-EPRI fuel performance evaluation program described in Reference 2. A discussion of the gap width data appears in Section 3.5 of Reference 2.

Since drawing specifications, tolerances and fabrication procedures are similar for System 80 fuel assemblies and the fuel assemblies examined from ANO-2 Cycle 1, as-built data from fuel assemblies in the latter core can be used to characterize the systematic gap width for System 80 fuel assemblies. Drawing tolerances for the two cores are listed in Table 4-1.

REFERENCES

1. CEN-139(A)-P, "Combination of System Parameter Uncertainties in Thermal Margin Analyses for Arkansas Nuclear One Unit 2", Section 3.8, CE Power Systems, November, 1980.

2. EPRI Report RP586-1 Task B, "CE/EPRI Fuel Performance Evaluation Program-Fabrication and Characterization of Arkansas Nuclear One Unit II 16x16 Fuel Assemblies", CE Power Systems, October 1978.

TABLE 4-1

Specifications and Tolerances for System 80 and ANO-2

Fuel Assembly Pitch Dimension

Reactor	Pitch Dimension	Tolerance
System 80	0.506 in.	±0.005 in. (±0.010 in. from nominal acceptable at not more than 30 locations per spacer grid provided not more than two dimensions from a single point vary more than ±0.005 in. from nominal.)
ANO-2	0.506 in.	±0.005 in. (±0.010 in. from nominal acceptable at not more than 30 locations per spacer grid provided not more than two dimensions from a single point vary more than ±0.005 in. from nominal.)

Question 5

In Table 3-3, the most sensitive operating conditions were determined by selecting: one of three operating pressures (1750, 2250 and 2400 psi), one of four inlet temperatures (465, 550, 565, 615°F), and one of three design flows (75, 100, 120%) at a constant ASI. TORC simulations were then performed with nominal, adversely, and advantageously perturbed system parameters. The combination of pressure/temperature/flow conditions which displayed the largest overall MDNBR was then selected as most sensitive. Only 14 of 36 pressure/temperature/flow combinations were run in determining the most sensitive operating conditions.

Close inspection of Table 3-3 shows a number of conflicting trends. For example, at constant pressure and flow, both maximum and minimum values of inlet temperature can be found to give the greatest sensitivity. Additionally, at constant pressure and inlet temperature, both high and low values of flow will provide maximum sensitivity. This suggests some interaction between operating parameters with respect to MDNBR sensitivity and implies that it may be necessary to run all 36 combination (3 x 4 x 3) of pressures/temperatures/flows to accurately determine the most sensitive operating conditions. Furthermore, completion of the pressure/temperature/flow run matrix does not ensure that the most sensitive operating conditions have been identified, only that the most sensitive operating conditions of the selected values have been found. Demonstrate that Table 3-3 does indeed give the most sensitive operating conditions.

Response:

Based upon past experience the 14 operational states contained in Table 3-3 of Reference 1 were selected as probable limiting states. However, to respond to the concern raised in this question, CE has analyzed the remaining conditions in the operational matrix. In addition to completing the matrix of operating conditions CE has analyzed two additional operating states at 2000 psia. The results of this expanded matrix are presented in Table 5-1 with the actual values of MDNBR listed in Table 5-2.

Although the state of [ ] yields a slightly larger sensitivity than that used in the Ref. 1 analysis [ ] examination of the data in Table 5-1 indicates that the maximum sensitivies are clustered in the region of [ ] Because the difference in sensitivities is so small, the slight increase in sensitivity found in responding to this question will have negligible impact upon the final MDNBR design limit.

Reference

1. Enclosure 1-P to Letter LD-82-054 from A. E. Scherer (CE) to D. G. Eisenhut (NRC), "Statistical Combination of Uncertainties", May, 1982.

TABLE 5-1

% MDNBR for Perturbations in System Parameters
at Various State Parameters

Flow	1785 psia				2000 psia				2250 psia				2400 psia			
75%																
100%																
120%																
T	465	550	565	615	465	550	565	615	465	550	565	615	465	550	565	615

Table 5-2
Additional MDNBR Values for Perturbed System Parameters
At Various State Parameters

Press./Temp./Flow*	MDNBR System Parameters Adversely Perturbed	MDNBR System Parameters Advantageously Perturbed	Δ MDNBR (%)
1765/ 465 / 75			
1785/ 550 / 75			
1785/ 565 / 75			
1785/ 615 / 75			
1785/ 465 / 100			
1785/ 550 / 100			
1785/ 565 / 100			
1785/ 615 / 100			
1785/ 465 / 120			
1785/ 550 / 120			
1785/ 565 / 120			
1785/ 615 / 120			
2000/ 550 / 100			
2000/ 565 / 100			
2000/ 550 / 120			
2000/ 565 / 120			
2250/ 465 / 75			
2250/ 550 / 75			
2250/ 565 / 75			
2250/ 615 / 75			
2250/ 465 / 100			
2250/ 550 / 100			
2250/ 565 / 100			
2250/ 615 / 100			
2250/ 465 / 120			
2250/ 550 / 120			
2250/ 565 / 120			
2250/ 615 / 120			
2400/ 465 / 75			
2400/ 550 / 75			
2400/ 565 / 75			
2400/ 615 / 75			

*psia/°F/% thermal margin design flowrate

TABLE 5-2 (cont.)

Additional MDNBR values for Perturbed System Parameters at Various State Parameters

Press./Temp./Flow*	MDNBR System Parameters Adversely Perturbed	MDNBR System Parameters Advantageously Perturbed	Δ MDNBR (%)
2400/ 465 / 100			
2400/ 550 / 100			
2400/ 565 / 100			
2400/ 615 / 100			
2400/ 465 / 120			
2400/ 550 / 120			
2400/ 565 / 120			
2400/ 615 / 120			

*psia/°F/% thermal margin design flowrate

Question 6: (p. A-2):

Table A-1, which lists the coded set of system parameters used to generate the response surface, shows no difference between cases 1 and 2. Is this correct?

Response:

A typographical error was found in Case 2 of Table A-1, the line should read:

Case Number	Enthalpy Rise Factor	Systematic Pitch	Systematic Clad O.D.
2	-1.00	-1.00	1.00

Table A-2 lists the actual numerical value of systematic clad O.D. used in the analysis, and is in agreement with the corrected set of coded values listed above.

Question 7:

It is assumed that since the TORC code (Combustion Engineering 1975, 1977) was used for both DNB data analysis and for DNB evaluation in the reactor, the uncertainties in the code are cancelled in the reactor application. Although it is agreed that the code uncertainty is small and perhaps conservative, the conservativeness is not confirmed for all cases nor is the smallness quantified. This problem exists for all subchannel codes. Justify why the TORC code should be exempt from this source of uncertainty.

Response:

C-E has addressed the subject of TORC code uncertainties in responses to questions regarding the SCU analyses for Calvert Cliffs (Ref. 1). It is C-E's position that the calculational uncertainty in TORC/CE-1 methodology is accommodated in the design DNBR limit. This implicit allowance for TORC uncertainty results from use of the TORC code to determine local coolant conditions for data obtained from the CHF experiments which support the CE-1 CHF corrrelation (Ref. 2 & 3).

In a related question concerning TORC predictions of coolant enthalpy in analyses of CHF test sections and the reactor core it was demonstrated (Reference 4) that TORC/CE-1 conservatively predicts DNBR. Thus, any calculational uncertainty in the TORC code is inherent in the CE-1 statistics which are stochastically combined with the system parameter uncertainties to yield the design DNBR limit.

References

1. "Response to First Round Questions on the Statistical Combination of Uncertainties Program, Part 2 (CEN-124(B)-P", February, 1981.

2. CENPD-162-P-A, "C-E Critical Heat Flux", September, 1976.

3. CENPD-207-P, "CE Critical Heat Flux - Part 2 Nonuniform Axial Power Distribution", June, 1976.

4. Enclosure to BG&E-9676-575, "Response to Second Round Question on the Statistical Combination of Uncertainties - Reports CEN-139(A)-P and CEN-124(B)-P-Part 2", Question 9, April, 1981.

Question 8:

The manner in which the most sensitive ASI and the most sensitive operating conditions are determined implicitly assumes that there is no interaction between ASI and operating conditions. This should be either demonstrated or justified.

Response:

The interaction between ASI and operating conditions has been examined by perturbing the system parameters for various axial shape indices at various operational states. The two operational states examined in this study [ ] were chosen from Table 3-3 of Reference 1 because they resulted in large sensitivites of MDNBR to the system parameters considered in the System 80 analysis. Similarly, axial shapes which covered a range of ASI values and resulted in large sensitivities were selected from Table 3-2 of Ref. 1. Additional cases were also run at [ ] In total, 26 additional D-TORC analyses were run to determine 13 sensitivities that could be used together with data from Ref. 1 to examine interaction effects between pressure/inlet temperature/flow and ASI.

Results from these analyses are summarized in Table 8-1. Examination of these results indicates that the state of [ ] yields a greater sensitivity [ ] than was found for the state parameters used to generate the MDNBR response surface. This increase in sensitivity would have a small effect on the calculated design MDNBR limit that is compensated for by conservatism in the methodology used to combine system and state parameter uncertainties. As explained in discussions during review of previous SCU analyses, this conservatism in the overall methods arises because system parameter and state parameter uncertainties are combined separately. While each set of parameters is statistically combined, the results from each analysis are applied in a non-statistical manner to calculate margin to DNB.

Reference

1. Enclosure 1-P to Letter LD-82-054 from A. E.Scherer (CE) to D. G. Eisenhut (NRC), "Statistical Combination of Uncertainties", May, 1982.

TABLE 8-1

Interaction Effect of Simultaneous Changes in Operating Conditions and Axial Power Distribution on MDNBR Sensitivity to Perturbations in System Parameters

		MDNBR		
Operational State	A.S.I.	System Parameters Adversely Perturbed	System Parameter Advantageously Perturbed	Δ MDNBR (%)
Press./Temp./ % Flow				

[ ]

Question 9:

The discussion of the inlet flow distribution is unclear. One possible interpretation is that the lowest of three observed values was used. However, three values are not sufficient to characterize a distribution, and certainly the lowest of three is not an acceptable lower bound on the potential values. Please clarify the method used to account for this uncertainty.

Response

The method used to account for the uncertainty on the core inlet flow distribution is described below.

Three test runs were made on a reactor flow model to determine the core inlet flow distribution. A complete (core-wide) core inlet flow distribution was determined from each test run. This procedure provided three observed values for each fuel assembly location. Recognizing that three observations per location is not a sufficient sample to obtain meaningful statistics, it was decided to treat the uncertainty associated with the core inlet flow distribution data in a deterministic manner.

A quarter core or quadrant map of the core inlet flow distribution was constructed by "folding over" the core-wide flow distribution maps. The basis for this operation is that the reactor flow model has geometric quadrant symmetry and the flow distribution is also expected to be nearly symmetric on a quadrant basis. The resulting quadrant map generally has twelve observed values of inlet flow per fuel assembly location. Fuel assemblies on the core centerlines have fewer observed values, but these locations are not limiting from a thermal margin standpoint.

An average quadrant core inlet flow distribution map was then constructed by averaging the observed values in each fuel assembly location based on up to twelve observed values.

The quadrant map containing all of the inlet flow observed values was examined to determine the lowest observed fuel assembly inlet flow values and to identify the assembly locations where they occurred. The two lowest values found anywhere on the map, out of a possible 241x3 values, are [ ] and [ ] as shown in Figure 1; these values express the ratio of the inlet flow rate to a particular fuel assembly relative to the average fuel assembly inlet flow rate. For comparative purposes, the lowest observed value in the limiting fuel assembly location (channel No. [ ] in Figure 1) was [ ]

For each of these two lowest flow locations, the lowest observed inlet flow values to the four immediately neighboring fuel assembly locations were selected. The lowest observed values in

the neighboring assemblies were chosen even though, in most cases, the lowest neighboring flow values occurred in different test runs and/or different quadrants than the run and quadrant containing the lowest two values (the [ ] and [ ] values).

At this point, two five assembly clusters were identified as shown in Figure 1; each central fuel assembly in the cluster contained one of the lowest observed values ([ ] or [ ]) and its four neighbors also contained the lowest observed values in those locations. An average of the five assembly minimum inlet flows in each cluster was calculated. The five assembly cluster having the [ ] inlet flow value for the central assembly had the lower five-assembly average inlet flow value, [ ]. The other cluster had a five-assembly average inlet flow value of [ ]. Minimum DNBR is sensitive to the inlet flow values in the neighboring assemblies as well as that in the limiting assembly. The five-assembly cluster having the lower five-assembly average inlet flow value ([ ]) and the second lowest central assembly inlet flow value ([ ]) was chosen as the localized inlet flow distribution for the limiting fuel assembly location. That is, this five-assembly cluster of minimum inlet flow rates was imposed deterministically at the limiting fuel assembly location as shown in Figure 2. The remaining fuel assemblies in the core were assigned inlet flow values from the average quadrant core inlet flow distribution map.

This approach is a conservative means of handling the effects of the inlet flow uncertainties because:

1. The near lowest observed inlet flow ([ ]) is applied deterministically to the limiting fuel assembly, even though the limiting assembly is in a different location from where this value occurred and has a significantly larger lowest observed value ([ ]).

2. The inlet flows to the four neighboring assemblies in the cluster containing the central assembly with the [ ] inlet flow value are the lowest inlet flow values observed in those four locations.

3. The five-assembly average inlet flow to the five assembly cluster imposed on the limiting assembly location is [ ], as compared to the five-assembly average inlet flow observed at the limiting assembly location of [ ] obtained by taking average observed flow values in each of the five assemblies.

In summary, to cover the inlet flow distribution uncertainty, the inlet flow to the five assemblies at the limiting location are reduced deterministically by about [ ] on the average relative to the average five-assembly inlet flow determined from the average quadrant inlet flow map.

FIGURE 1

Location of the Five Fuel Assembly Clusters Containing the Lowest Observed Inlet Flowrate Values

FIGURE 2

Inlet Flowrate Values Imposed on the Five Assembly Cluster Centered on the Limiting Assembly Location

<u>Qestion 10:</u> (p. 3-16)

On page 3-16, Table 3-2, the "advantageously perturbed" column for axial shape, +0.337, has a value less than nominal. Why? Also, there are several errors in the "% change" column.

<u>Response:</u>

Typographical errors were found on Table 3-2, the corrected lines should read:

Axial Shape Index	Nominal System Parmeters	System Parameters Adversely Perturbed	System Parameters Advantageously Perturbed	% Change Adverse + % Change Advantageous
+0.337	[			----]
0.000				
-0.001				]

Question 11: (p. 6-1)

In section 6-1, p. 6-1, line 5, σ_S = 0.0011711. On Line 6, σ_S is used as 0.001939, which is correct?

Response:

Typographical errors were found in section 6.1, the s:ntence should read:

"A comparison of TORC results and response surface predictions indicates that the 1 sigma error associated with the response surface is σ_S = 0.001939; at the 95% confidence level, this value is $\sigma_{S95} = (0.001939 \times \sqrt{5/1.15}) = 0.00404$."

Question 12: (p. 6-1)

In section 6-1, line 11, is there a square root symbol missing?

Response:

A typographical error was found on Line 11 of section 6.1, the sentence should read:

"The resultant MDNBR standard deviation, adjusted for the finite sample size used as $0.073971 \times \sqrt{1999/1986.131} = 0.075952$"