BIG ROCK POINT PHYSICS METHODOLOGY REPORT

REVISION 3

Consumers Power Company

Jackson, Michigan

October 11, 1982

9 pages

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2.2 OPERATION AND SURVEILLANCE (CONT'D)

shutdown margin, rod worth, notch worth, MAPLHGR, MCPR, MCHFR, assembly power and heat flux while allowing operation at the highest possible power level. The safety analysis verifies that these limits will be met, and in addition verifies that other parameters: reactivity coefficients, beta/lambda, liquid poison worth and scram reactivity insertions times, are within the assumptions used in the plant accident and transient analyses.

The startup physics test program consists of verification of shutdown margin, comparison of the zero power critical control rod density with predictions, and comparison of measured flux wire shapes with predicted ones.

During operation power distribution calculations are periodically performed to evaluate margin to thermal limits. Once a month calculated reactivity and flux wire activation shapes are compared with measurements to monitor the adequacy of the calculational model. The flux wire measurements are also used to calibrate the incore detectors and determine their alarm setpoints.

3.0 PHYSICS MODEL

3.1 OVERVIEW

The calculational sequence for Big Rock Point physics is diagrammed in Figure 3-1. The primary component of the sequence is the three dimensional reactor simulator program, GROK. The remainder of the sequence primarily involves the generation of input for GROK. The

4.8 METHOD OF STATISTICAL ANALYSIS (CONT'D)

The assumption of independence is not exactly true, but the second order effects should be small enough to ignore. For example, an error in the radial power distribution will cause a change in the axial power distribution, but the difference in the axial should be small enough to ignore. Another aspect of the independence assumption is that the point in the core that has the largest deviation of calculated to actual in one parameter does not also contain a large deviation in one or all of the other parameters.

4.9 MCPR UNCERTAINTY FACTOR

The minimum critical power ratio (MCPR) is expressed as the ratio of critical power level (CPL) to actual power level (APL). This ratio has to be greater than or equal to 1.32[7]. The ratio may be formulated as $P = CPL/APL \geq 1.32$. Using statistical propogation of errors, the uncertainty factor (U) for P is:

$$U = \sqrt{\left(\frac{\partial P}{\partial CPL} \sigma CPL\right)^2 + \left(\frac{\partial P}{\partial CPL} \sigma APL\right)^2}$$

By evaluating the partial derivatives, the equation becomes:

$$U = \sqrt{\left(\frac{1}{APL} \sigma CPL\right)^2 + \left(\frac{-CPL}{APL^2} \sigma APL\right)^2}$$

The standard deviation in the APL is equal to the standard deviation in the radial power distribution, 0.03766. (from Section 5.0), times the APL. The CPL can be formulated as $CPL = APL(1.32 + U)$. The standard deviation in the CPL can be formulated as:

$$\sigma CPL^2 = \left(\frac{\partial CPL}{\partial CHFR} \sigma CHFR \right)^2$$

CHFR - Critical Heat Flux Ratio

CHFR is expressed as the ratio of critical heat flux (CHF) to actual heat flux (AHF). The MCPR calculation forces the CHFR to equal

4.9 MCPR UNCERTAINTY FACTOR (CONT'D)

1.0 ± 0.01, by adjustment of the critical power ratio (CPR). Using statistical propogation of errors, the uncertainty factor (V) for CHFR is:

$$V = \sqrt{\left(\frac{\partial CHFR}{\partial CHF} \sigma_{CHF}\right)^2 + \left(\frac{\partial CHFR}{\partial AHF} \sigma_{AHF}\right)^2}$$

By evaluating the partial derivatives, the equation becomes:

$$V = \sqrt{\left(\frac{1}{AHF} \sigma_{CHF}\right)^2 + \left(\frac{-CHF}{AHF^2} \sigma_{AHF}\right)^2}$$

As AHF increases, V decreases. Thus, AHF will be chosen as the largest allowed, that is, CHF minus allowance for the uncertainty factor, or AHF equals CHF(1-V). The standard deviation in the actual heat flux (σAHF) is equal to the standard deviation in the peak heat flux, 0.094017 (from Section 5.0), minus the 2% heat balance error, times CHF(1-V) or 0.09186 times CHF(1-V).

The standard deviation in the critical heat flux (σCHF) is derived from the XN-2 critical heat flux correlation. Differentiating the correlation, with respect to the local peaking results in the following formulation for σCHF:

$$(\sigma_{CHF})^2 = \left(\frac{\partial XN\text{-}2}{\partial F} \sigma_{F1}\right)^2$$

This relationship for the σCHF indicates that the uncertainty in the CHF resulting from any other independent variable has been accounted for in the transient analysis. The partial derivative, in the above equation, is a function of mass velocity (G) and a non-uniform axial heat flux correction factor (F-factor). A study to determine conservative values for the mass velocity and the F-factor was performed by analyzing past cycles using GROK. Combining the results of the study with the local peaking factor uncertainty, from Section 5.0, the σCHF is 0.03395.

Evaluation of the uncertainty in the CHFR required that a conservative value for the CHF be determined. The CHF value was determined using the XN-2 correlation and conservative or limiting values for mass velocity, F-factor, reactor pressure, enthalpy, and local peaking. Values for mass velocity and F-factor are the same as those used in calculating σCHF. The enthalpy and reactor pressure were assigned full power values of 570.96 Btu/lb and 1,350 PSIA, respectively. Maximization of the CHF required the smallest local peaking factor (Fl). The limiting Fl was determined by evaluating past cycles, using GROK. The minimum Fl from the past cycles was determined to be 1.13986. This Fl must then be corrected for Fl uncertainty resulting in a Fl of 1.06593. Combining the above results yields a CHF of 1.0961×10^6 Btu/hr-ft^2.

Substitution of the above calculated values for AHF, σAHF, σCHF and CHF into the relationship for V results in a CHFR uncertainty of 0.11005.

A study was performed to determine a conservative value for the partial derivative of CPL with respect to the partial derivative of CHFR (∂CPL/ ∂CHFR). For each assembly, a linear relationship was defined using the variables CPR, APL and CHFR. This relationship can be formulated as follows:

$$\frac{\partial \mathrm{CPL}}{\partial \mathrm{CHFR}} = \frac{\Delta \mathrm{CPR(APL)}}{\Delta \mathrm{CHFR}}$$

The average ∂CPL/∂CHFR, from the study, was 3.53846 ± 0.59001 MWt. To bring the average ∂CPL/ ∂CHFR up to a 95/95 one-sided confidence level, the standard deviation should be multiplied by 1.645 and added to the average. Thus, ∂CPL/ ∂CHFR equals 4.50903 MWt. Substituting the values for the σCHFR and ∂CPL/∂CHFR into the equation for the σCPL gives a σCPL equal to 0.49622 MWt.

A formula for APL can be derived using Figure 4-6. Figure 4-6 is a graph of MCPR vs Assembly Power (MWt) A least squares fit was applied to the data and 99/99 confidence lines were drawn in. The equation for line 1 is:

$$\mathrm{MCPR} = -0.71382(\mathrm{APL}) + 3.95459$$

The above equation can be written in terms of U and APL as follows:

$$\mathrm{APL} = \mathrm{U}-2.63459/-0.71382$$

Substitution of the above calculated values for σAPL, CPL, σCPL and APL into the relationship for U results in a MCPR uncertainty of 0.1531.

5.0 SUMMARY AND CONCLUSIONS

The reactor physics methods employed at Consumers Power Company are very similar to methods used elsewhere in the industry. The computer models are or are derived from widely accepted codes which are well tested and documented.

Agreement with measured data and higher order calculations has demonstrated the accuracy and applicability of the methodology. Reactivity is consistently predicted at both cold and hot operating conditions, and power distributions agree well with the measurements, and higher order calculations indicating that the various neutronic effects are being properly modeled. The table below symmarizes the various uncertainty factors at a 95/95 one or two sided confidence level.

Parameter	Type	Uncertainty Factor
Bundle Power	one sided	3.7661%
Axial Power	one sided	5.3045%
Local Peaking	one sided	6.4861%
Peak Heat Flux*	one sided	9.4017%
MAPLHGR*	one sided	0.0784
MCHFR*	one sided	0.3228
Void Coefficient	two sided	0.0351
MCPR	one sided	0.1531

*The uncertainty factor includes the effects of the 2% heat balance error.

BRP Cycles 14 & 17 MCPR vs Assembly Power

99/99 Confidence Lines Included

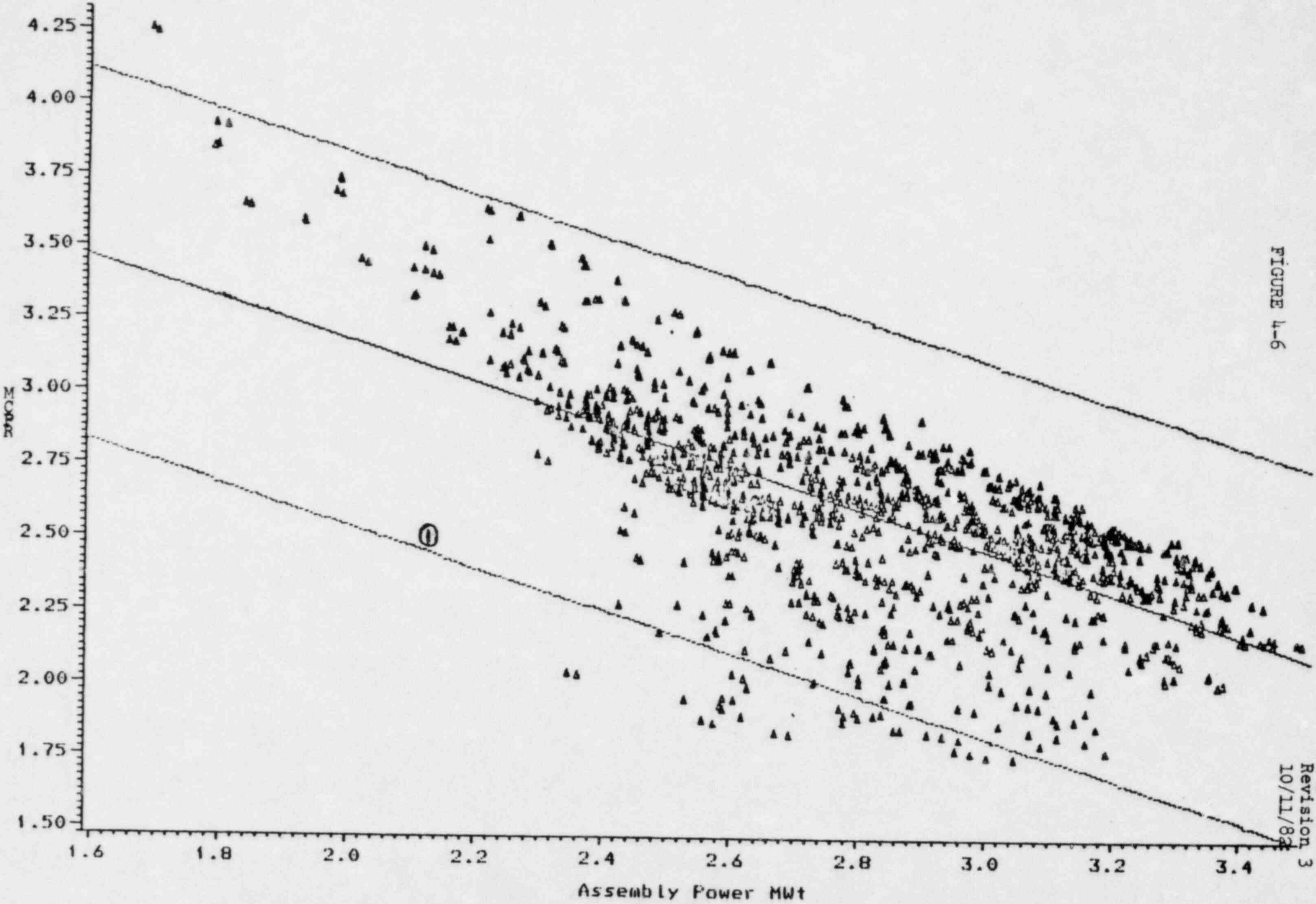

FIGURE 4-6

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