ATTACHMENT

Response to Request for Additional Information
WCAP-8720, Addendum 2

Question #1

Will the modified annular gap conductance model described in Addendum 2 to WCAP-8720 be used for all new licensing calculations which rely on the PAD fuel performance code? If not, please identify which analyses will continue to rely on the unmodified version of the code and why this is appropriate.

Response

The modified annular gap conductance model will be used to calculate initial stored energy for safety calculations. All rod design evaluations described in Chapter 4 of the SARs will continue to be performed with the NRC approved version 3.3 of the code.

Peak fuel temperatures occur near beginning of life and changing the gap conductance model without re-normalization of the other empirical code models has a negligible effect on calculated temperatures. Minimum fuel temperatures used in safety analyses occur when the pellet-cladding gap is closed and the modified gap conductance equation is equivalent to the existing gap conductance equation.

It would not be appropriate to use the PAD code with the modified gap conductance equation in any other applications, since the other empirical code models have not been re-normalized to the revised fuel temperature predictions. The existing NRC approved PAD code version 3.3 is still valid for these analyses.

Question #2

A statistical analysis of HPR-80 measurements versus PAD predictions is reported in Addendum 2. However, the overall code uncertainties appear to be based only on the more recent data (IFA-431, IFA-432 and IFA-513). What overall code uncertainties result when both the more recent and the previously reported data (HPR-80, WAPD-228, AE-318 and IFA-226) are considered? Do the older data show the same predictive trends with respect to power, burnup and gap size as reported for the newer data?

Response

Thermocouple data for HPR-80, WAPD-228, AE-318 and IFA-226 were analyzed with the modified gap conductance model. Data from the ANL tapes were used for HPR-80, AE-318, and IFA-226. Data from the first three power ramps of the IFA-226 rods were analyzed. Results of the comparisons are shown in Figures 2.1, 2.2, and 2.3. The same predictive trends with respect to power and gap size exist for both the older and newer data. The average M/P value for the older data is 0.97 with no gap size or power level trends. The trend with burnup was not investigated since two of the data sets are for very low burnups only.

The comparisons for the older data have more scatter than for the more recent data. A significant fraction of the large underpredictions are for rod IFA-4 which has a large uncertainty on the as-built gap size. If the underpredictions for IFA-4 are disregarded, an uncertainty of, [ ]+ must be added to the predicted values to bound 96% of the comparisons. With the more recent data [ ]+ was added to bound 96% of all comparisons. The conclusion is that the modified gap conductance model gives predictions for the older data with the same accuracy as for the newer data and that the most likely cause of the increased scatter is due to experimental uncertainties.

(a,c)

(a,c)

Question #3

Verification of the modified PAD code is limited to data with burnups below approximately 5 MWd/kgU. However, Westinghouse has stated that analyses remain valid for burnups beyond 5 MWd/kgU. Please confirm this finding by providing (a) modified PAD code predictions of a representative sample of previously reported, high burnup data (see Attachment B to the original version of WCAP-8720) and (b) modified and unmodified PAD code predictions for a representative, high burn-up, licensing calculation (e.g., rod internal pressure). Please describe the latter in sufficient detail to permit a staff audit calculation.

Response

Verification of the modified gap conductance model was limited to the burnup range of 0 to 5000 MWD/MTU because of the uncertain impact on fuel temperatures of fission gas release and thermocouple decalibration at higher burnups.

It was stated in Addenda 2 that the thermal model (modified gap conductance equation) developed was valid for burnups greater than 5000 MWD/MTU in commercial LWR fuel because the ranges of fuel variables included in the gap conductance model derivation (gap size, fuel densi y, power level, and gas composition) spans the range expected at much igher burnups. It was not stated, nor was it intended to imply, that ne PAD code with this single modification and without modification of t e other fuel temperature dependent empirical models was applicable o all fuel rod evaluations.

The modified gap conductance model will only be used f r those applications explicitly stated in the response to Question #1. The PAD code with the revised gap conductance model and with no modification to other empirical models would not be expected to accurately predict all the high burnup data in Appendix B of WCAP-8720. High burnup evaluations w ll continue to be performed with PAD version 3.3 as approved by the NRC.

Question #4

Do the fuel geometry and radial power distributions as umed for the Halden BWR data reported in WCAP-8720 Addendum 2 appropriatel consider the effects of the modified flux spectrum, highly enriched fuel an central thermocouple hole present in these rods?

Response

The radial power distribution and fuel geometry do app opriately consider the effects of the modified flux spectrum, highly enri hed fuel, and the central thermal couple hole present in the rods. The bove items were accounted for by using prototypical input parameters t generate the radial power distribution and by comparing the measured and P D code calculated burnup distribution.

The burnup dependent radial power distribution was gen rated by the LASER code which computes the neutron flux in a reactor latt ce in the energy range of 0 to 10 MeV. In the calculations for the IFA 431, IFA-432, and 513 rods, the D_2O concentration, D_2O volume, fuel enri hment, thermocouple hole, moderator temperature, assembly geometry, and rc geometry were considered in the analyses. In the analyses it was al o determined that the thermocouple hole, pellet eccentricity, and pellet relocation do not significantly perturb the radial power distribution of a solid IFA-431, 432 & 513 pellet, that is concentric with the cladding The annular pellet radial power is usually 2 to 4% higher than the solid pellet radial power, since the same amount of heat is being produced in an annular pellet for a smaller quantity of fuel.

The calculated and measured burnup distribution were compared. The measured results are summarized in Reference A. In Figure 4.1, the results are illustrated for pellet 14 of IFA-431-6. In the figure, the measured data points were azimuthally averaged and normalized to 1 at the rod center. The error bars in the figure represent the 0.01 atoms % measurement uncertainty in the measured results. Excellent agreement exists between the measured and calculated results at a fractional radius of about .5, and near the pellet outside diameter the measured burnup is less than 5% greater than the calculated burnup. If one of the measured burnup samples had not been lost, better agreement between the measured and calculated results near the pellet outside diameter would be expected.

Reference A - C. Nealley, et al., "Post-Irradiation Data Analysis for NRC/PNL Halden Assembly IFA-431", NUREG/CR-0797 (PNL-2975) Battelle, Pacific Northwest Laboratories, Richland, Washington.

Question #5

Our contractor, Battelle Pacific Northwest Laboratories, has reported (Ref. 1) descrepancies between published Halden data and that provided to Westinghouse by the Electric Power Research Institute. Battelle has also reported (Ref. 2) lower than anticipated fill gas pressures for the same rods. What impact do these considerations have on the conclusions reached in WCAP-8720 Addendum 2?

Reference 1 - C. E. Beyer (PNL) letter to J. C. Voglewede (NRC) dated March 29, 1983.

Reference 2 - C. E. Beyer, E. R. Bradley and D. D. Lanning (PNL) letter to J. C. Voglewede (NRC) dated December 22, 1982.

Response

When Westinghouse initially obtained the data from the Electric Power Research Institute in August 1981, EPRI representatives stated that the errors in the data had been eliminated. Westinghouse also reviewed samples of the graphical data in the Battelle reports and the tabulated data obtained from EPRI and found no differences between the data sources.

However, a modification was made to our data to correct for the errors in NUREG/CR-1950 described in the errata sheet issued on August 31, 1981. In all of the analyses, helium loss was not considered because of the uncertainties in the quantity and rate of helium loss. However, if the IFA-432-1 fuel rod lost 84% of its helium content near the beginning of the irradiation period, the PAD code calculated fuel centerline temperatures would increase approximately 10^{o}F. This would result in a better measured temperature-predicted temperature agreement for IFA-432-1 and would not impact the conclusions in WCAP-8720 Addenda 2.

Question #6

The modified annular gap conductance model described in the Addendum assumes a larger degree of fuel relocation at lower powers than at higher powers. Some Halden data (Ref. 3) indicate that the opposite may be true, or that a relocation threshold may exist. In light of these alternate interpretations, please describe why the Westinghouse approach is appropriate.

Reference 3 - D. D. Lanning, "Experimental Evidence for the Dependence of Fuel Relocation Upon the Maximum Local Power Attained," Battelle Pacific Northwest Laboratories Report PNL-SA-10810, October 1982. Presented at the Tenth Water Reactor Safety Research Information Meeting, Gaithersburg, Maryland, October 11-15, 1982.

Response

The modified gap conductance model is intended to simulate increases in gap conductance due to pellet eccentricity, clad ovality and/or pellet cracking and relocation. The thermocouple data do not conclusively indicate the dominant physical mechanism. At typical limiting steady state powers of current design LWR fuel rods, the modified gap conductance equation gives a gap size reduction equivalent to a [

]$^{+}$ reduction in the fabricated cold gap size, which is substantially (a,c)
less reduction than is used in some relocation models. The fact that the model predicts a larger amount of "relocation" at lower powers than at higher powers could be interpreted to mean that eccentricity, rather than relocation, is the dominant physical mechanism. This hypothesis is supported by the fact that the increases in gap conductance seem to agree

more closely with the increases expected from pellet eccentricity than with the larger increases predicted with relocation models. Even if relocation is the dominant mechanism and a "threshold" power is required, the proposed model is still valid since the limiting powers for safety analyses are in excess of the threshold powers for relocation. It should also be noted that the modified gap conductance equation matched measured values at the lower thermocouple locations which experienced lower peak power levels.

The reason why the Westinghouse approach is appropriate is that it gives effective gap size reductions that are of the magnitude expected from known physical phenomena and that it matches measured data.

Question #7

The absolute reduction in gap size predicted by the annular gap conductance model appears to depend on the current hot gap size. Because of fuel swelling and other time-dependent effects, does this imply that the total reduction is reversible?

Response

The total gap size reduction consists of components that are reversible and components that are not reversible. Pellet thermal expansion and cladding elastic deflections are reversible. Gap size changes due to densification, swelling, and cladding creep are not reversible.

FIGURE 2.1

MEASURED VS PREDICTED CENTERLINE TEMPERATURE

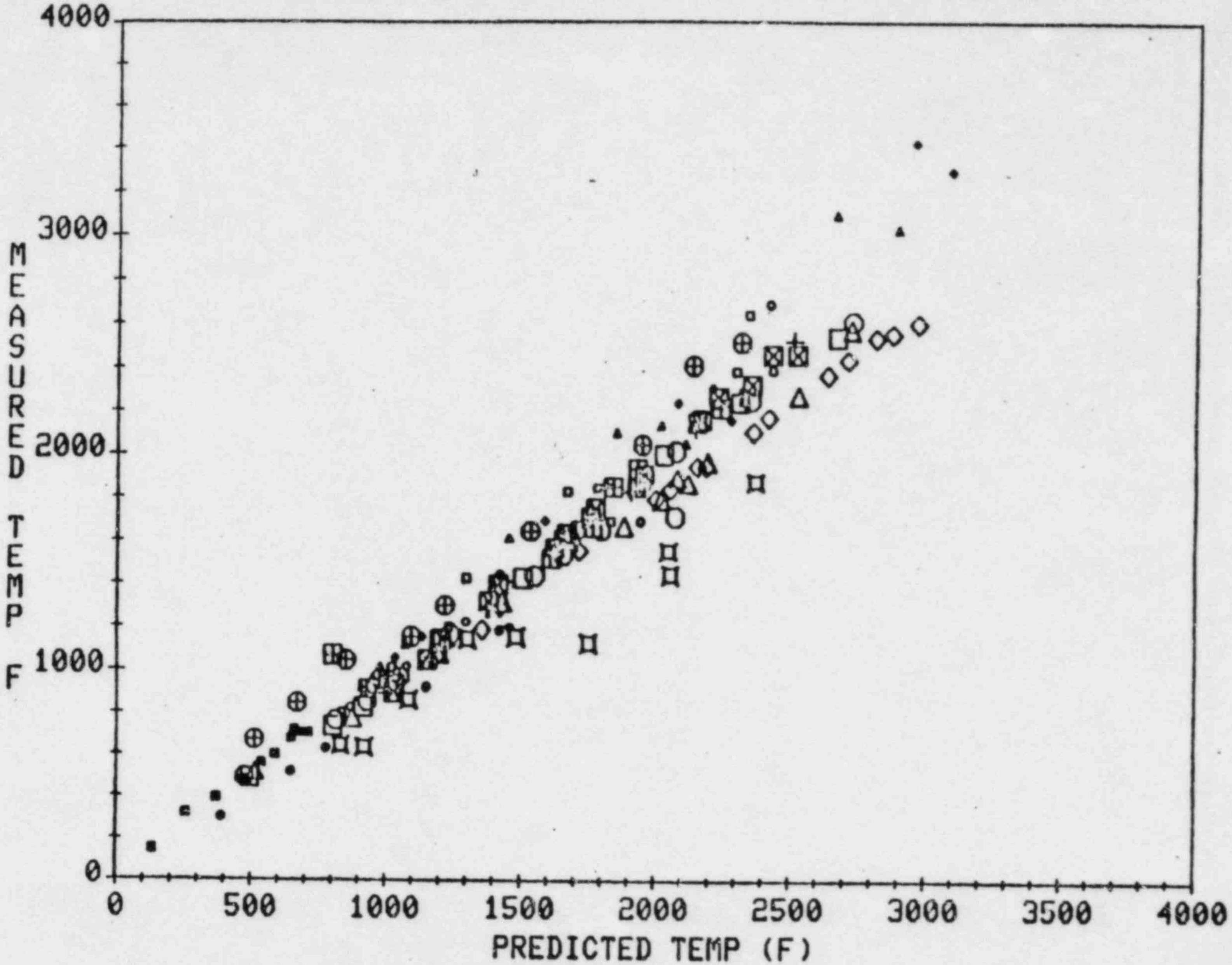


FIGURE 2.2

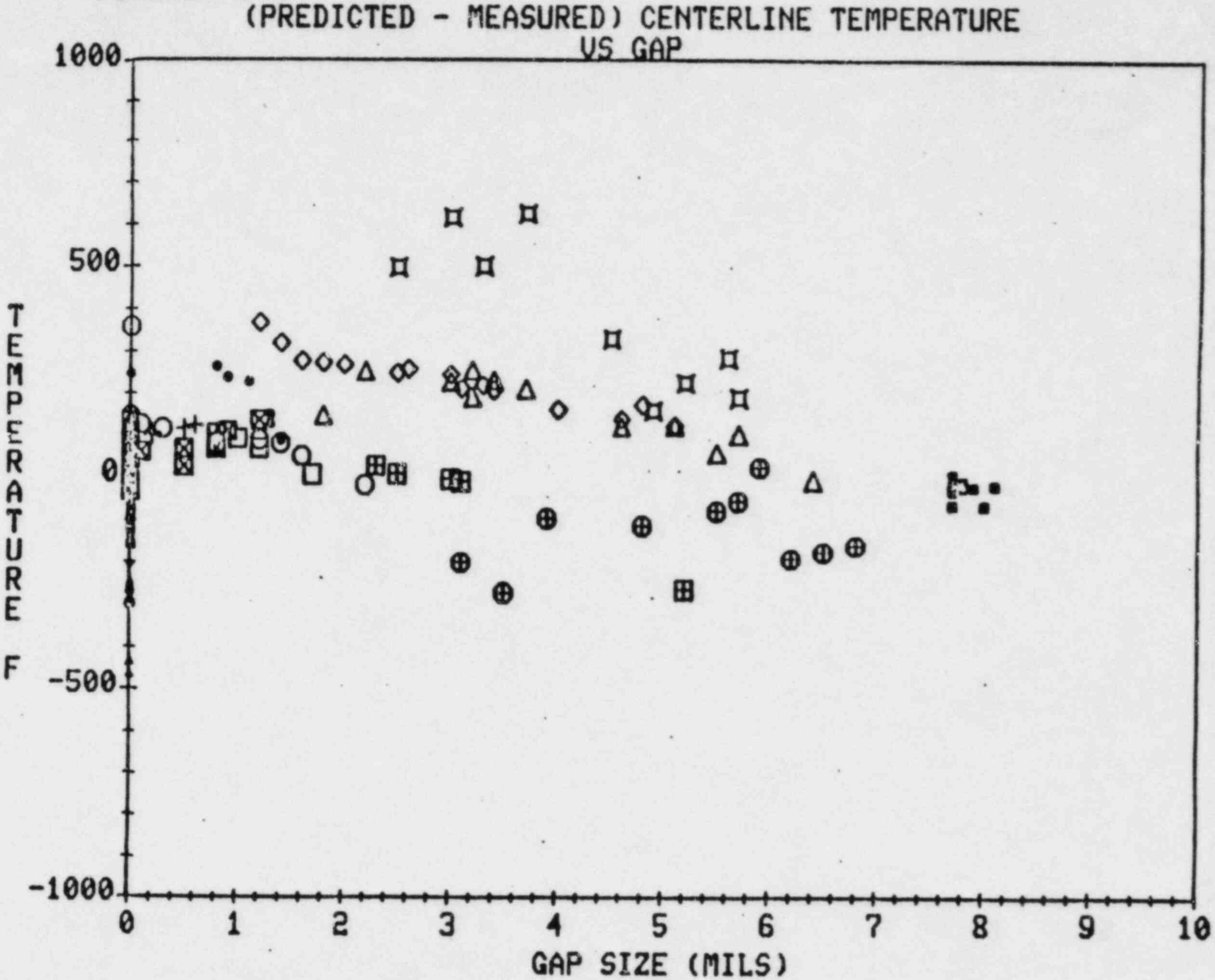
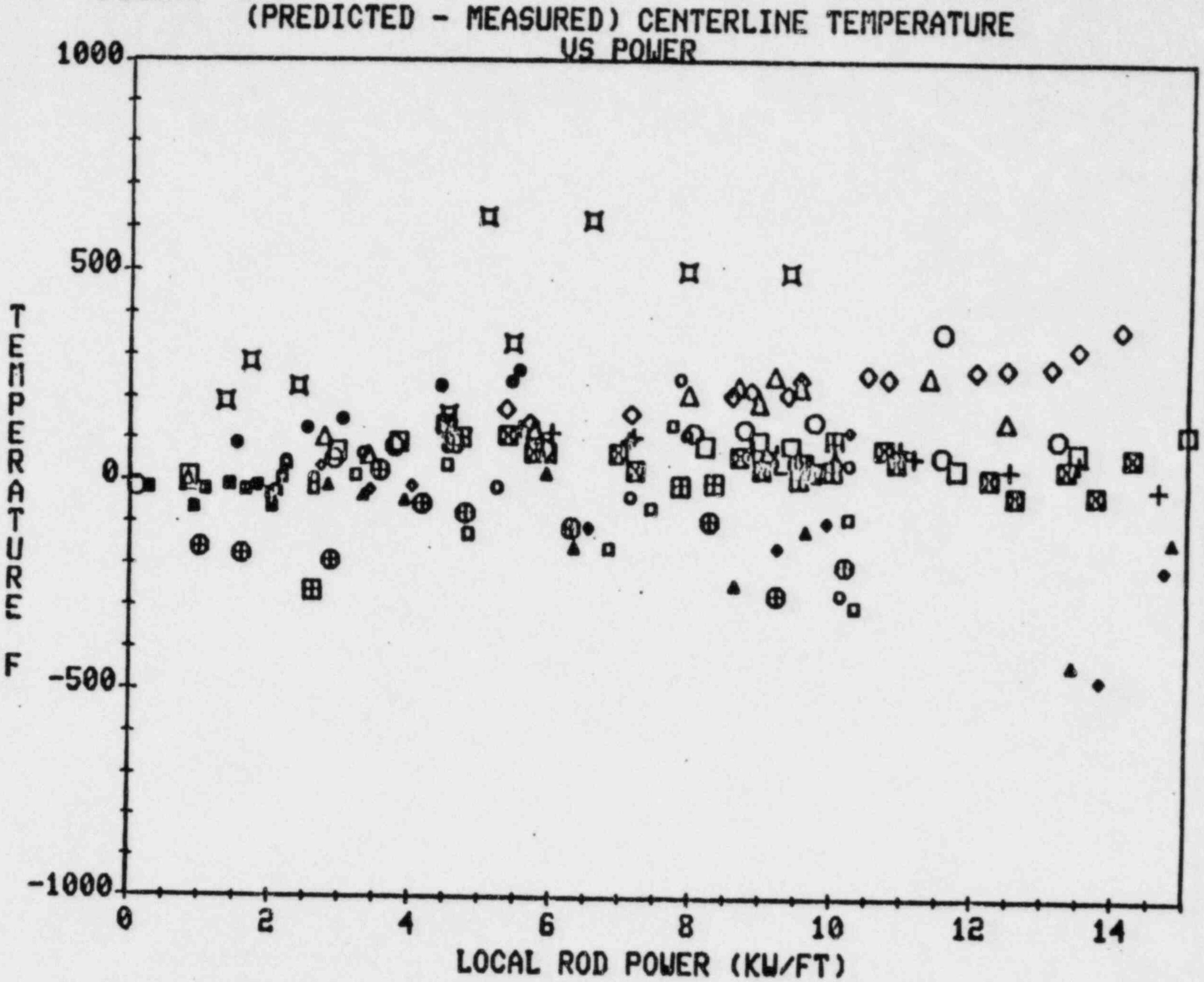

(PREDICTED - MEASURED) CENTERLINE TEMPERATURE
VS GAP
1000
500
0
-500
-1000
TEMPERATURE
F
0
1
2
3
4
5
6
7
8
9
10
GAP SIZE (MILS)

FIGURE 2.3



(PREDICTED - MEASURED) CENTERLINE TEMPERATURE
VS POWER
1000
500
0
-500
-1000
TEMPERATURE F
0
2
4
6
8
10
12
14
LOCAL ROD POWER (KW/FT)

Figure 4.1: Comparison of PAD Code Calculated Fuel Burnup Distribution and the Measured Fuel Burnup Distribution: IFA-431-6 Pellet 14