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PALISADES CYCLE 6 SETPOINT VERIFICATION WITH 50% STEAM GENERATOR TUBE PLUGGING

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1.0 INTRODUCTION

This report provides a description of the methods used by ENC to set and verify setpoints and limits on the operation of the Palisades Nuclear Power Plant. The report further provides a basis for reflecting operational changes on the LCOs and trip setpoints.

Section 2.0 describes the methodology to determine or verify certain limiting conditions for operation (LCOs).

The thermal margin/low pressure trip (TM/LP) is the subject of Section 3.0. The methods for calculating the constants in the trip function, the transients for which the trip prevents the SAFDLs from being violated, the assumptions about peaking factors used in setting the trip, and axial shape monitoring techniques are discussed. The treatment of the TM/LP trip is discussed in some detail since it is the trip which prevents a variety of transients from threatening thermal margin without challenging other trip functions.

Throughout the discussion, the interplay of LCOs with trips and trips with other trips is highlighted, as are the bases for assuming that any trip can provide DNB protection. The role of plant transient analysis in verification of the trip is included. The treatment of uncertainties is described throughout the report.

2.0 LIMITING CONDITIONS OF OPERATION

The limiting conditions of operation (LCOs) for Palisades include radial peaking factors, linear heat generation rates as a function of elevation, and vessel inlet temperature as a function of pressure and flow. In addition to these functions, axial shape monitoring (discussed in Section 3.3) can be imposed to limit the power peaking during reactor operation. These LCOs are necessary to provide protection for transients which terminate by a trip function with no basis in thermal margin (low flow trip) or which do not result in a reactor trip. The most limiting transients are usually the inadvertent insertion of a full length control element assembly (CEA) or the four-pump coastdown. Other transients which terminate in trips such as high pressurizer pressure trips are potentially limiting and should be reviewed as a part of the LCO assessment.

The following sections cover inlet temperature limits associated with the overpower trip, discuss the CEA drop and four-pump coastdown events as limiting transients, and describe the treatment of uncertainties.

2.1 INLET TEMPERATURE LIMITS

The inlet temperature limit was calculated such that it provided protection against DNB during the most limiting transient from full power operation. It is demonstrated in Section 2.2 that the most limiting transient is an inadvertent drop of a full length CEA. This particular transient does not necessarily result in a reactor trip. Therefore, protection against the possible return to power with enhanced peaking due to the anomalous control rod insertion pattern is provided by the inlet temperature LCO. The inlet temperature LCO is set such that the hot channel

does not exceed the DNBR criterion during this transient. To determine the inlet temperature LCO, a series of XCOBRA-IIIC[1] runs were made to determine the pressure and flow at which ENC's XNB critical heat flux correlation[2] reached the 95/95 DNB limit of 1.17.[3] The XCOBRA-IIIC calculations were run assuming a power of 2167.7 MWt (2125.2 MWt plus a 2% power uncertainty) and at a peak interior pin radial peaking factor of 1.96 (1.64 plus a 3% engineering allowance, and a 16% rod drop peaking allowance). The results of the analysis are given in Table 2.1.

The inlet temperature values do not reflect the uncertainty allowances for the measured plant variables nor for the transient offsets. In obtaining the LCO from the value given in Table 2.1, a 50 psi allowance on pressure was added to account for the control band in steady state operation. A 3% flow uncertainty was also added to correct for flow measurement uncertainties. The inlet temperature limit was increased by 7°F to account for a cold leg temperature measurement uncertainty of 2°F and a bias of 5°F in core inlet temperature to account for differences in heat removal rates in asymmetrical plugged steam generators.

In addition to the measurement and control uncertainties, three changes due to the transient were included. These include a reduction of pressurizer pressure by 20.3 psi, an increase in flow of 1.38 Mlb/hr resulting from an increase in the cold leg water density, and an 8°F reduction in the cold leg temperature. These biases were obtained from the transient simulation of the CEA drop event in Reference 4.

Fitting a functional form to the data in Table 2.1 and including the adjustments results in an inlet temperature limit curve,

$$T_{inlet} = 548.4 + (P_{pr}-1970.3) * (0.04 + 0.00015\ (P_{pr}-1970.3)) + 1.27\ (W_V-97.6)\ , \qquad (2.1)$$

where P_{pr} is the pressurizer pressure in psia and W_V is the vessel flow in Mlb/hr.

Operation with T_{inlet} limited by Equation 2.1 ensures with a 95% probability at 95% confidence that no anticipated operational occurrence (AOO) will result in the hot channel having a pin in DNB.

2.2 LIMITING TRANSIENTS

Two transients which require the LCOs to guarantee their DNBR performance are the CEA drop and the loss of coolant flow (LOCF). The verification of the transient performance is performed by simulating the response of the relevant variables over time, determining the point at which MDNBR would occur, and using the system variables as input to XCOBRA-IIIC to calculate the MDNBR. Figures 2.2 through 2.9 show the transient responses as modeled for Palisades Cycle 6.(4) Table 2.2 summarizes the transient conditions for both the CEA drop and the LOCF at the time of MDNBR, and gives the MDNBRs as calculated by XCOBRA-IIIC. Note that the CEA drop, which does not trip the reactor, has a conservative radial peaking factor attached. The MDNBRs quoted in Table 2.2 correspond to the worst axial shape allowed by Figure 2.1.

This analysis serves to validate the LCOs with regard to DNBR protection. LOCA/ECCS analysis provides the other verification of the acceptability of the LHGRs.

Table 2.1 Inlet Temperature Calculations

Pressure[1] (psia)	Flow[1] (Mlb/hr)	T_{inlet}[1] (^oF)
1860	90.09	531.9
1860	94.05	537.8
1860	98.01	543.5
1860	101.97	548.1
1860	105.93	552.6
1860	109.89	557.0
1880	90.09	532.5
1880	94.05	538.5
1880	98.01	543.7
1880	101.97	548.9
1880	105.93	553.3
1880	109.89	557.7
1900	90.09	533.3
1900	94.05	539.3
1900	98.01	544.4
1900	101.97	549.6
1900	105.93	554.1
1900	109.89	558.4
1920	90.04	534.1
1920	94.05	540.0
1920	98.01	545.2
1920	101.97	550.1
1920	105.93	554.8
1920	109.89	559.2
1940	90.09	534.8
1940	94.05	540.6
1940	98.01	546.0
1940	101.97	550.9
1940	105.93	555.4
1940	109.89	560.0

(1) Uncertainties have not been included in these values.

Table 2.2 Core Boundary Conditions for MDNBR Calculations

Variable	Values(1) Loss of Coolant Flow	CEA Drop
Power(2) (MWt)	2107.7	2237.4
Flow (Mlb/hr)	78.5	97.4
T_{inlet} (^{o}F)	542.4	534.2
Pressure (psia)	1943.5	1929.7
Radial Peaking	1.6892	1.9595
MDNBR	1.579	1.372

(1) These values include all error allowances.

(2) Based on the heat flux at the time of MDNBR.

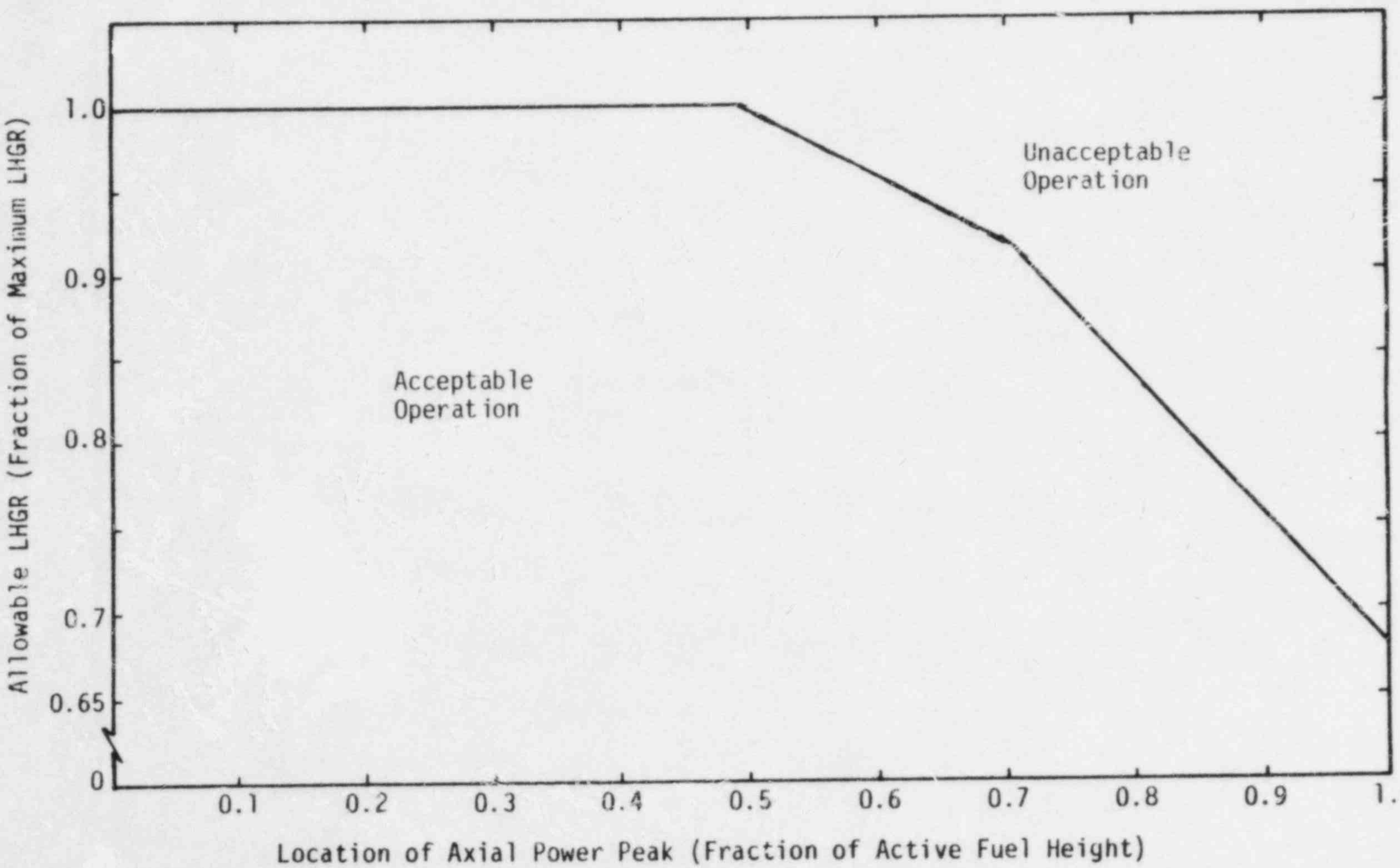

Figure 2.1 Limiting Condition for Operation Based on Linear Heat Generation Rate

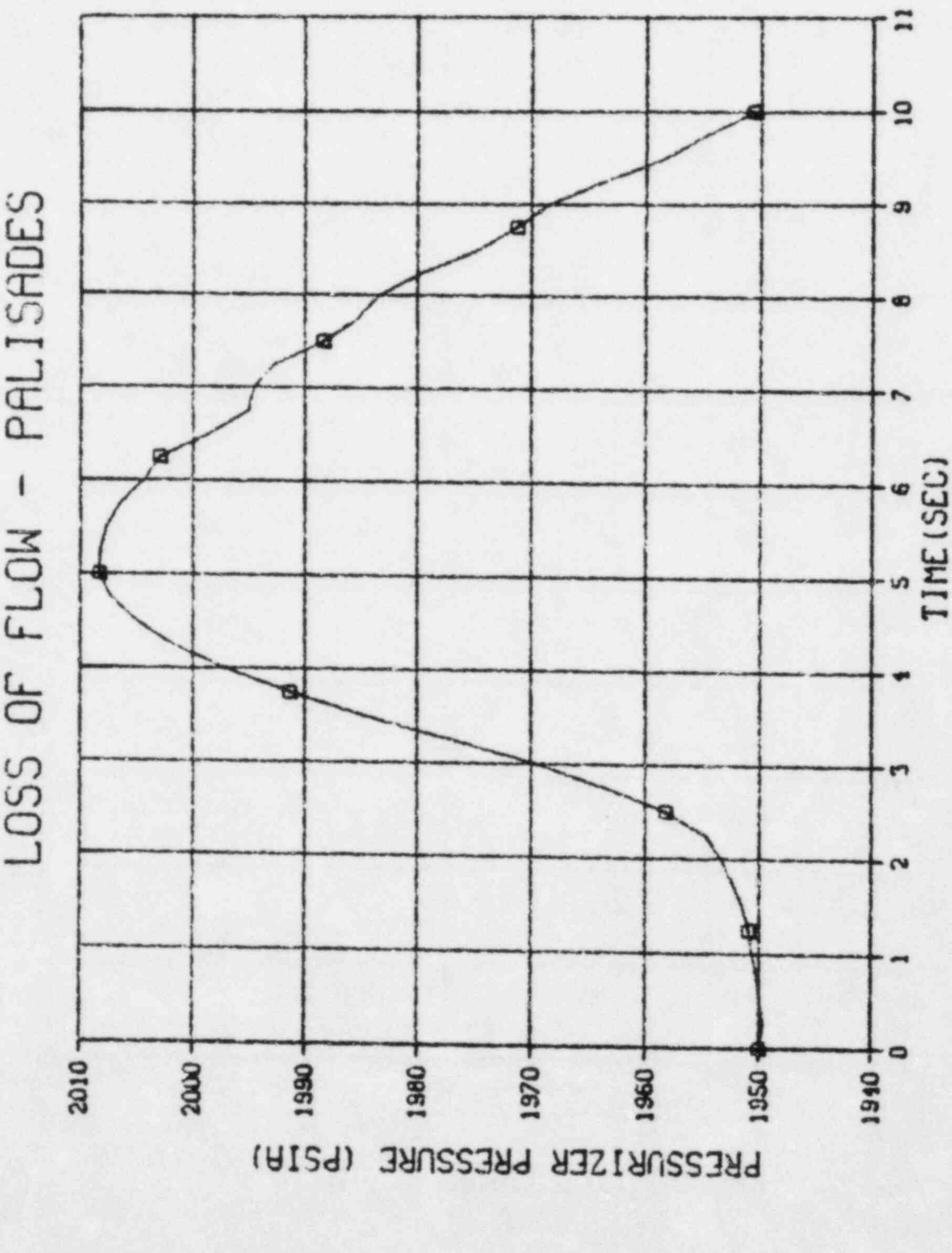

Figure 2.2 Pressurizer Pressure for Four-Pump Coastdown

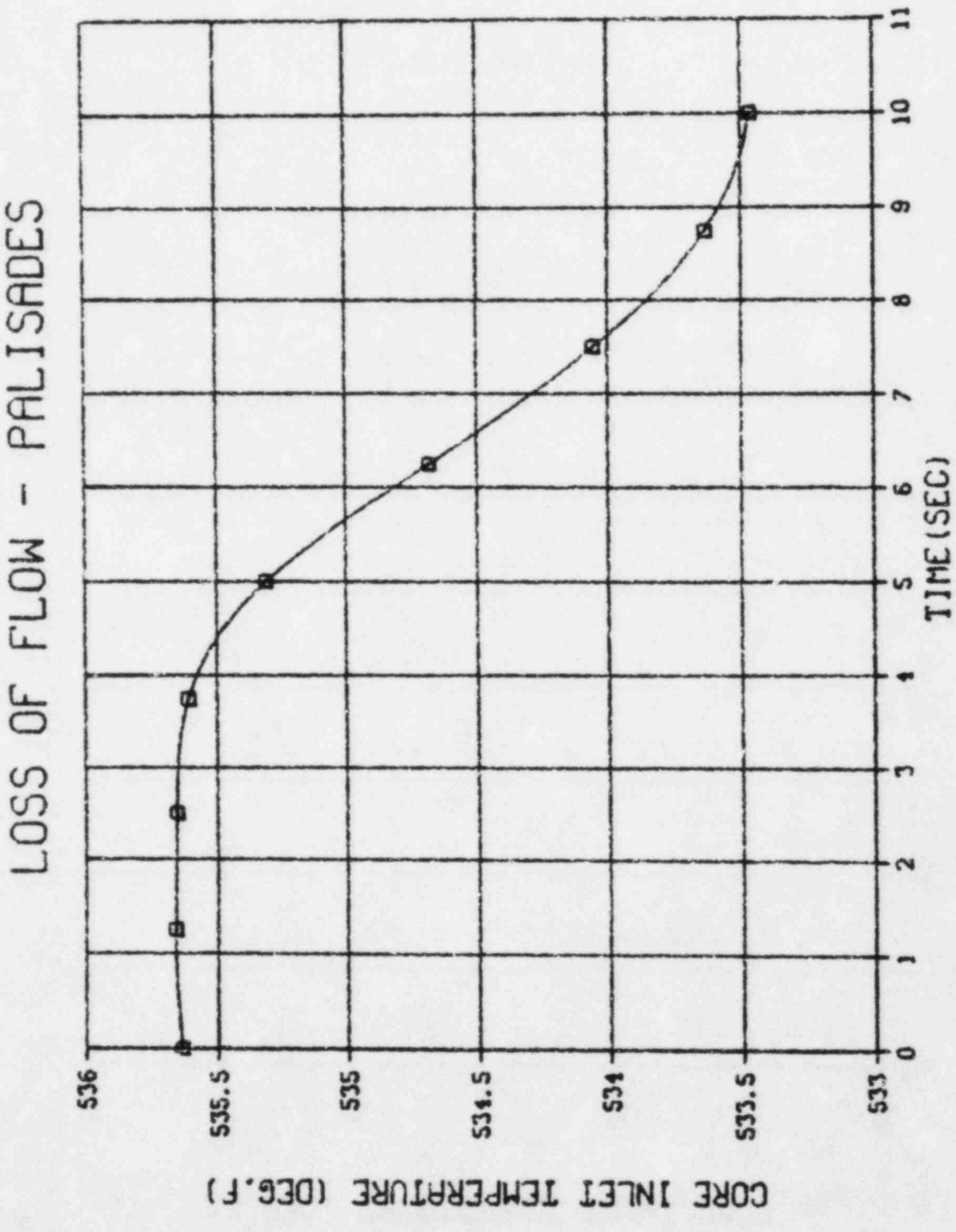

Figure 2.3 Core Inlet Temperature for Four-Pump Coastdown

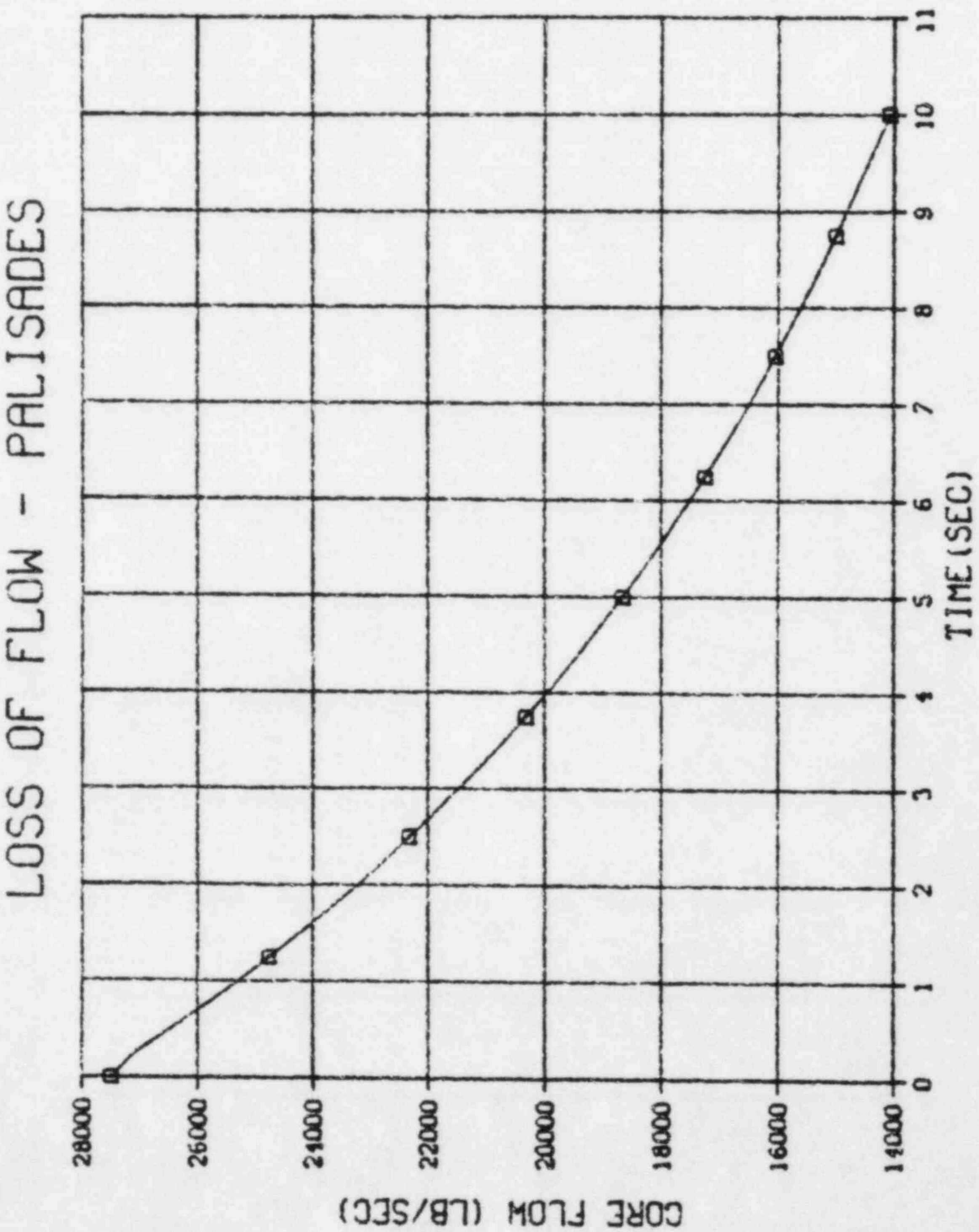

Figure 2.4 Core Flow for Four-Pump Coastdown

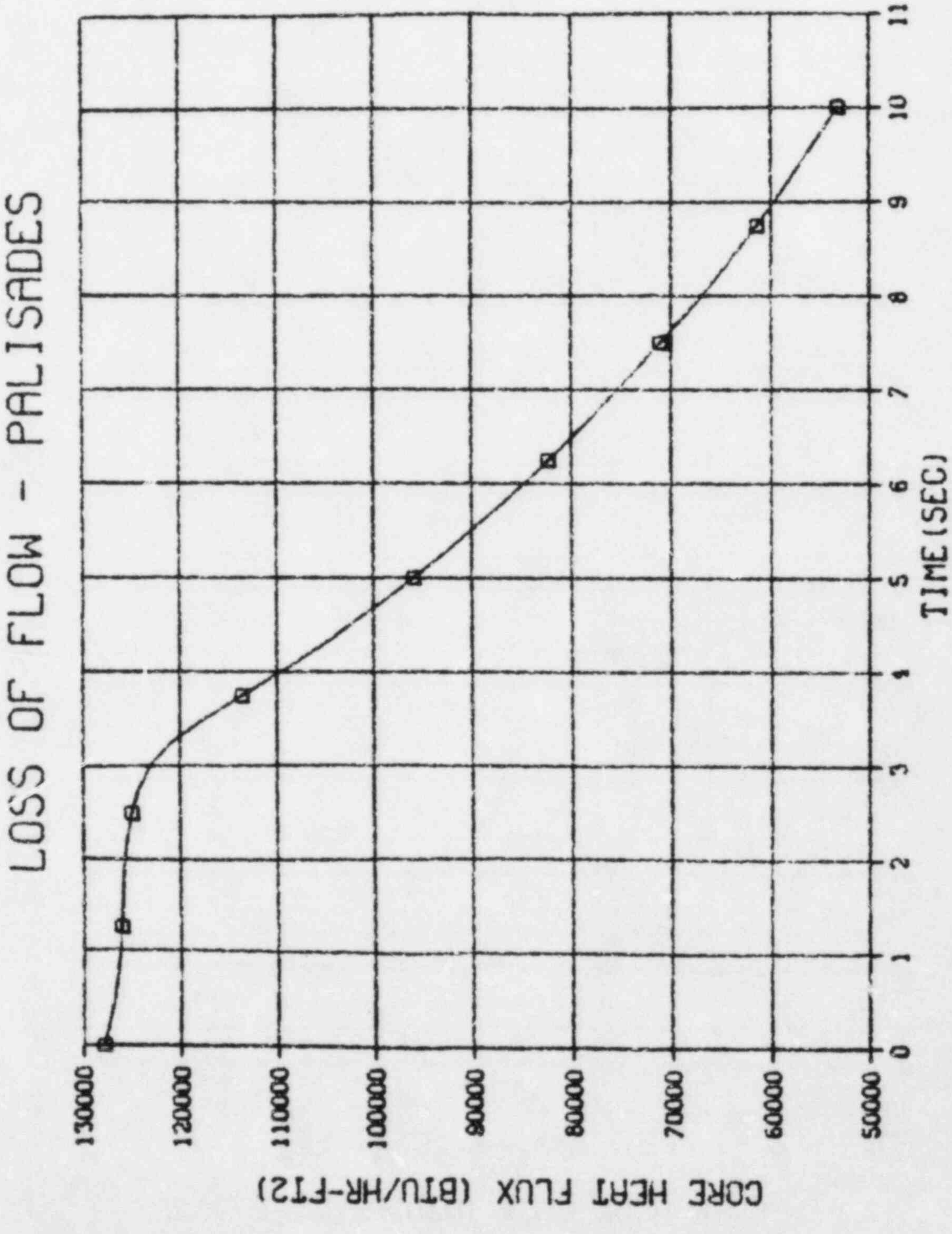

Figure 2.5 Core Heat Flux for Four-Pump Coastdown

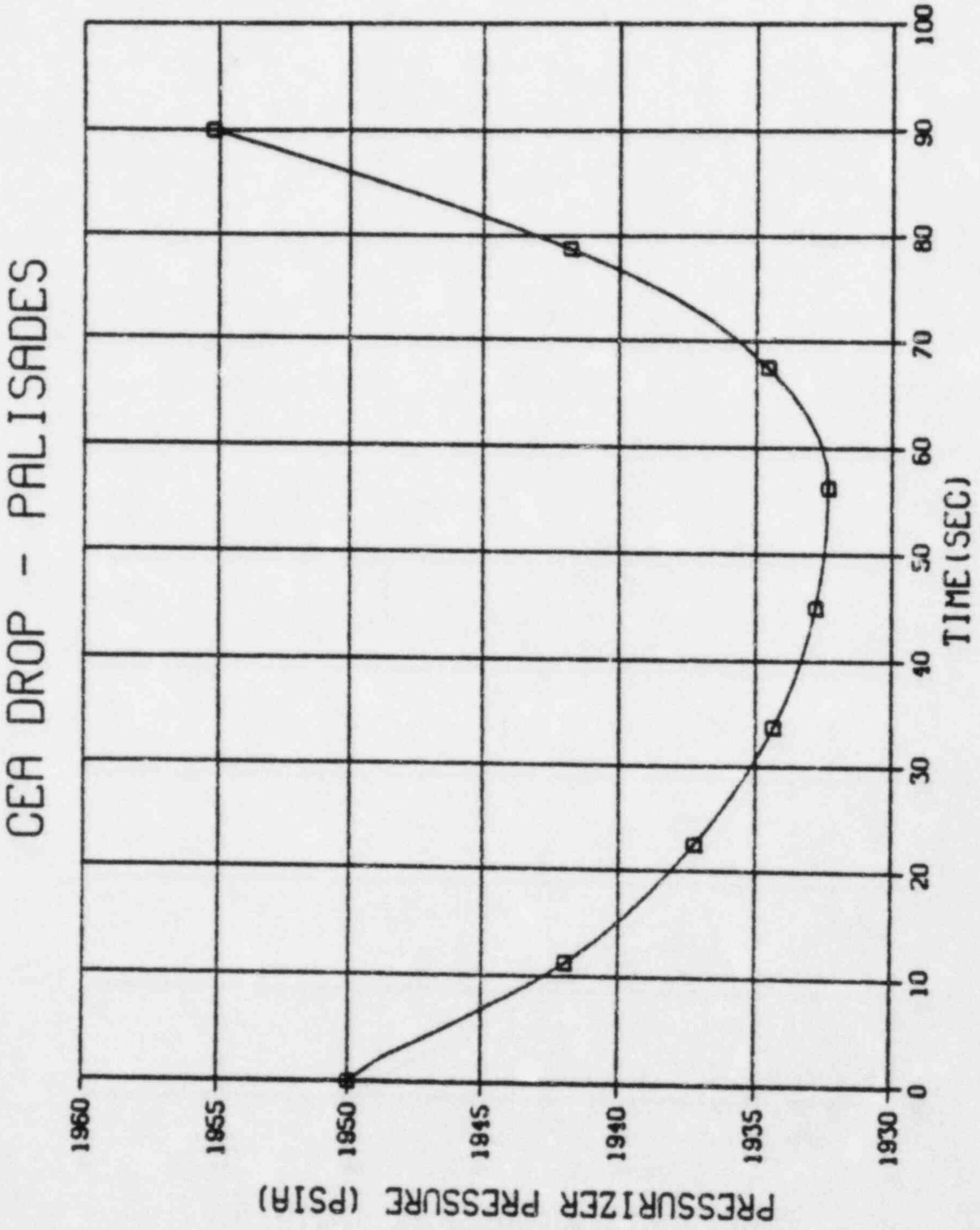

Figure 2.6 Pressurizer Pressure for CEA Drop

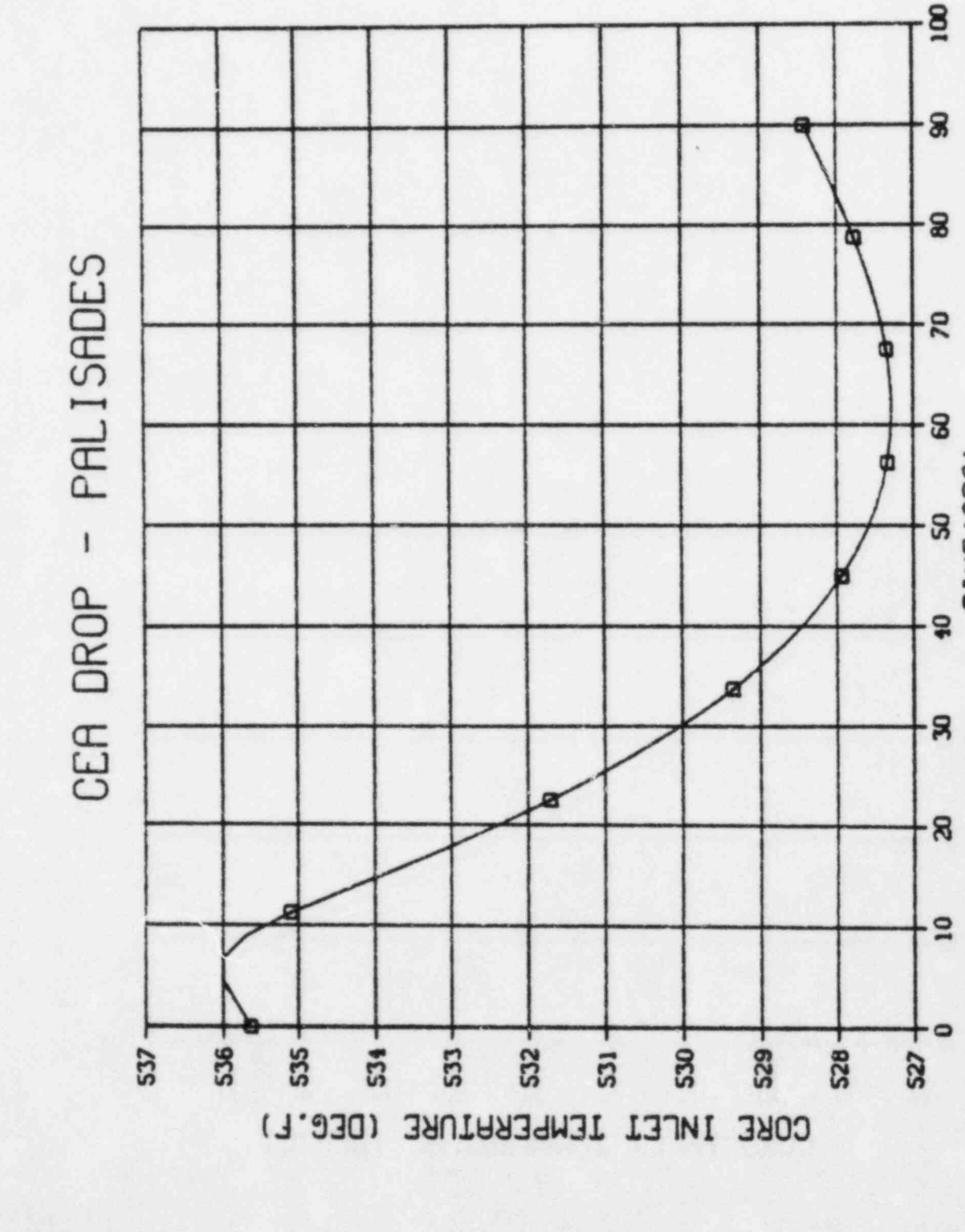

Figure 2.7 Core Inlet Temperature for CEA Drop

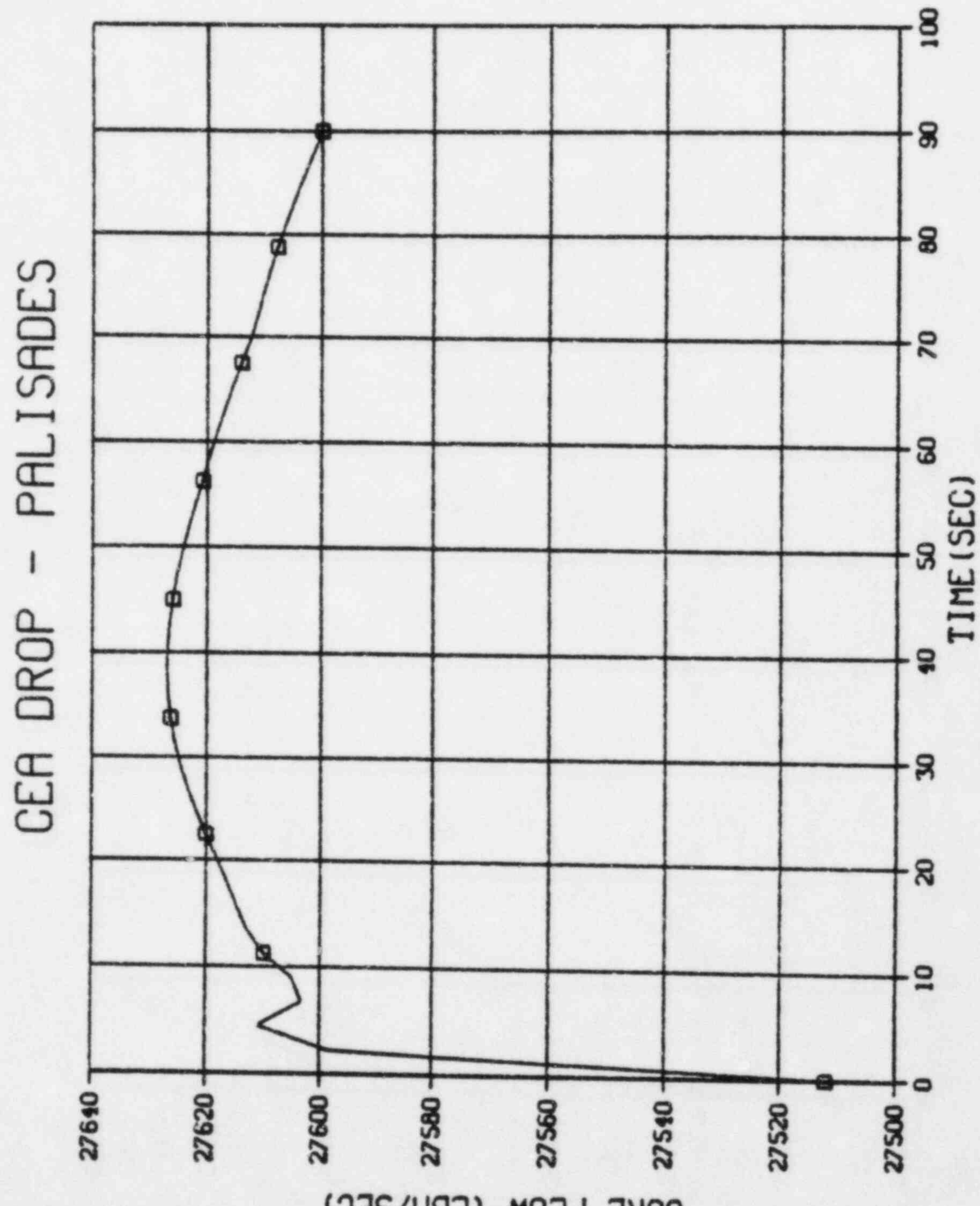

Figure 2.8 Core Flow for CEA Drop

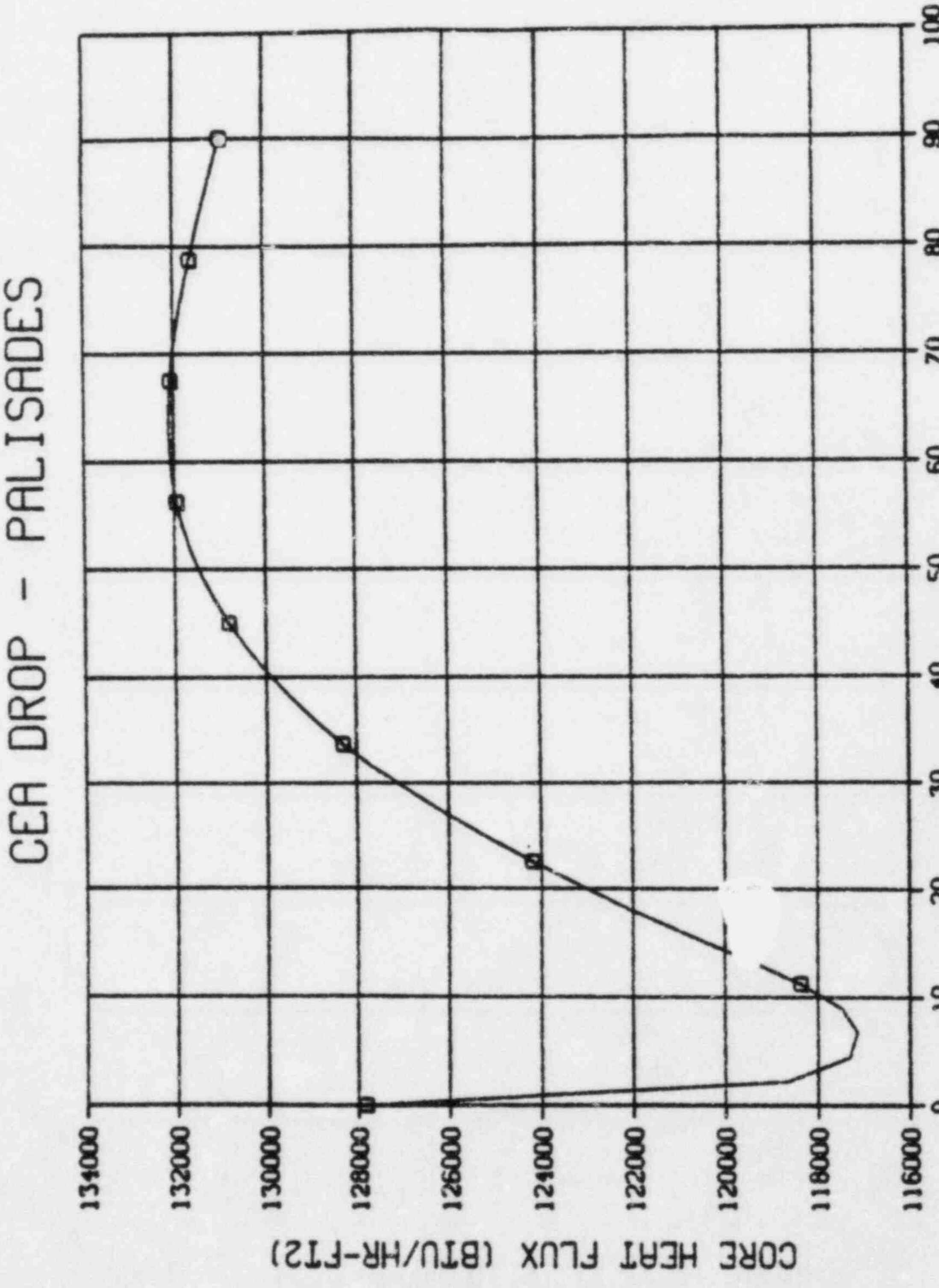

Figure 2.9 Core Heat Flux for CEA Drop

3.0 THERMAL MARGIN/LOW PRESSURE (TM/LP) TRIP

The TM/LP trip is the part of the plant's reactor protection system (RPS) which is designed to protect against slow heatup transients and depressurization events. The trip precludes fuel damage during these events by initiating a scram signal before the fuel rods encounter departure from nucleate boiling (DNB) or the hot leg becomes saturated.

This section describes the bases for the TM/LP trip along with an analytical derivation of the trip function. A discussion of measurement uncertainties and transient allowances is included in Section 3.2.2.

3.1 TM/LP PROTECTED TRANSIENTS

Generally, the protection of the plant against penetrating DNB for overpower transients is provided by the high neutron flux trip. The protection is demonstrated by performing overpower calculations with XCOBRA-IIIC. The assumptions made in demonstrating this protection are that pressure, flow, inlet temperature and core peaking are at the nominal values corrected by measurement or control uncertainty.

Two transients which violate these assumptions, the CEA drop and the four-pump coastdown, were discussed in Section 2.2. In Reference 4, the action of the low flow trip was seen to protect against rapid flow decreases. The vessel inlet temperature limit protected the CEA drop event.

Another group of transients which violate one or more of the assumptions are those for which the inlet temperature, pressure and power change without reaching either the high flux or high pressure trips. These transients are generally slow heatups of the primary system caused by a power mismatch between the primary system and the steam generator or depressurization with or without slow power ramps. The TM/LP trip serves as the means

of protecting against fuel rods experiencing DNB and hot leg saturation during these transient events. Events that are protected by the TM/LP trip include:

- Rod Withdrawals
- Boron Dilution
- Excess Load
- Loss of Load
- Loss of Feedwater
- RCS Depressurization

In each of these transients, the reactor coolant system (RCS) is either heating up or decreasing in pressure. Depending on the severity of the event, the consequences may provide an environment in which DNB may occur. The TM/LP trip function and associated RPS logic provides the input to the scram signal to prevent fuel damage by mitigating the off-normal plant behavior which characterizes these transients.

The TM/LP functional relationship is based on various assumptions dealing with plant operating conditions, with the other trip systems, and with the limiting conditions of operation (LCOs). The validity of the TM/LP trip in terms of offering plant protection is contingent on maintaining these operating conditions within acceptable limits. Administrative controls quantified in the LCOs ensure the functional integrity of the TM/LP trip.

3.2 ANALYTICAL BASIS FOR THE TM/LP TRIP

3.2.1 Safety Limit Lines

The safety limit lines consist of a series of isobaric curves corresponding to the inlet coolant temperature and reactor power that

produce either hot leg saturation or DNB. These safety limit lines provide the analytical basis for establishing the functional form of the TM/LP trip. Hot leg saturation limits tend to be bounding for low to mid-range powers and high inlet temperatures while DNB limits plant operation for mid- to high powers and low inlet temperatures. This subsection describes the analytical procedure used to obtain the safety limit lines.

Figure 3.1 shows the safety limit lines constructed for Palisades with 50% steam generator tube plugging for pressurizer pressures of 1535, 1635, 1735, 1835, 1935 and 2035 psia. The curves given in Figure 3.1 are not sufficient by themselves to construct the TM/LP trip since they do not include measurement uncertainties or transient biases. Uncertainties and transient allowances are addressed in Section 3.2.2.

The plant operating conditions used in this analysis are given in Table 3.1 and are representative of plant operation with 50% steam generator tube plugging. Also shown in Table 3.1 are conditions characteristic of a reference case for 22% tube plugging. For this analysis, reactor thermal power is decreased to 84% of rated design as a result of the increased tube plugging level. Flow was decreased 18% because of the increased loop resistance caused by increased plugging of the steam generators. The safety limit lines were calculated using a nominal primary loop recirculation flow of 99 Mlbm/hr.

The core configuration assumed for this analysis consisted of ENC Reload H, I and J fuel types, and the results are applicable for plant configurations which are no more DNB limited than Cycle 6.

Peak interior rod radial peaking factors as a function of core power are given below:

$$F(f) = 1.15\ (1.64) \qquad f < 0.50$$

$$F(f) = 1.64\ (1 + 0.3(1-f)) \qquad 0.50 \leq f \leq 1.00 \qquad (3.1)$$

$$F(f) = 1.64 \qquad f \geq 1.00$$

where f = fraction of 2125.2 MWt.

A variable high power trip (VHPT) limits the axial and radial peaking conservatisms required in setting the TM/LP. The VHPT protects against the transients list in Section 3.1 by imposing administrative controls during part power operation. The controls require the manual resetting of the high neutron flux trip setpoint to exceed the initial power by no more than 10%. The peaking allowances used in the analysis are limited by the maximum power bias allowed by the VHPT (10%). This 10% power bias prevents the reactor from reaching high powers with peaking factors appropriate to part power. The part power peaking can however be substantially higher than full power peaking since the administrative controls on power peaking are the LHGR limit discussed in Section 2.0 and the radial peaking. The maximum peaking factor which must be accounted for in the analysis is limited to the peaking factor representative of measured power less 10% (i.e., the peaking to be applied to a transient which reaches 100% power is the peaking corresponding to 90%). This provides considerable relief in peaking factors used to set the safety limit lines. An alternative to the VHPT consisting of axial shape monitoring is discussed in Section 3.3.

For the following analysis, it was assumed that the total allowed peaking for operation with 50% steam generator tube plugging did not change from limits established for lower plugging levels.

ENC's XNB critical heat flux correlation with a 95/95 limit of 1.17 was used to calculate the safety limit lines. Justification of applicability of XNB to Palisades geometry was given in Reference 3. The XCOBRA-IIIC computer code was used to calculate the DNB limiting portions of each curve. DNB limiting portions were calculated by selecting the inlet temperature which would produce a DNBR of 1.17 for a given pressure and power. These calculations resulted in a family of curves for each pressure. Also for each pressure and power, the inlet temperature which would produce saturation in the hot leg was calculated. For each pressure and power, the minimum of the two inlet temperatures was selected. The curves in Figure 3.1 are the result of these calculations.

3.2.2 Measurement Uncertainties and Transient Allowances

The intent of this section is to establish justification for measurement uncertainties and transient allowances employed in this analysis. Uncertainties are applied to the TM/LP trip so as to conservatively bound reactor and RPS operation. Terms are applied to the TM/LP trip to account for uncertainty in plant parameter measurements including potential decalibration. In addition, transient specific allowances are made for biases inherent in the operation of plant measurement instruments. Transient delays become important when the value of a state parameter changes and are defined as the difference in time between physical change and instrument detection of

that change. In this report, measurement uncertainties and transient allowances will be identified as uncertainties and will not be explicitly distinguished except for cases in which clarification is required.

Uncertainties considered in this analysis may be grouped into three categories in terms of quantities applicable to the evaluation of the TM/LP trip. The first category addresses uncertainties associated with core inlet temperature. Two primary sources contribute to this uncertainty. First is a cold leg temperature measurement uncertainty. The value of this uncertainty is taken to be 2°F. This value was used in analyses given in Reference 5.

The second inlet temperature uncertainty accounts for unequal cold leg inlet temperatures induced by non-uniform steam generator performance due to differences in plugging levels. This condition results in asymmetric cooldown and heatup transients. In order to estimate the impact of the asymmetrical plugging (60%/40%), a simple loop balance was performed using LOOPT.[6] This provided an estimate the flow differences in the two loops. Based on the loop flows, the power rejected by the loop was calculated using:

$$P_L = W_L \, Cp \, (T_{H,L} - T_{C,L}) \quad , \qquad (3.2)$$

where P is the power loss in loop L, W_L is the flow in loop L, Cp is the specific heat of the coolant at constant pressure, and $T_{H,L}$ and $T_{C,L}$ are the hot and cold leg temperatures for loop L, respectively. A second relationship was invoked to obtain a solution,

$$P_L = U A_L \left(\frac{T_{H,L} + T_{C,L}}{2} - T_{sec}\right), \qquad (3.3)$$

where U is the heat transfer coefficient for the steam generator, A_L is the heat transfer area in the steam generator, and T_{sec} is the temperature in the steam generator.

Equating the two expressions for power results in a solution for the hot and cold leg temperatures. Iterating the process including the LOOPT calculation provides a power, flow and temperature balance which indicates 4^oF temperature difference between the two legs. A 25% conservatism was employed and a 5^oF allowance on inlet temperature selected.

The second category of uncertainties consist of those that affect core power. Three sources of power uncertainty were accounted for in this analysis. The first uncertainty is due to the error in the thermal power calibration on the steam generator. The value used, both in this analysis and in the analyses presented in Reference 5, is 2% power.

The second source of power uncertainty is due to the temperature sensing errors in the ΔT power calculator. Thermal power is inferred from the difference between primary loop hot and cold leg RTD readings. An analysis was performed to assess the difference between power inferred by ΔT measurements and power determined from steam side thermal calibrations. Daily plant heat balance data, consisting of 715 points covering the period from 1979 to 1983, were used as the basis for evaluation. Results indicate that power determined by the steam side thermal power calibration was 1.1235 times the power inferred by the corresponding primary loop ΔT readings. This discrepancy is most likely due to imperfect mixing

between the core support barrel bypass flow and the reactor outlet which persists to the hot leg RTD location. The factor of 1.1235 is the mean bias term and will be accounted for in the formulation of the TM/LP trip function presented in Section 3.2.3. The statistical variation of the difference between steam side thermal power calibration and ΔT inferred power was determined using one-sided distribution free statistics for 700 data points.(7) The lower one-sided 99% probability point at 99% confidence is 1.0666. Calculations of the skewness indicates that the distribution is symmetric about the mean. The difference between the mean and the lower one-sided probability point is 0.0569. The 0.0569 value is a measure of the uncertainty in power inferred by ΔT. The impact to actual core power due to the variation in ΔT inferred power may be quantified in the following manner:

$$\overline{P} = \alpha \overline{P}_{\Delta T} \tag{3.4}$$

where α = 1.1235

$\overline{P}$ = average core power

$\overline{P}_{\Delta T}$ = average power inferred by ΔT measurements.

The error in ΔT inferred power is proportional to the average power level. Therefore, the upper bound on the error in P is given by,

$$\gamma \overline{P} = (\alpha - \beta) P_{\Delta T} \tag{3.5}$$

where β = 0.0569

γ = fractional uncertainty bound on $\overline{P}$

Substituting,

$$\gamma \alpha \overline{P}_{\Delta T} = (\alpha - \beta) \overline{P}_{\Delta T} \tag{3.6}$$

$$\gamma = \frac{\alpha - \beta}{\alpha} = \frac{1.1235 - 0.0569}{1.1235} = 0.95 \qquad (3.7)$$

Therefore the uncertainty in actual core power due to statistical variations in ΔT measurement is about 5%.

The third source of power uncertainty is a pure bias due to delays in instrument responses when transient changes occur in the primary coolant state. Three transient delays are accounted for in this calculation:

(1) Transport delay accounting for the time required to transport a segment of fluid from the cold leg RTD to the hot leg RTD. The value of this term is determined by the effective steady-state flow volume between the hot and cold leg RTDs in the direction of flow divided by the volumetric flow rate. The value of time delay due to coolant transport at full flow was evaluated to be 8.33 sec.

(2) RTD and thermowell temperature measurement delay produces a significant bias for medium speed transients. The RTD response used was 12 seconds for both the hot leg and the cold leg RTD. This corresponds to the NRC prescription for Rosemont 104 RTDs.[8]

(3) Scram delay is defined as the difference in time between a scram signal and CEA holding coil release. The value used in this analysis and in previous analyses is 0.6 sec.

Combining these three delays resulted in a total transient delay time of about 21 seconds.

From Reference 9, the average temperature ramp rate at which the high pressurizer pressure trip intervened during a slow control rod withdrawal from part power is $0.08^{o}F$/sec. The corresponding power ramp was

about 0.1%/sec. Applying a value for a transient delay of 21 seconds and doubling the result to add conservatism, the bias in power due to transient delay is about 4%.

Combining the sources of power uncertainty yields an overall uncertainty on power of about 11%.

It is important to note that the transient uncertainties in the TM/LP calculation is the only category which deals explicitly with the form of the transients in which the TM/LP must intervene to protect against DNB. Further, the only assumptions about the form of the transient were that the temperature ramp rate at which the high pressurizer pressure trip or the variable high power trip had to intervene was 0.16^{o}F/sec. and that the power ramp was less than or equal to 0.2%/sec. Thus, protection of DNB during the slow heatup transients can be verified via plant transient simulations to demonstrate the intervention of the VHPT or the high pressurizer pressure trip at the assumed heatup and power ramp rates.

Finally, the third category of uncertainty is pressure uncertainty. From Reference 5, the pressure uncertainty used in this analysis was 165 psia. This value accounts for pressure measurement uncertainties, as well as time-dependent decalibration and transient delays in the pressure measurement response.

Table 3.2 summarizes the inlet temperature, power and pressure uncertainties used in this present analysis. In addition to these uncertainties, a 3% heat flux uncertainty and a 6% flow uncertainty were included in the XCOBRA-IIIC DNBR calculations. The heat flux uncertainty is applied to account for manufacturing tolerances in the fuel (i.e., an Engineering factor). The flow uncertainty is applied to account for a loop flow measurement uncertainty and the core bypass flow.

3.2.3 Derivation of the TM/LP Trip Function

This section describes the derivation of the TM/LP trip function from the safety limit curves discussed in the preceding sections. The TM/LP function calculates a limiting pressure, P_{VAR}, based on reactor conditions at a given time. The trip logic compares P_{VAR} to the measured system pressure. If the difference between the system pressure and P_{VAR} is equal to or less than 50 psia, a pre-trip alarm activates an annunciator in the control room. If system pressure falls below P_{VAR}, the plant scrams and thereby protects against fuel damage for slow transient events.

Reference 10 provides the empirical form of the TM/LP trip function. The form is as follows:

$$P_{VAR} = AT_H - BT_C - C \tag{3.8}$$

where
P_{VAR} = calculated pressure based on system conditions (psia)
T_H = hot leg RTD temperature (^oF)
T_C = cold leg RTD temperature (^oF)
A,B,C = constants

Equation 3.8 may be simplified to contain variables related to the safety limit lines. Specifically,

$$P_{VAR} = A\,\Delta T + (A-B)\,T_C - C \tag{3.9}$$

where $\Delta T = T_H - T_C$ (^oF)

The constants A and B are quantified in the following manner:

$$A = \frac{-S_L\,[K_1 + K_2\,(T_C - T_{CO})]}{V_S} \tag{3.10}$$

$$(A-B) = \frac{1 - S_L \; B_P \; K_2/[K_1 + K_2 \; (T_C - T_{CO})]}{V_S} \tag{3.11}$$

$$B_P = K_1 \; \Delta T + K_2 \; \Delta T \; (T_C - T_{CO}) \tag{3.12}$$

where S_L = slope of a constant pressure safety limit line ($^oF/\%$)

V_S = vertical spacing of adjacent safety limit lines (^oF/psia)

T_{CO} = inlet temperature at nominal power, flow and pressure (^oF)

B_P = percent of full power (% of 2125.2 MWt)

K_1, K_2 = constants

Determination of the TM/LP trip function requires a family of parallel, equally spaced safety limit curves. Accounting for uncertainties. Figure 3.2 shows a bounding, yet not overly restrictive, set of parallel, equally spaced safety limit lines. From Figure 3.2,

S_L = $-0.55^oF/\%$

and V_S = 0.06^o/psia

for power less than 100%. The calculation of a set of coefficients for power greater than 100% is based on the slopes and spacings above 100% power.

Following the procedure outlined in Reference 10, constants K_1 and K_2 are evaluated using points from Figure 3.3 corresponding to 100% power at 1700 and 2200 psia. Calculation of K_1 and K_2 are based on a nominal inlet temperature ($T_{CO}=535^oF$), nominal flow rate (W_V=99 Mlbm/hr), and nominal full power (Q = 2125.2 MWt, B_P = 100%). From Figure 3.2:

For P = 2200 psia , $T_C = 563^oF$

$\Delta T = 48.69^oF$

For P = 1700 psia , $T_C = 533^oF$

$\Delta T = 50.11^oF$

The values for ΔT at both 2200 and 1700 psia have been reduced by a factor of 1.1235 to account for the difference between power inferred by ΔT and actual power. Section 3.2.2 discusses the basis for the factor of 1.1235.

Substituting the values of T_C and ΔT into Equation 3.12 for both 1700 and 2200 psia, constants K_1 and K_2 may be determined. The values of K_1 and K_2 were calculated to be:

$$K_1 = 1.9937\ (\%/^oF)$$

$$K_2 = 0.00194\ (\%/^oF^2).$$

Using T_C=563^oF corresponding to 2200 psia and full power along with K_1 and K_2, constants A and (A-B) are readily evaluated. From Equations 3.10 and 3.11,

$$A = 18.8269\ \text{psia}/^oF$$

and $$(A-B) = 17.5325\ \text{psia}/^oF.$$

The final remaining constant to be evaluated is the term C given in Equation 3.9. Again using conditions corresponding to 2200 psia and full power from Figure 3.2, C can be calculated by appropriate substitution into Equation 3.9. That is,

$$P_{VAR} = A\,\Delta T + (A-B)\,T_C - C$$

where

P_{VAR} = 2200 psia

ΔT = 48.69^oF

T_C = 563^oF

A = 18.8269 psia/^oF

$(A-B)$ = 17.5325 psia/^oF

The resulting value of C is 8587.479 psia. Therefore, the functional form of the TM/LP trip becomes:

$$P_{VAR} = 18.8269\ \Delta T + 17.5325\ T_C - 8587.479\ (Q \leq 100\%) \qquad (3.13)$$

where ΔT = difference in hot and cold leg RTD measurements (^{o}F)

T_C = cold leg RTD measurement (^{o}F)

Similarly, the curve above 100% power can be expressed by a slope and vertical spacing,

$$S_L = -0.70^{o}F/\%$$

and $V_S = 0.06^{o}F/psia.$

Following the same procedure discussed above results in,

$$P_{VAR} = 23.9615\ \Delta T + 17.7687\ T_C - 8970.464\ (Q > 100\%) \qquad (3.14)$$

Figure 3.3 shows the plot of Equations 3.13 and 3.14 for various pressures. Also shown are the bounding linear safety limit lines discussed previously. It can be seen that the function of P_{VAR} provides a conservative approximation to the core safety limit lines.

3.3 AXIAL SHAPE MONITORING

The calculation of the safety limit lines and the TM/LP discussed in the preceding sections relied heavily on the VHPT to place limits on the maximum radial and axial peaking required in the DNBR calculations. This section describes the manner in which axial shape monitoring can provide an equivalent limit on the power peaking required in the TM/LP analysis.

The method for monitoring axial shapes in Palisades is based on the PDC methodology used in Westinghouse plants and the justification for its use

is provided in Reference 11. The key to power peaking monitoring is the use of the ex-core flux detectors. There are eight detectors located outside the vessel at four different azimuthal positions and two axial locations. Each vertical pair constitutes a system for monitoring power and axial offset, AO, as follows:

$$Q_{neutron\ flux} = C[O_{upper} + O_{lower}] \quad (3.15)$$

and

$$AO = \frac{O_{upper} - O_{lower}}{O_{upper} + O_{lower}} \quad (3.16)$$

where O_{upper} and O_{lower} are the outputs from the upper and lower flux detectors, respectively, and C is a calibration constant which is adjusted to provide agreement between the neutron flux power, $Q_{neutron\ flux}$, and the thermal calibration.

As the core develops either top or bottom peaked power distributions, as might occur in a xenon oscillation, the AO will become larger in magnitude. The larger in magnitude the AO, the higher the axial peak. A typical correlation of ~1400 axial shapes selected during a xenon oscillation is shown in Figure 3.4. Note that maintaining a relatively small |AO| would imply extremely small axial peaking factors.

To apply these observations to DNBR protection via the TM/LP and, in particular, to make the monitoring program equivalent to the VHPT as a part of the basis for the TM/LP, the AO band which provides equivalent DNBRs must be established. This may be done by first calculating the MDNBR for a 100% power case using the 90% axial and radial peaking limits. These are obtained from

the radial peaking, Equation 3.1, and the LCO on LHGR, Figure 2.1. All of the shapes which can be generated by inducing severe xenon transients in the reactor core are calculated and the MDNBR corresponding to that shape at 100% power and maximum radial peaking is determined. A curve of MDNBR versus AO is obtained in this fashion. Typically, it would resemble Figure 3.4 except it would be inverted and somewhat flatter for negative AOs since top-peaked cores exact a significant DNB penalty.

The maximum and minimum AOs which provide DNBRs greater than or equal to that calculated for the 90% peaking conditions, adjusted to account for AO calibration error ($\pm$6%, typically), is the required monitoring band.

Table 3.1 Nominal Plant Operating Conditions

	Previous Conditions	Present Conditions
Plugged SG Tubes (% of 17028 tubes)	22	50
Reactor Power (% of 2530 MWt)	100	84
Primary Pressure (psia)	2010	1950
PCS Flow Rate (10^6 lbm/hr)	122	99
Average Temperature (^oF)	561	564
Inlet Temperature (^oF)	537	535

Table 3.2 Uncertainties Applied to Formulation of the TM/LP Trip Function

Source	Value of Uncertainty
Inlet Temperature	
Measurement	2°F
Asymmetric S.G. Plugging	5°F
Power	
ΔT Measurement Variation	5%
Thermal Power Calibration	2%
Transient Delay	4%
Pressure	
Measurement and Transient Delay	165 psia
Fuel Tolerances	
Engineering Heat Flux Peaking Augmentation	3%
RCS Flow	
Measurement Uncertainty) Bypass Flow)	6%

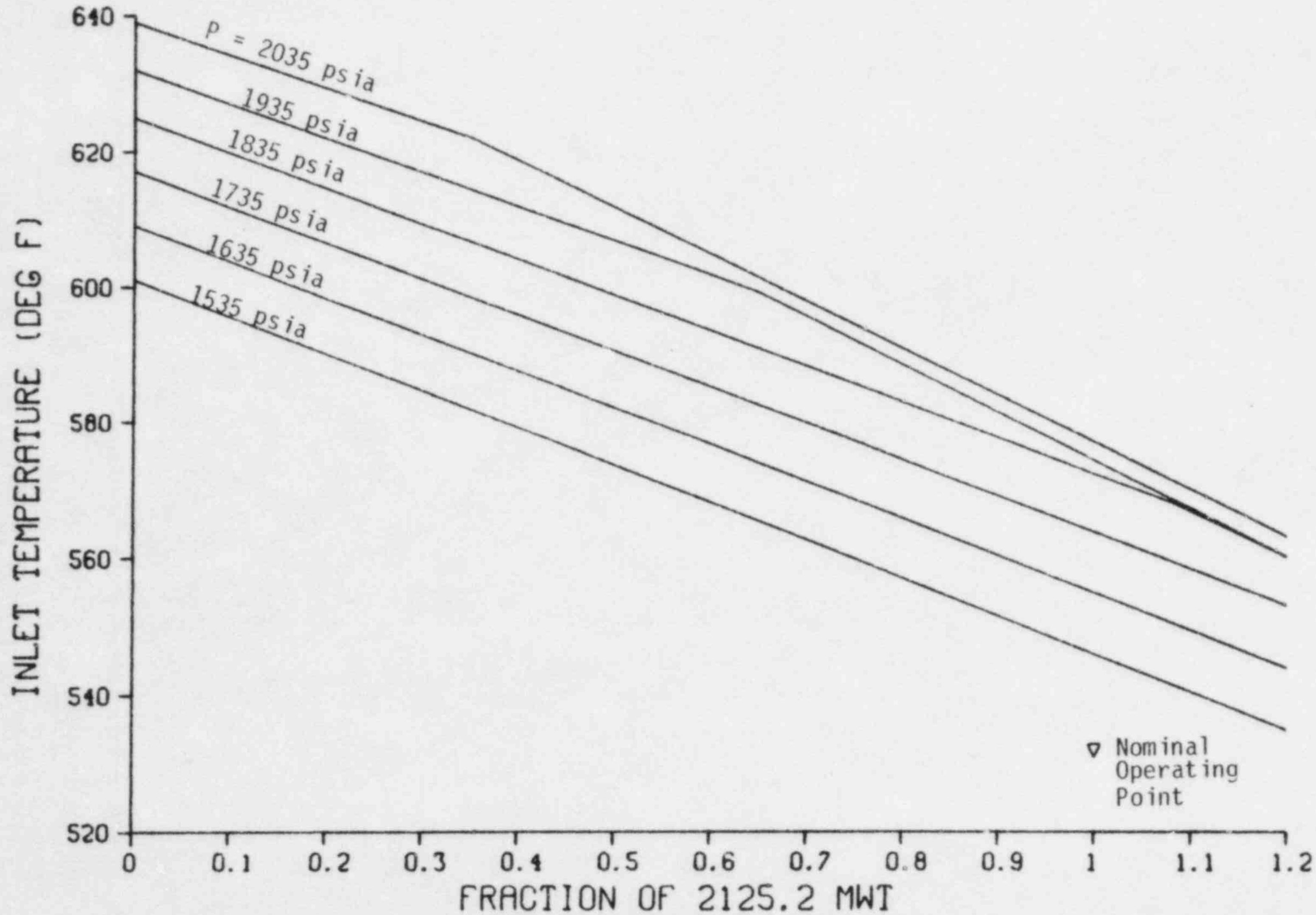

Figure 3.1 Safety Limit Lines for Palisades with 50% Steam Generator Tube Plugging

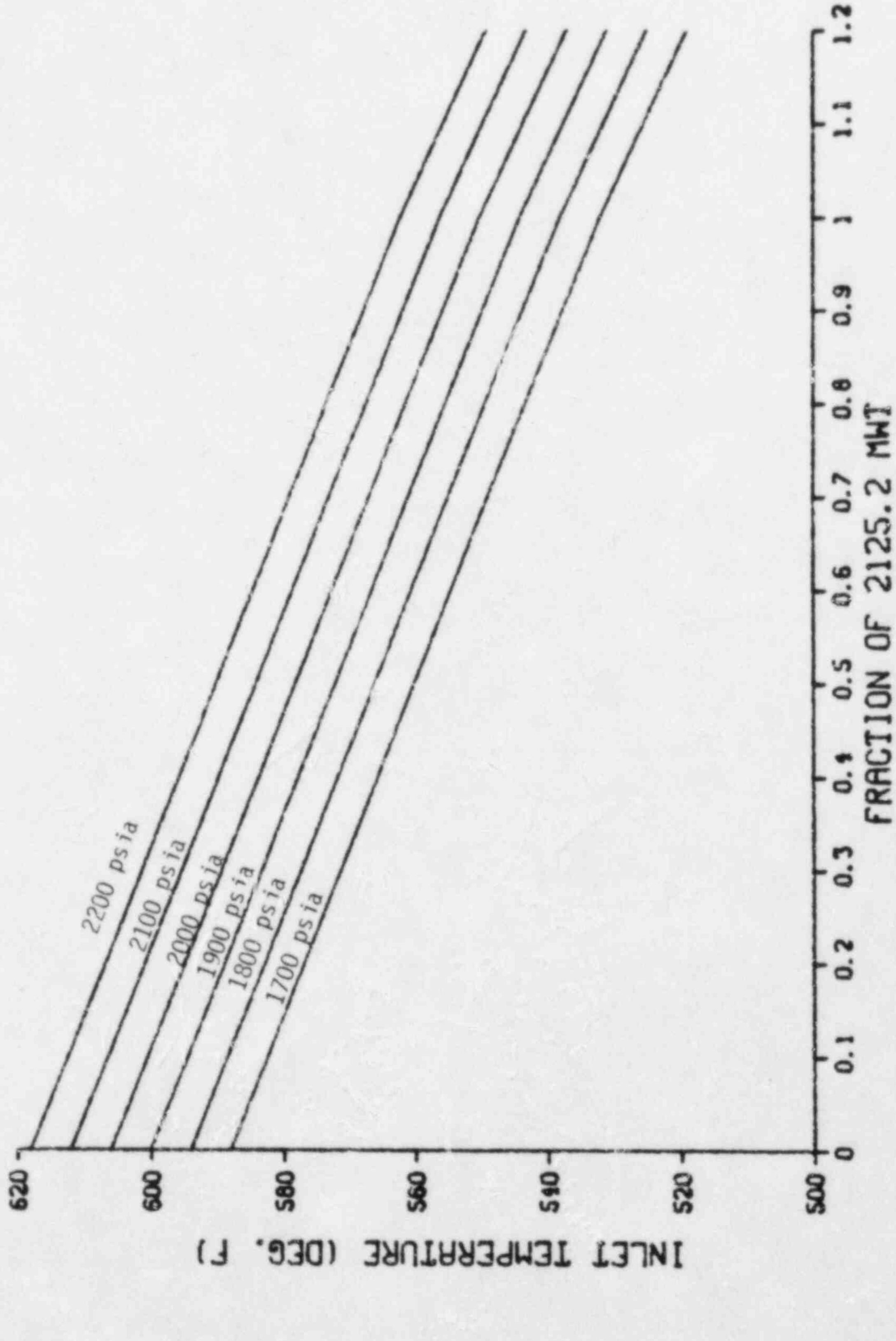

Figure 3.2 Bounding Safety Limit Lines Including Uncertainties

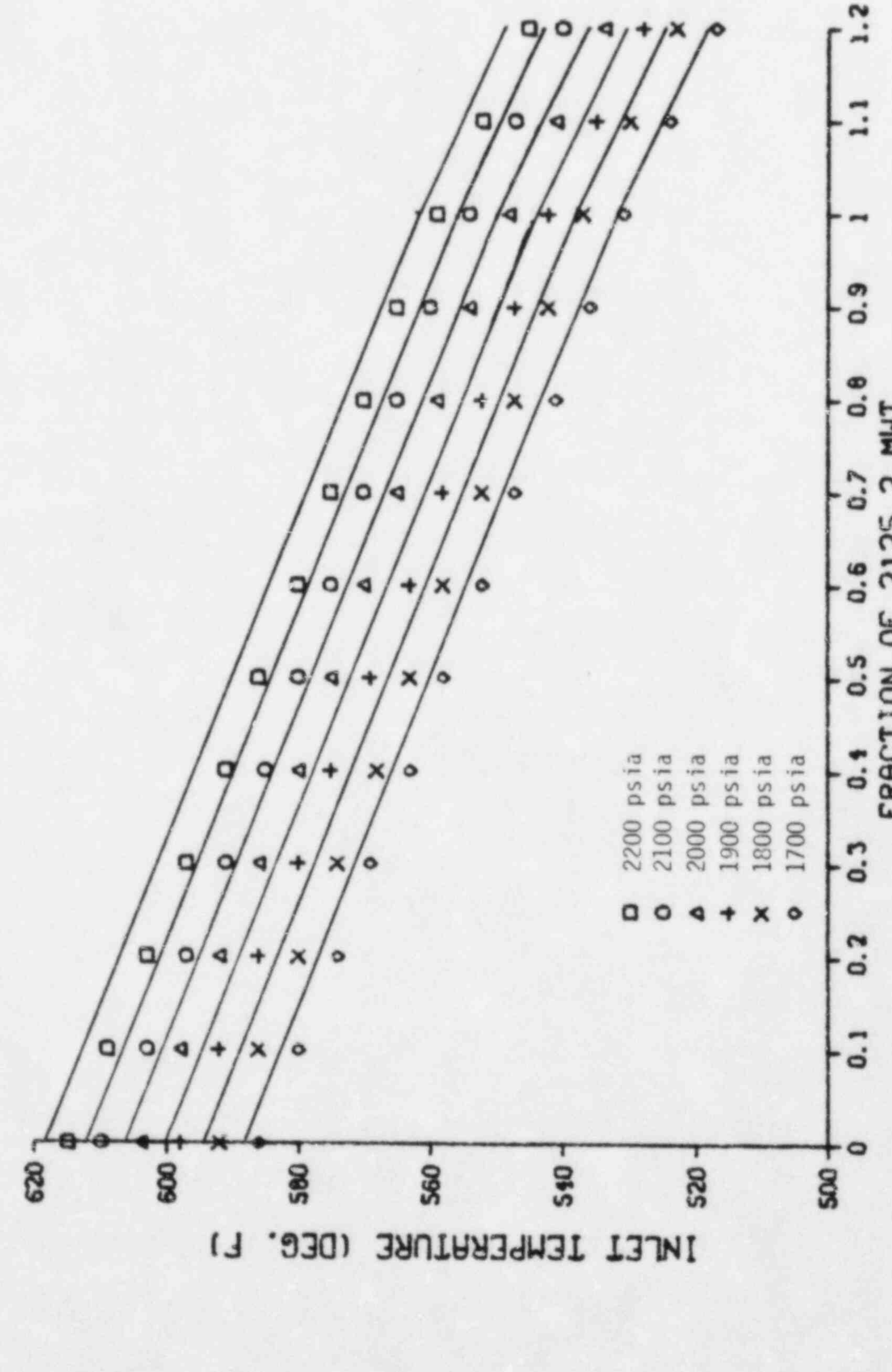

Figure 3.3 Comparison of Safety Limit Lines and TM/LP Generated Points

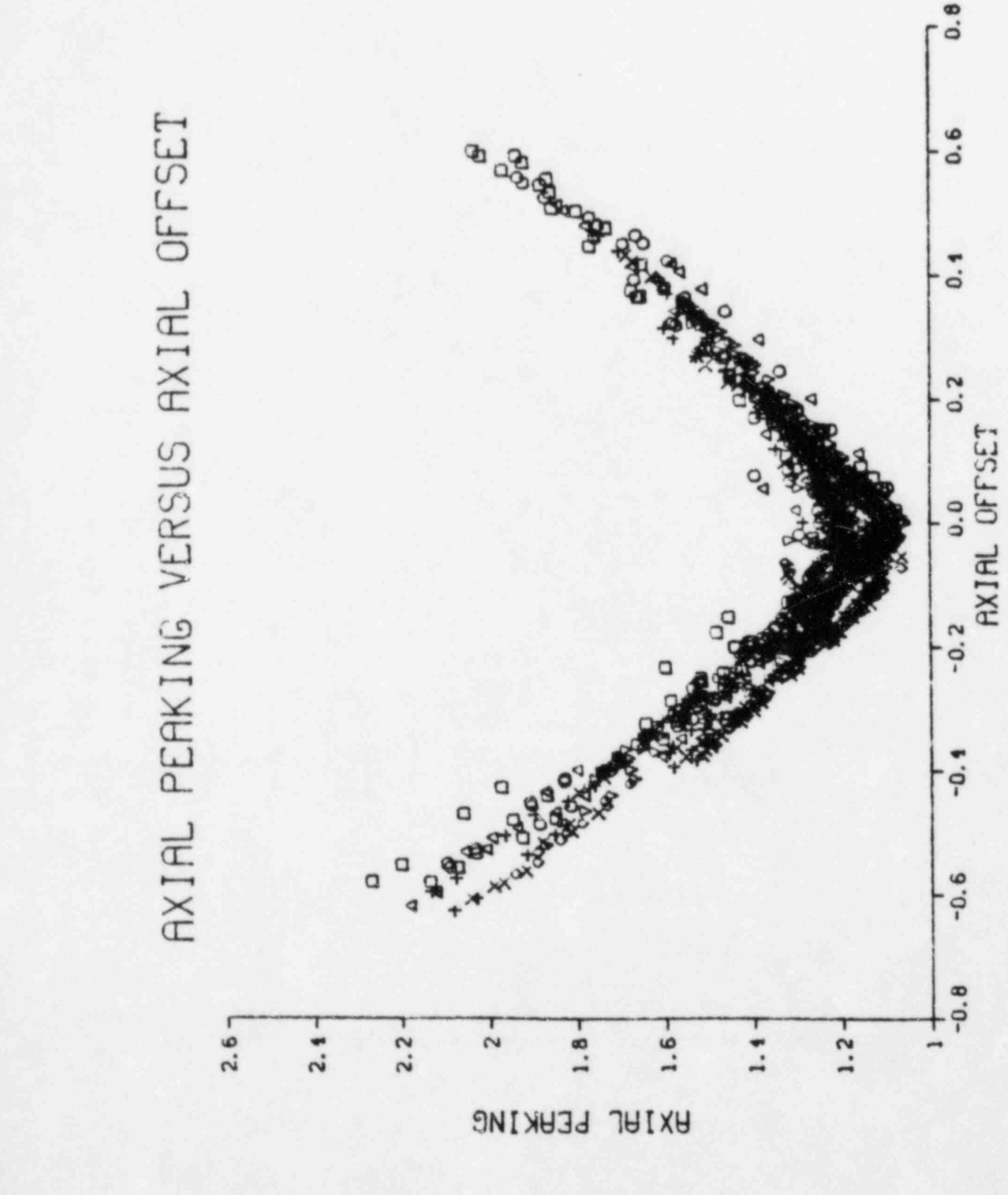

Figure 3.4 Axial Peaking versus Axial Offset

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PALISADES CYCLE 6 SETPOINT VERIFICATION WITH 50% STEAM GENERATOR TUBE PLUGGING

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