RACE CODE

METHODOLOGY AND VERIFICATION

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1.0 INTRODUCTION

The RACE code wa. developed to perform transient critical power ratio (CPR) calculations using output from the RETRAN[1] computer code. It can also be used for static CPR calculations. The code calculates critical power for a hot channel using the GEXL[2] CPR correlations.

The RACE code allows the user to specify the conditions of the hot channel and, using RETRAN data for pressur· flow, subcooling and heat flux, will calculate the CPR during the course of a transient. The re-edit capability of RETRAN is used to obtain the transient input parameters for the RACE code. Some flexibility is provided to the user on which parameter he will specify and the core location the data is extracted from.

2.0 METHODS

In order to calculate the CPR for the hot channel, the detailed thermal hydraulic conditions of the hot channel must be known. This includes the nodal heat generation and nodal quality for each axial node in the channel and the boiling length in the channel. In order to calculate these parameters the bundle flow, power generation, subcooling and pressure need to be specified for the initial steady state condition and for each time step in the transient that a CPR calculation is required.

The hot channel heat generation is determined from the core average heat generation using a fixed set of peaking parameters. These include the local and radial peaking factor and the axial power shape. In addition to the peaking factors, the GEXL correlation uses an Rfactor to relate the hot rod to the average fuel rod. These are also input parameters. The peaking factors remain constant for the calculation. The maximum total peaking factor (axial x radial x local) is usually a design limit for the fuel assembly or a value to put the initial steady state CPR on the operating limit for CPR.

The hot channel average heat generation is given by:

$$PA = \frac{POWER \times RPEAK}{560.0}$$

where

POWER = core power generated in fuel which is transferred through the clad wall. (BTU/HR)

RPEAK = radial peaking factor

The hot channel flow can be edited directly from RETRAN or the hot channel flow can be calculated from the core average flow assuming the hot channel flow, as a fraction of the core average flow, remains constant. The hot channel flow is calculated as follows:

$$G_{HC} = \frac{W_{core} \times (1 - BPFF) \times FRAC \times 3600}{1.0 \times 10^6 \times AF}$$

where: G_{HC} - Hot channel flow in Mlb/hr-ft^2

W_{core} - Total core flow lb/sec

BPFF - Bypass flow fraction

FRAC - Hot channel flow as a fraction of the average core flow

AF - Channel flow area ft^2

With the nodal power and bundle flow calculated, the nodal quality change in the channel is calculated.

For I = 1 $\quad X(1) = \dfrac{PA \times PZ(1)}{G_{HC} \times HFG \times AF \times 2} - SUBC/HFG$

For I > 1 $\quad X(I) = X(I-1) + \dfrac{PA \times (PZ(I) - PZ(I-1))/2}{G_{HC} \times HFG \times AF}$

where: X - Quality

HFG - Enthalpy of Evaporation

SUBC - Inlet Subcooling BTU/lb$_m$

PZ(I)- Normalized Axial Peak for NODE I

The boiling length, LB, is determined from the point that the nodal quality, X, becomes positive.

The GEXL correlation use a critical quality versus boiling length method to calculate critical power. The generic forms of the correlations is:

GEXL: X_c = f(G,P,DQ,LB,R)

where: G - Bundle flow

DQ - Thermal Diameter

R - Generalized local peaking pattern factor

P - Pressure

The correlations use cross sectional bundle average parameters. The R factor is used to predict the local peaking effects.

The critical power ratio for this correlation is defined as the ratio of the bundle power which would produce equilibrium quality equal to but not exceeding the correlation value (critical quality), to the bundle power at the reactor condition of interest (i.e., the ratio of critical bundle power to operating bundle power). In this definition, the critical power is determined at the bundle flow, subcooling and pressure which exist at the specified reactor condition. The specific reactor conditions are obtained from RETRAN at the desired time steps in the transient analysis. The range of conditions over which the correlation is considered to be valid are shown in Table 2.1.

3.0 VERIFICATION

The RACE code verification was performed to insure that tne CPR correlations are coded correctly and that the transient CPR calculation is correct. This was done by comparing the CPR calculated by RACE with a CPR that is calculated independently of the RACE code.

The CPR verification utilized results from GE ODYN/SCAT[3] analysis for Oyster Creek Cycle 9 (reference cycle) and Cycle 10 reloads. For the initial CPR, the RACE results compare well with the GE values (table 3.1) The difference between RACE and the vendor's ICPR is less than 1.5%. The difference is attributed to methods in calculating hot channel quality and boiling length. For the delta CPR, the ODYN/RACE results (Table 3.2) follow the ODYN/SCAT results closely for the transients analyzed; Turbine Trip without Bypass (TTWOBP), Feedwater Controller Failure (FWCF) and Loss of Feedwater Heating (LOFWH). However, ODYN/RACE results do not distinguish between differences in fuel design as in the case of the ODYN/SCAT results. This is due to the fact that the RACE code used a channel flow that is a fraction of average core flow from ODYN for both fuel designs. The fraction is kept constant throughout the transient while the SCAT code performs a transient hot channel flow calculation. In order to properly distinguish delta CPR for a mixed core of different fuel mechanical designs, the input to RACE must distinguish between the different hot channel flows. For reload analysis, a transient hot channel model is set up for each fuel mechanical design.

The verification work shows that the RACE code correctly calculates the CPR for a transient using the correlation coded.

TABLE 2.1

GEXL CORRELATION: RANGE OF CONDITIONS

Pressure:	800 to 1400 psia
Mass Flux:	0.10×10^6 to 1.25×10^6 lb/hr-ft^2
Inlet Subcooling:	0 to 100 BTU/lb
Local Peaking:	1.61 corner rod to 1.47 interior rod

TABLE 3.1

COMPARISON OF TRANSIENT INITIAL CPR

		ICPR	
CYCLE	FUEL	FUEL VENDOR*	RACE
9	GE	1.32	1.326
9	ENC	1.30	1.317
10	GE	1.32	1.322
10	ENC	1.29	1.299
11	GE	1.35	1.359
11	ENC	1.32	1.331

* Ref. 3.0

3077C

TABLE 3.2

COMPARISON OF TRANSIENT DELTA CPR

			DELTA CPR	
CYCLE	FUEL	TRANSIENT	ODYN/SCAT*	ODYN/RACE
9	GE	TTWOBP	0.25	0.227
9	ENC	TTWOBP	0.23	0.228
10	GE	TTWOBP	0.25	0.230
10	ENC	TTWOBP	0.22	0.228
10	GE	FWCF	0.20	0.204
10	ENC	FWCF	0.18	0.201
10	GE	LOFWH	0.12	0.126
10	ENC	LOFWH	0.11	0.121

* Ref. 3.0

4.0 REFERENCES

1.0 RETRAN-02 A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems, NP-1850-CCM, Rev. 3, Computer Code Manual, June 1987.

2.0 General Electric BWR Thermal Analysis Basis (GETAB): Data, Correlation and Design Application, NEDE-10958-A, January 1977.

3.0 General Electric Reload Fuel Application for Oyster Creek, NEDO-24195, May 1984.

Additional Information in Response to Question 1.

Four startup tests have been reanalyzed using the algebraic slip option (as opposed to the dynamic slip originally used). Those tests were the level setpoint change, the pressure setpoint change, turbine trip and the generator trip. Those tests cover the small perturbations to the severe pressurization conditions. Results presented in figures 1.1 - 1.8 show that the algebraic slip gives results comparable to the dynamic slip in comparison to plant data. Furthermore, use of the algebraic slip model in the content of GPUNs overall RETRAN modeling, provides a more conservative result (in terms of ΔCPR) than the current licensing model (ODYN) for the reload transients analyzed (see Table 1.1). An additional model uncertainty has been included for use of algebraic slip and is discussed with the additional information provided for questions 15 and 21. As such, the use of the algebraic slip model is acceptable for its intended application.

Figure 1.9 shows a schematic of the data flow for a transient critical power ratio calculation using GPUN methods. The RETRAN system model calculation is performed for a given event and the output is stored on a data tape. This tape contains all the thermal hydraulic (T/H) and neutronic results which provide time-dependent boundary conditions to a RETRAN hot channel analysis. The hot channel model uses system power and upper and lower plenum pressure, flow and enthalpy as boundary conditions at each time step. For licensing calculations, a generic design axial power distribution is used in the hot channel calculation. GPUN uses this axial power shape since it is an approved power shape for use in the General Electric Thermal Analysis Basis (GETAB) which GPUN utilizes for its MCPR safety limit. The hot channel power is set such that the initial steady-state CPR is at or greater than the established MCPR operating limit since ΔCPR increases with increasing initial CPR.

The output of the hot channel analysis is also stored on tape. A RETRAN re-edit is run to produce a data file containing the hot channel data needed for the CPR calculation. This includes the hot channel power, mid-plane pressure, flow and inlet enthalpy at each time step in a format that is used by the RACE code.

Figure 1.10 is a simplified flow diagram of the RACE code. RACE utilizes the same bundle power and axial power shape used in the hot channel. The hot channel data is read and CPR is calculated at each time step. The code determines initial CPR, minimum CPR and the maximum change in CPR (ΔCPR = ICPR - MCPR).

The CPR calculation is iterative in nature. The RACE code calculates the critical quality using the GEXL correlation and compares it to the quality in the bundle. Bundle power is scaled while all other input parameters remain constant, such that the hot channel enthalpy rise matches the critical quality which is also changing with the change in boiling length. When the bundle quality matches the critical quality, the solution is converged and CPR is calculated. This steady-state calculation is performed at each time step which is a conservative application of the correlation (reference 15 in TR-045) to a transient condition.

Additional Information in Response to Question 1 (CONTINUED)

In addition to the verification work presented in the RACE supplemental documentation, the RACE code methodology was run against publically available critical heat flux data including some data that was available from the GE CHF data base. The data from the GE da.a base includes 130 16 rod bundle test points with a symmetric cosine axial power shape. The mean CPR for these data points as calculated using the RACE methodology is 1.0054 ± 0.0248 which falls in the one sigma band of the published result of 0.9885 ± 0.0360 for the 7X7 data base. This provides additional assurance that the RACE methodology correctly calculates CPR.

While the comparisons in the RACE supplemental documentation of the ODYN/RACE and ODYN/SCAT result are non-conservative with the RACE analysis in some cases, the RETRAN/RACE results are conservative relative to the ODYN/SCAT for the transients analyzed.

The differences between ODYN/SCAT and ODYN/RACE results are attributed to using the core average flow instead of the hot channel flow as stated in the RACE supplemental documentation. To further support this argument, a plot (figure 1.11) of hot channel flow, total core flow, and heat flux normalized to 1.0 shows that at peak flux, the hot channel flow is less than the core average flow (hence lower CPR with hot channel flow). Therefore, the use of a fixed hot channel flow as a fraction of total core flow would be non-conservative and explains the results of the ODYN/RACE vs. ODYN/SCAT comparisons. Later in the transient the normalized hot channel flow is greater than the normalized core flow as we discussed in the July 21, 1988 meeting.

The differences in ICPR between GE and GPUN calculations is attributed to differences in calculating quality and boiling length in the RACE and SCAT codes. These differences are not considered significant given the overall conservatism in the RETRAN/RACE results.

Table 1.1

ΔCPR Comparison Between RETRAN & ODYN*

	GE 8X8		EXXON VB	
	ODYN	RETRAN	ODYN	RETRAN
TTWOBP	0.24	0.291	0.22	0.294
FWCF	0.20	0.203	0.18	0.198

* From Section 4.1.3 and 4.3 of TR-045.

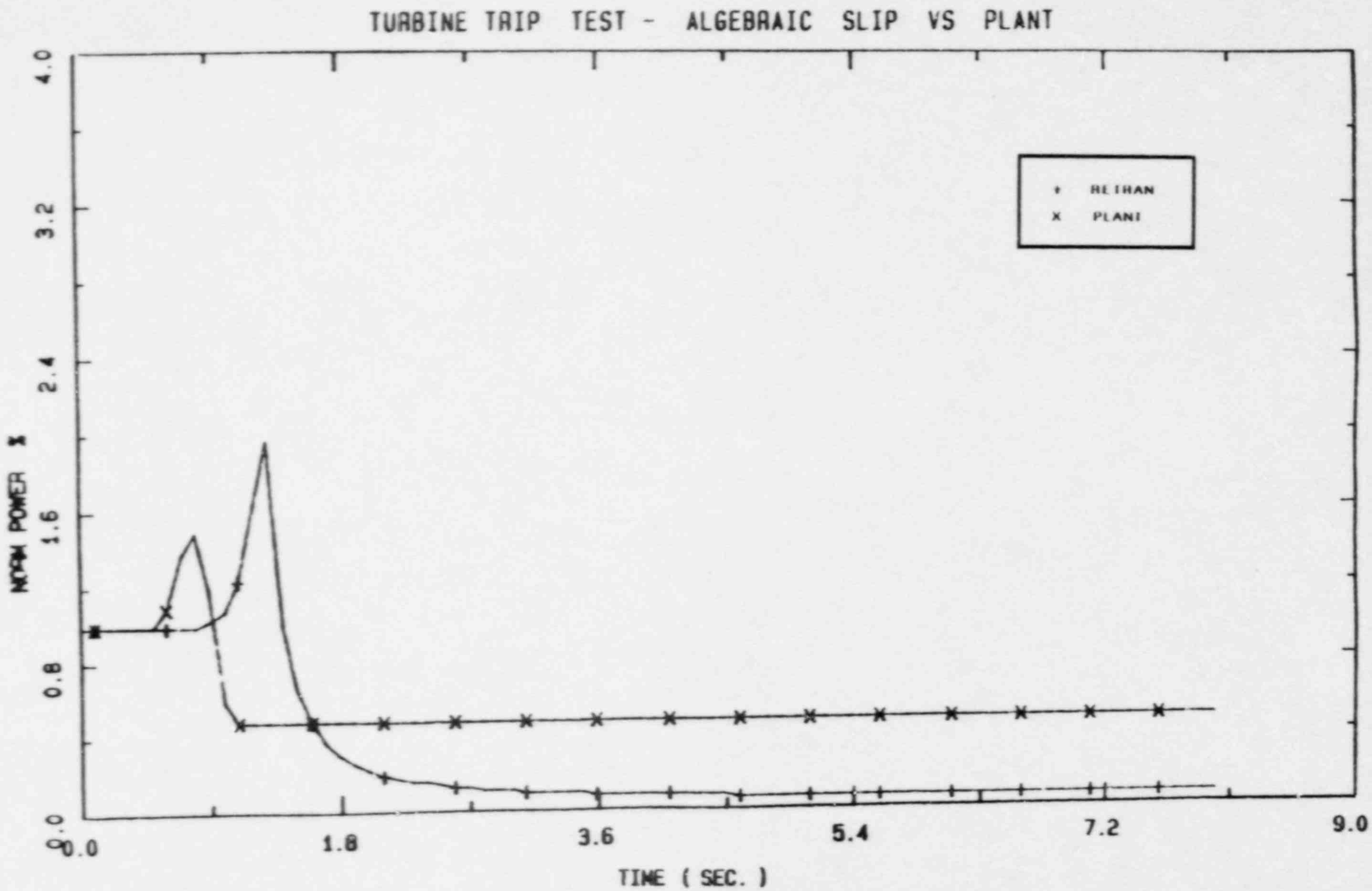
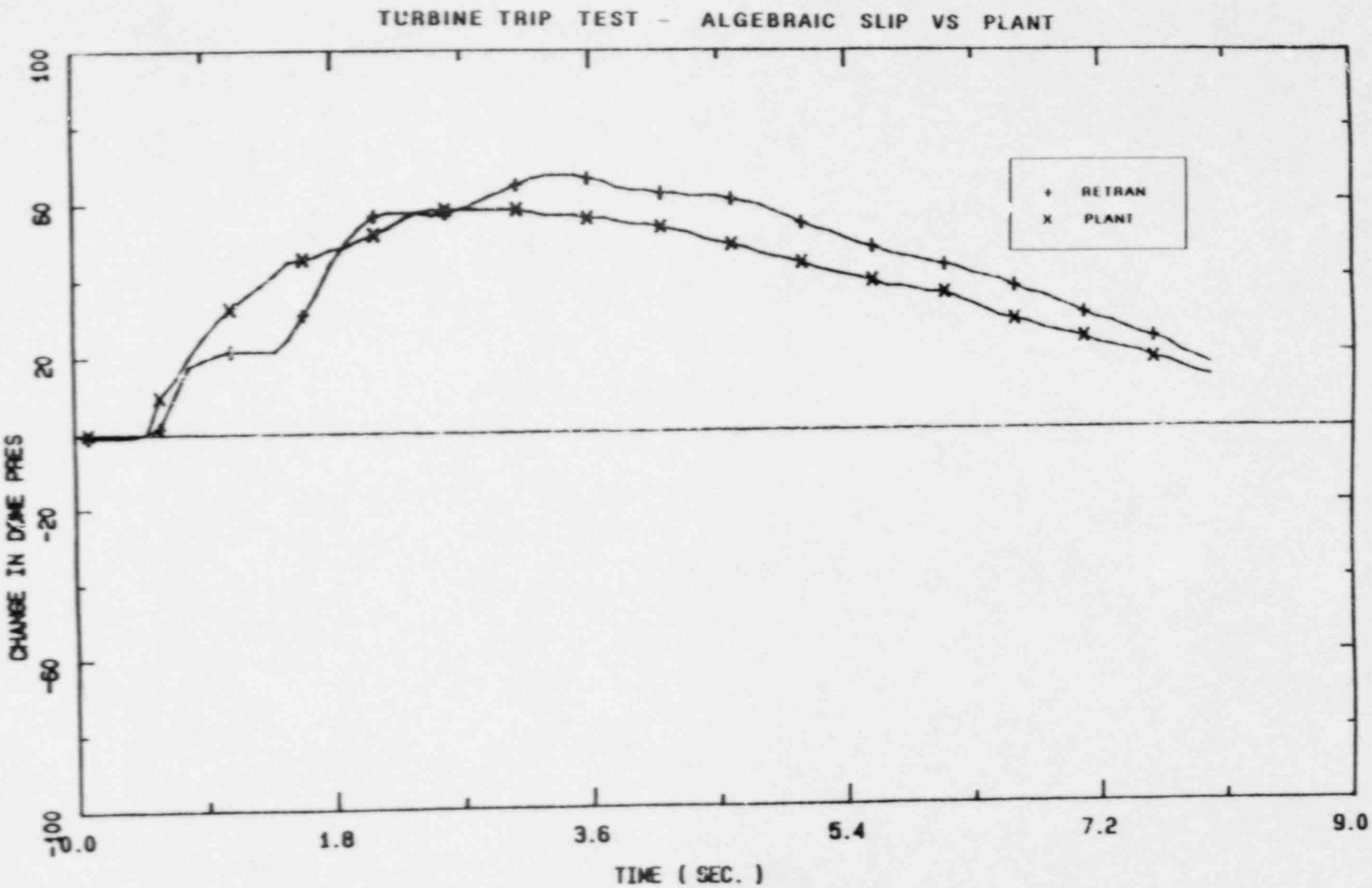

TURBINE TRIP TEST - ALGEBRAIC SLIP VS PLANT
+ RETRAN
x PLANT
NORM POWER %
4.0
3.2
2.4
1.6
0.8
0.0
0.0
1.8
3.6
5.4
7.2
9.0
TIME (SEC.)

Figure 1.1



TURBINE TRIP TEST - ALGEBRAIC SLIP VS PLANT
+ RETRAN
x PLANT
CHANGE IN DOME PRES
TIME (SEC.)
100
60
20
-20
-60
-100
0.0
1.8
3.6
5.4
7.2
9.0

Figure 1.2

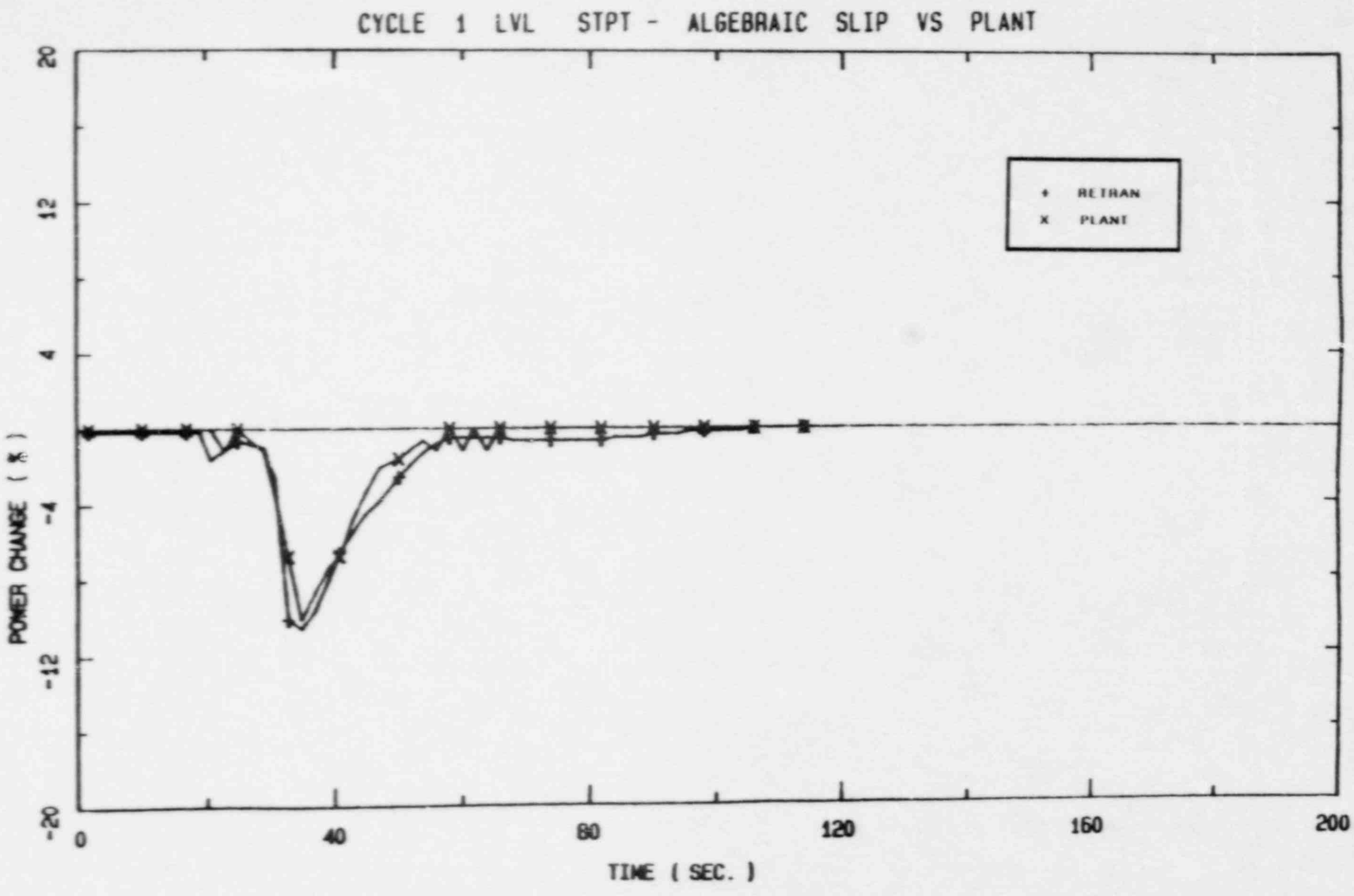

CYCLE 1 LVL STPT - ALGEBRAIC SLIP VS PLANT
20
12
4
-4
-12
-20
POWER CHANGE (%)
0
40
80
120
160
200
TIME (SEC.)
+ RETRAN
x PLANT

Figure 1.3

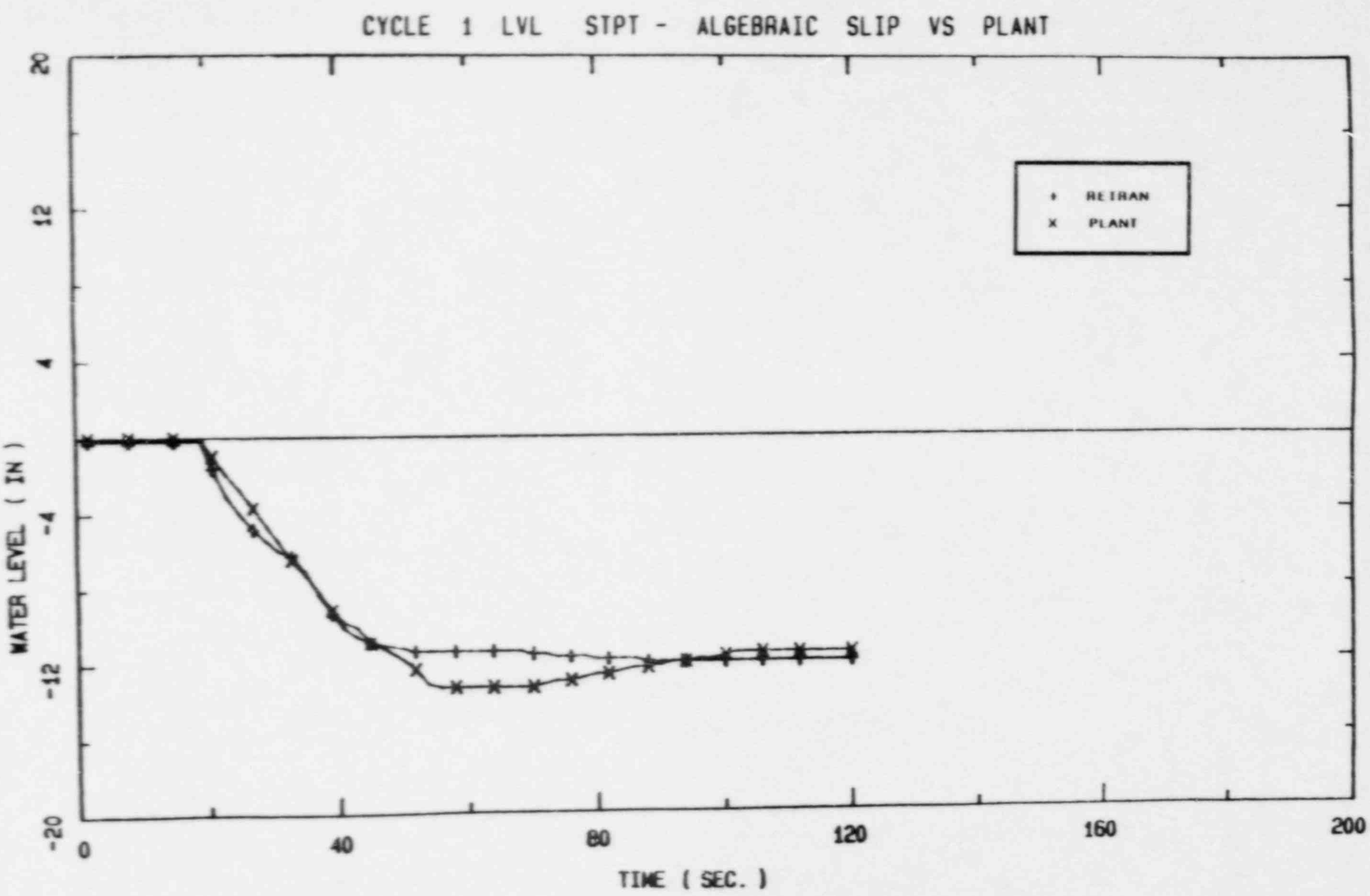
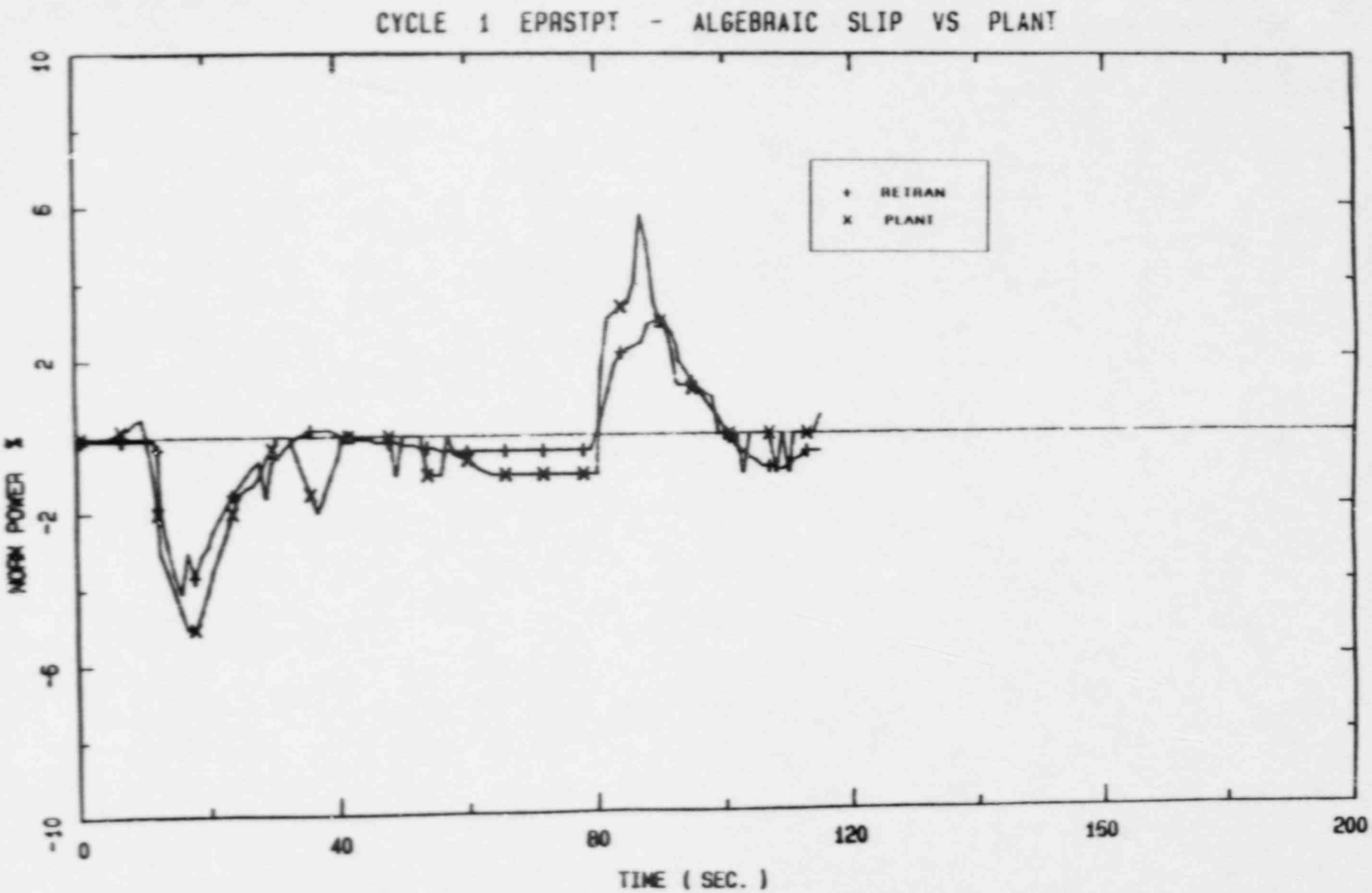

CYCLE 1 LVL STPT - ALGEBRAIC SLIP VS PLANT
+ RETRAN
x PLANT
20
12
4
-4
-12
-20
WATER LEVEL (IN)
0
40
80
120
160
200
TIME (SEC.)

Figure 1.4



CYCLE 1 EPASTPT - ALGEBRAIC SLIP VS PLANT
NORM POWER %
10
6
2
-2
-6
-10
0
40
80
120
150
200
TIME (SEC.)
+ RETRAN
x PLANT

Figure 1.5

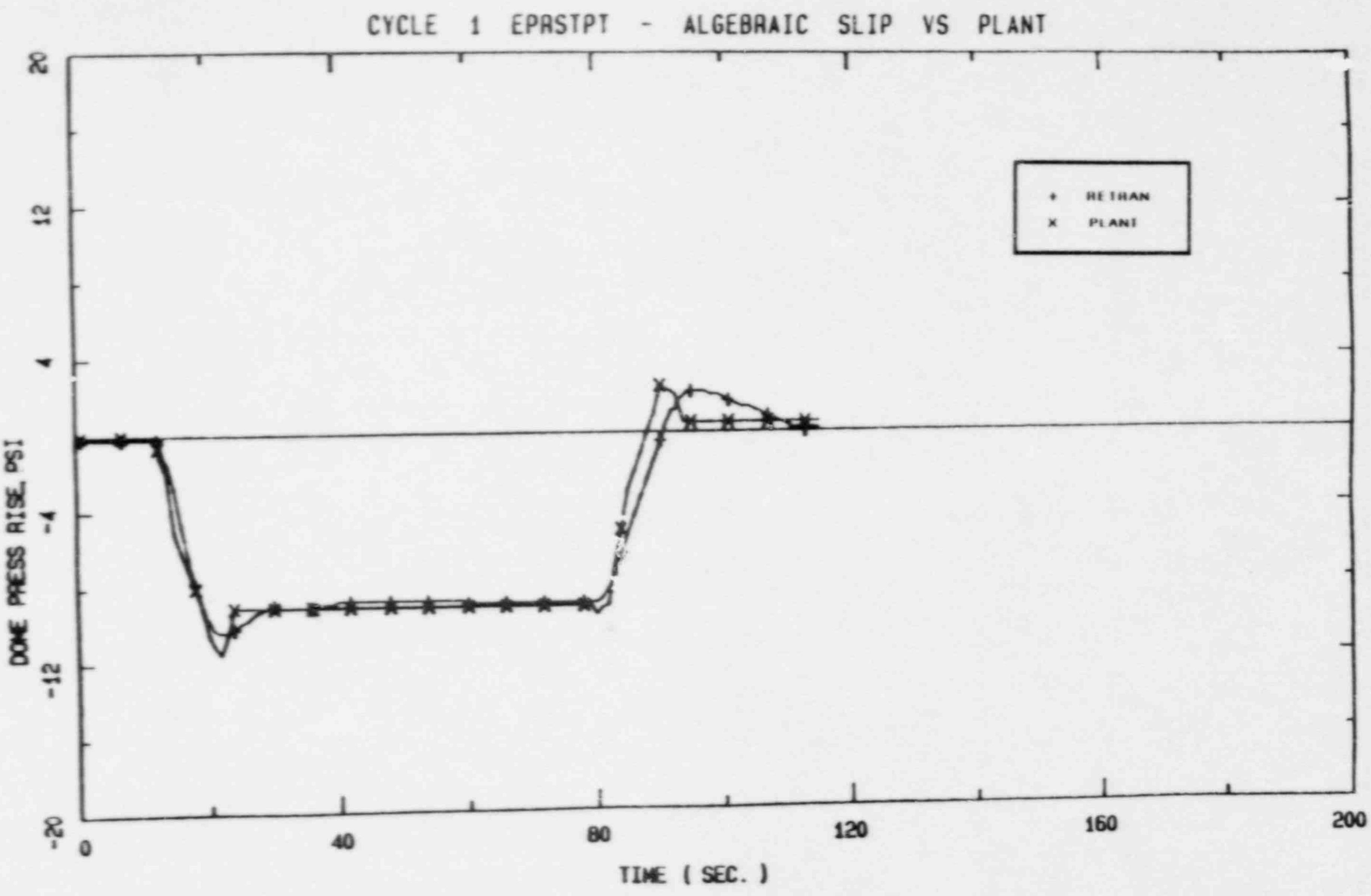

CYCLE 1 EPRSTPT - ALGEBRAIC SLIP VS PLANT
+ RETRAN
x PLANT
DOME PRESS RISE PSI
20
12
4
-4
-12
-20
0
40
80
120
160
200
TIME (SEC.)

Figure 1.6

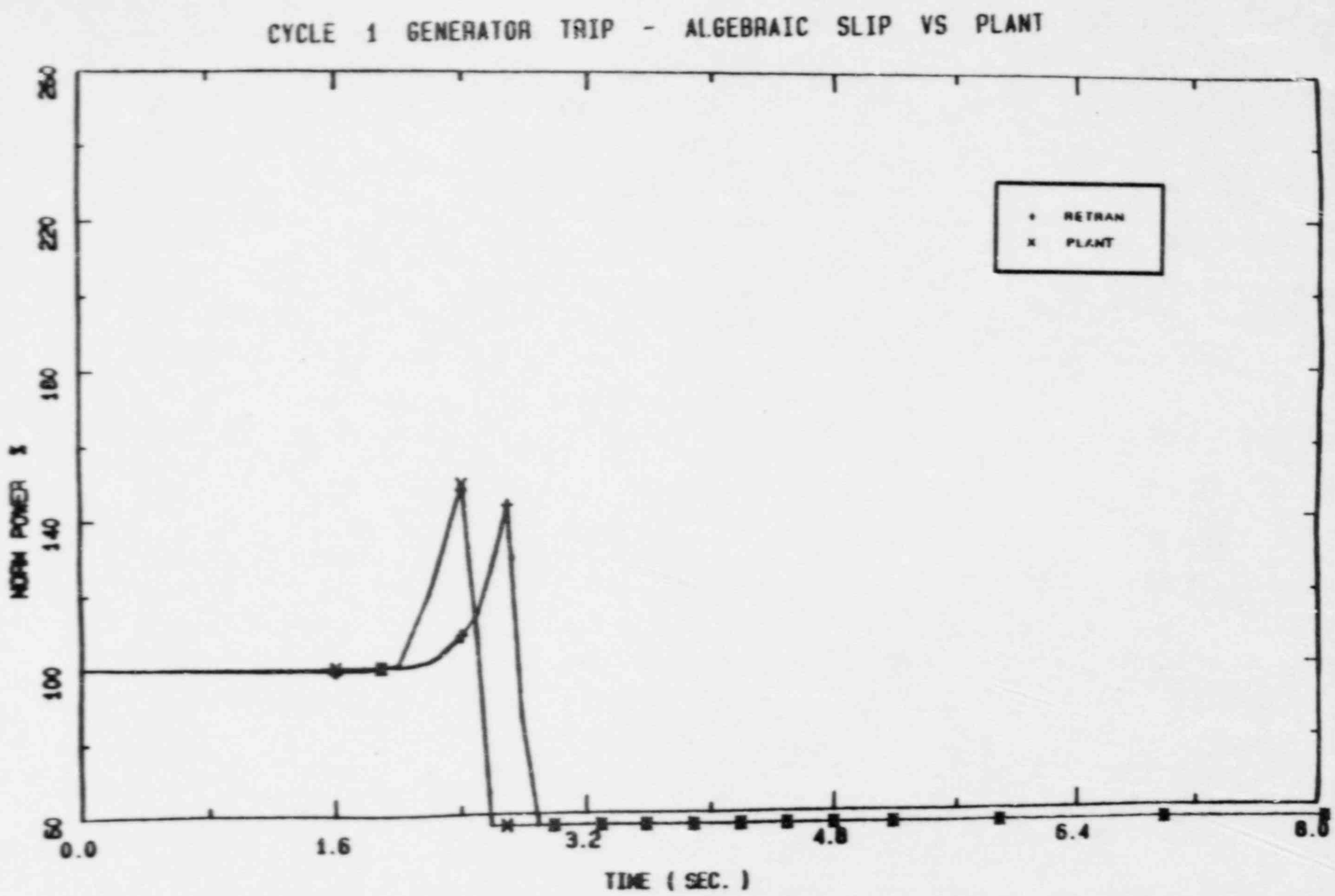

CYCLE 1 GENERATOR TRIP - ALGEBRAIC SLIP VS PLANT
NORM POWER %
260
220
180
140
100
60
0.0
1.6
3.2
4.8
6.4
8.0
TIME (SEC.)
+ RETRAN
x PLANT

Figure 1.7

CYCLE 1 GENERATOR TRIP - ALGEBRAIC SLIP VS PLANT

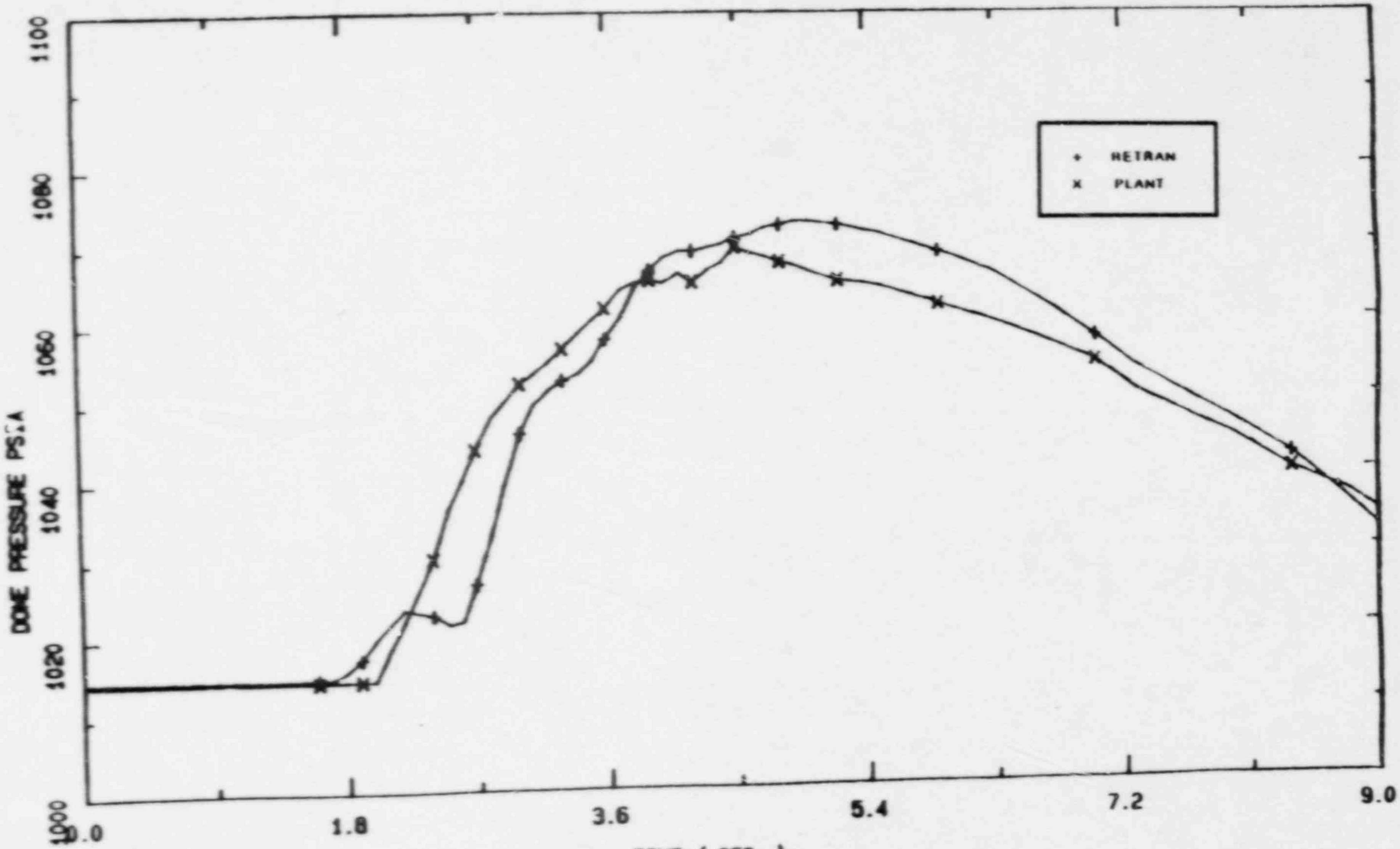
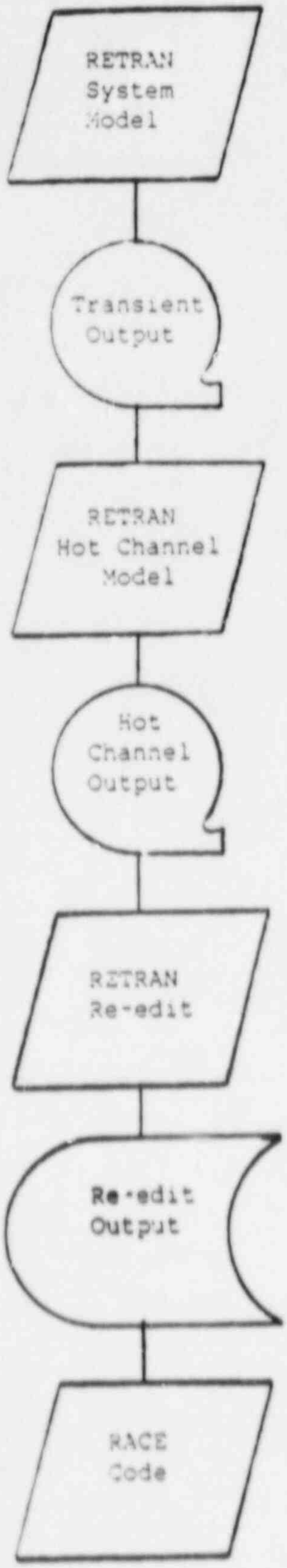


Figure 1.8

FIGURE 1.9

RETRAN/RACE CPR CALCULATION



Transient to be analyzed is executed.

Transient output is saved on tape.

Hot channel model is executed. Reads transient tape utilizing system power and upper and lower plenum pressure, flow and enthalpy as boundary conditions at each time step.

Hot channel output is saved on tape.

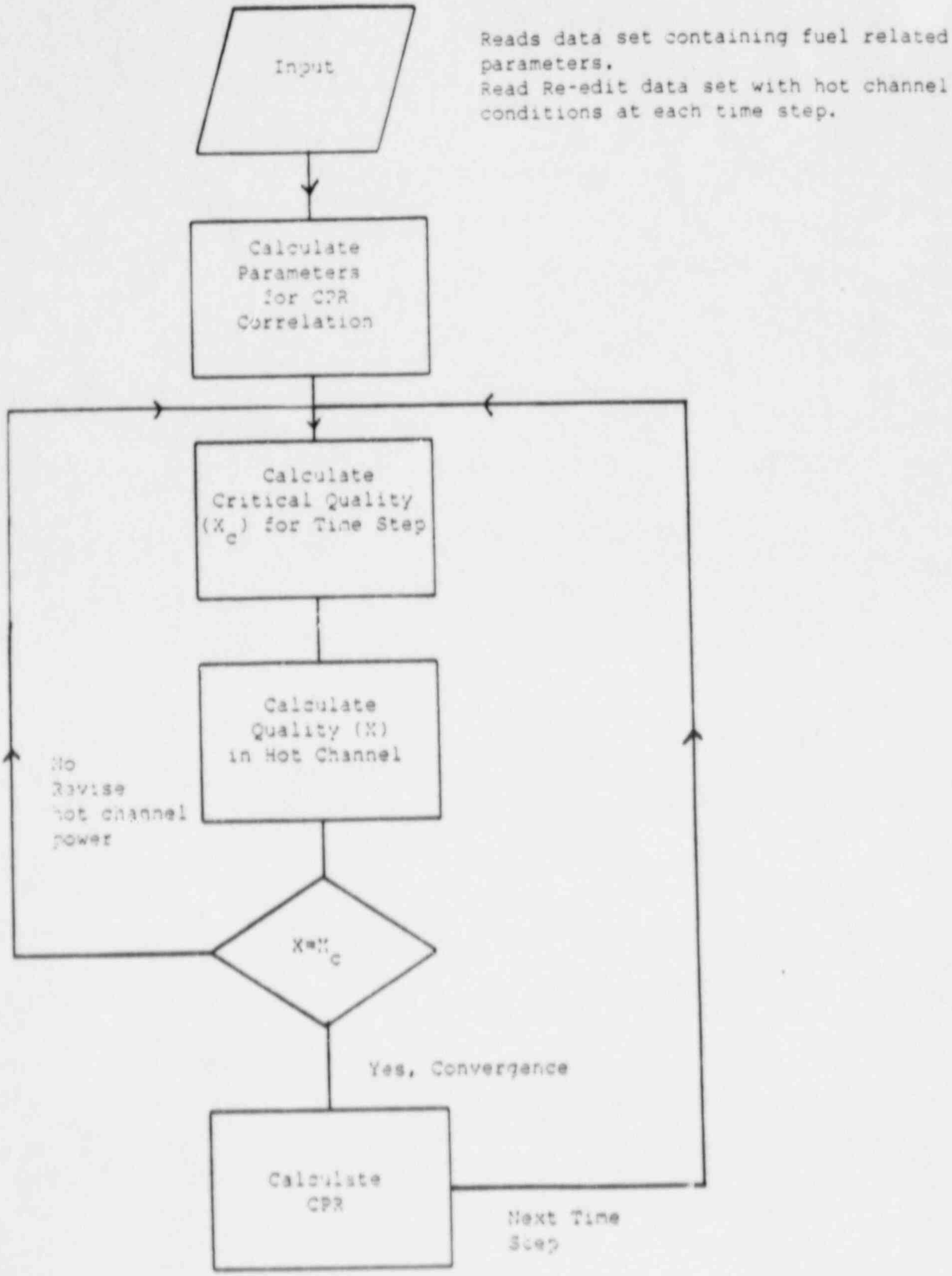
Re-edit of hot channel tape is executed.

Re-edit output for hot channel power, mid-plane pressure, flow and inlet enthalpy at each time step is written to a data set.

RACE code reads data set and calculates CPR at each time step and determines ΔCPR for the transient.

FIGURE 1.10

RACE CODE FLOW CHART



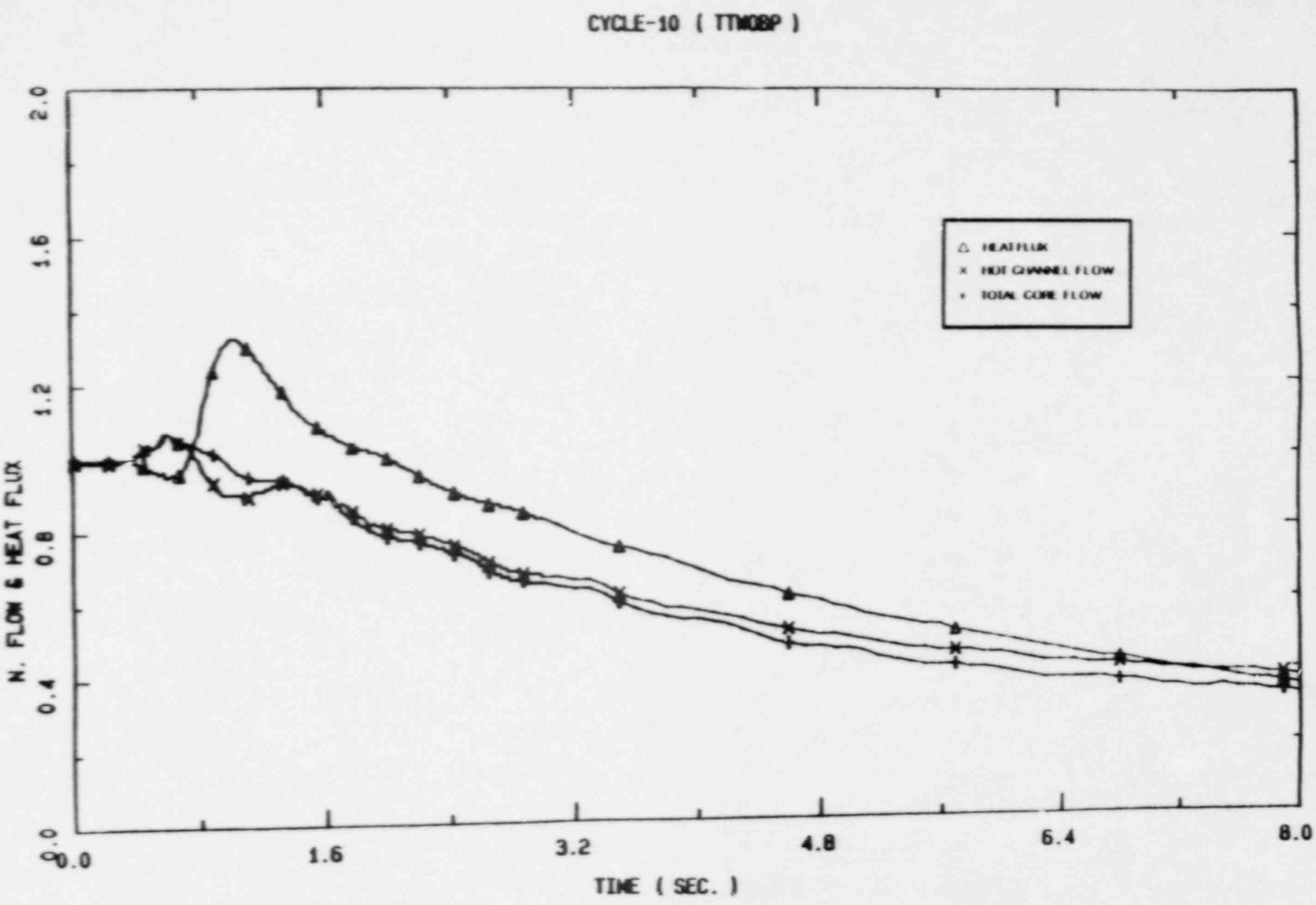

CYCLE-10 (TTWOBP)
N. FLOW & HEAT FLUX
TIME (SEC.)
HEATFLUX
HOT CHANNEL FLOW
TOTAL CORE FLOW
0.0
0.4
0.8
1.2
1.6
2.0
1.6
3.2
4.8
6.4
8.0

Figure 1.11

Additional Information in Response to Question 4.

- The 10% Error: The strip charts containing plant data for the startup tests were analyzed for noise level and thickness of recording pen. An error margin in the range of 3.5% to 16.6% was calculated (for wide range pressure, it was 33%, a 3.3 psi error for 10 psi delta) for the change (delta) in different parameters. A 10% average was taken for all tests as part of the screening criteria.

- The 5% Error: We are comparing a computer code result against plant data which has some measurement uncertainties. If the computer code results are to be meaningful, they ought to be within the measurement uncertainties of the plant data. Oyster Creek specific measurement uncertainties are available in NEDO-24195 (Table 5-1, attached). Inspecting this table shows that the highest uncertainty is in the core total flow which is 5%. This value (one sigma) was used as a bounding value for the code's calculated margin. The interpretation given to this value is that if the code can calculate a parameter within 5% of its average (the word true used in the report may be misleading) value then it is regarded as an acceptable result. The total error margin is, therefore, taken at 15%. It is important to remember that the same model is used to benchmark all tests and therefore, some tests may be quite close to code results while others close to the 15% margin and even some are beyond this acceptance margin, in which case we present arguments as to why we think the result is acceptable. In all cases such acceptability is either based on the deviation being in a conservative direction in which case we are accepting a penalty or the absolute values are so small (although in percent they seem high) that they are within the "noise" level.

  In order to factor in the fact that some parameter (e.g., dome pressure) has a very low uncertainty margin (0.5%) compared to the 5% core flow, another restriction was imposed. As stated in our previous answer in round 1, the deviation between the absolute values of the plant parameter and the code results should be within two standard deviations of the measurement uncertainty for each individual parameter as given in Table 1.0 of our previous response.

  Remember the 15% is on the change in a parameter while the two sigmas are on absolute values. This restriction is quite severe (sometimes the 2σ is more restrictive than the 15%) in addition to the requirement that no safety system should be challenged in a way not according to test sequence.

The attached table summarizes a comparison between plant-RETRAN-15% margin-the 2σ and absolute error between plant and RETRAN.

Table 4.1

Comparison Between Plant-RETRAN and Acceptance Criteria

Test	Parameter	Max. Change During Test		15% Margin	2σ	Error (Plant Vs. RETRAN)
		Plant	RETRAN			
Pressure Setpoint	Dome Press. (psi)	12	11	1.8	10	1
	Power %	5.5	3.5	0.825	2	2
Level Setpoint	Level (in)	13	11	1.95	3.2	2
	Power	10	11.5	1.5	2	1.5
MSIV Closure	Level (in)	57	54	8.55	3.2	3
	Dome Press. (psi)	50	33	7.5	10	17(1)
Bypass Valve	Dome Press. (psi)	3	3.5	0.45	10	0.5
	EPR Press. (psi)	3	4	0.45	10	1.0
Turbine Trip	Power (%)	51	90	7.65	2	39(2)
	Dome Press. (psi)	60	75	9	10	15(2)
Generator Trip	Power (%)	50	48	7.5	2	2
	Dome Press. (psi)	60	55	9	10	5
Pump Trip	Core Flow (lb/s)	11944	11444	1791.6	1694.4	3500(2)
Recirc. Flow	Core Flow (lb/s)	2800	4230	420	1694.4	370
	Level (in)	3.5	3.7	0.525	3.2	0.2
	Power (%)(3)	12.5	11	1.875	2	1.5
	Dome Press. (psi)	12.5	20	1.875	10	7.5

(1) Corresponds to wide range pressure instrument which is not as accurate as the normal narrow range instrument used during normal power operation.

(2) More conservative.

(3) Initial power drop exceeded criteria, which is believed to be due to unavailable runback data.

Table 5-1

UNCERTAINTIES USED IN STATISTICAL ANALYSIS

Quantity	Standard Deviation (% of Point)	Comment
Feedwater Flow	1.76	This is the largest component of total reactor power uncertainty.
Feedwater Temperature	0.76	These are the other significant parameters in core power determination.
Reactor Pressure	0.5	
Core Inlet Temperature	0.2	Affect quality and boiling length.
Core Total Flow	5.0	This uncertainty is for non-jet pump plants and includes the allowance due to bypass flow uncertainty.
Channel Flow Area	3.0	This accounts for manufacturing and service induced variations in the free flow area within the channel.
Friction Factor Multiplier	10.0	Accounts for uncertainty in the correlation representing two-phase pressure losses.
Channel Friction Factor Multiplier	5.0	Represents variation in the pressure loss characteristics of individual channels. Flow area and pressure loss variations affect the core flow distribution, influencing the quality and boiling length in individual channels.
TIP Readings	8.7	These sets of data are the base from which gross power distribution is determined. The assigned uncertainties include all electrical and geometrical components plus a contribution from the analytical extrapolation from the chamber location to the adjacent fuel assembly segment. Also included are uncertainties contributed by the LPRM system. LPRM readings are used to correct the power distribution calculations for changes which have occurred since the last TIP survey. The assigned uncertainty affects power distribution in the same manner as the base TIP reading uncertainty.
R Factor	1.6	This is a function of the uncertainty in local fuel rod power.
Critical Power	3.6	Uncertainty in the GEXL correlation in terms of critical power.

Additional Information in Response to Question 5.

In order to test the proper behavior of the model for different parameters, the TTWOBP has been chosen where all model options are activated and a discussion is presented below explaining the principal phenomena and the corresponding computed parameters. The basic description of the event is presented in Section 4.1 and Table 4.1 of TR-045.

Figure 5.1 shows total reactivity and power vs. time. This total reactivity will start to turn around once the scram reactivity dominates the transient (it is not possible to plot the reactivity components for one-dimensional kinetics under MOD4). Many processes contribute to the core reactivity. The first and most important is void collapse due to the fluid compression produced by the pressure wave thus causing a power increase. This power increase immediately starts to put heat into the coolant via the direct moderator heating phenomena which is faster than conduction, causing additional void formation which tends to mitigate the transient (this effect was demonstrated during the sensitivity analysis). The fluid compression phase is then followed by a rarefraction phase as the pressure wave oscillates thus reducing the positive reactivity due to the compression as more voids are produced. The doppler effect is generally regarded as having a small effect because of fuel time constant involved. Once the control rods start inserting past the first couple of nodes the scram reactivity will dominate and turn the transient around.

Figure 5.2 shows pressure behavior at steam chest (Vol. 217) nearest the Turbine Stop Valve where the high amplitude pressure wave produced due to valve closure is clearly seen. As the pressure wave travels along the contours of the steam lines, it gets attenuated and the pressure behavior in volume 203, which is close to the vessel, shows the attenuation effects reflected in the wave amplitude.

Figure 5.3 shows inlet and exit core flow during the early stages of the transient where an oscillatory component is clearly seen. The increase in inlet flow is due to pressure compression along the downcomer and recirc loop, in the direction of flow, while the decrease in exit flow is due to pressure compression along the separator, standpipe path which is against the direction of flow. The two compression effects are responsible for the fluid densification in the core as seen on average fluid density in different axial locations along the core, in Figure 5.4.

Figure 5.5 shows the heat flux in different axial nodes where the initial drop is due to increase in density.

Figure 5.6 is a plot of the liquid and vapor regions temperatures of the upper downcomer where the non equilibrium effect is clearly seen with vapor and liquid temperatures start as equal representing an equilibrium state, but this diverges during the pressurization phase with the vapor becoming superheated as indicated by the increase in temperature. As the pressurization effect runs its course, the temperatures of both phases converge to the equilibrium conditions.

It is therefore concluded that the model does capture all important phenomena with the correct behavior.

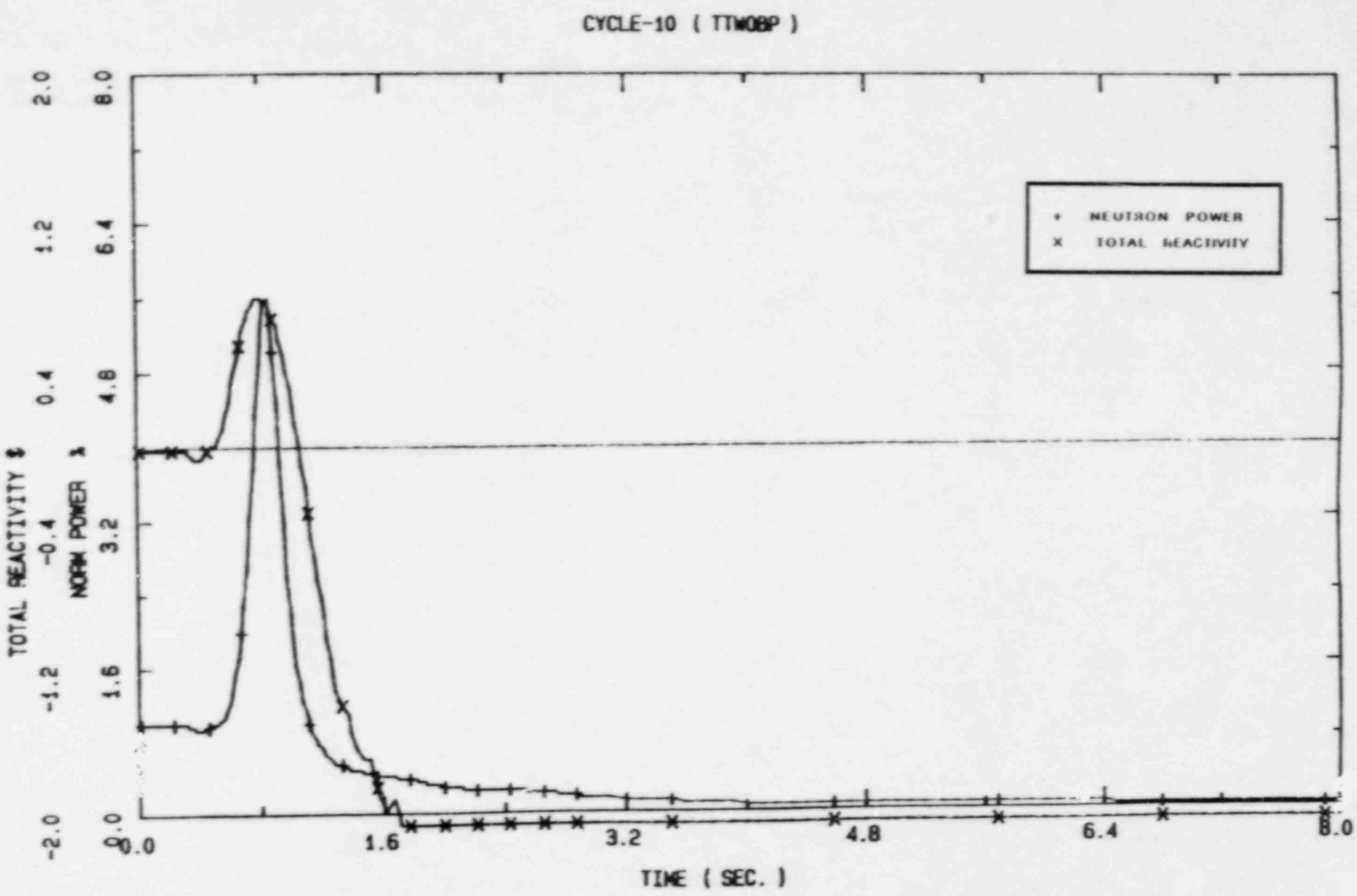


Figure 5.1 – Total Reactivity and Neutron Power

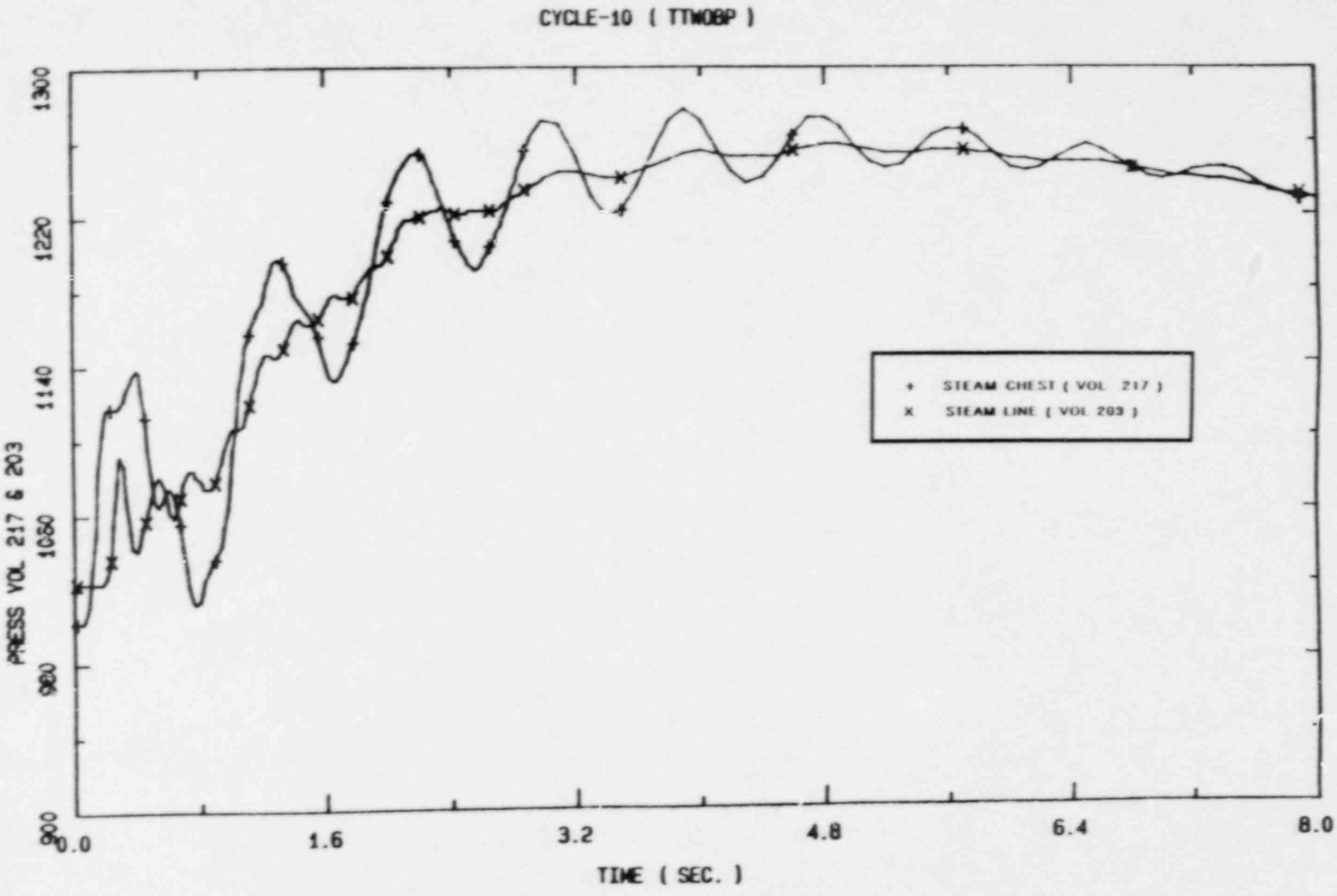


Figure 5.2 - Pressure Wave Oscillations / Amplitude at Steam chest and Steam line

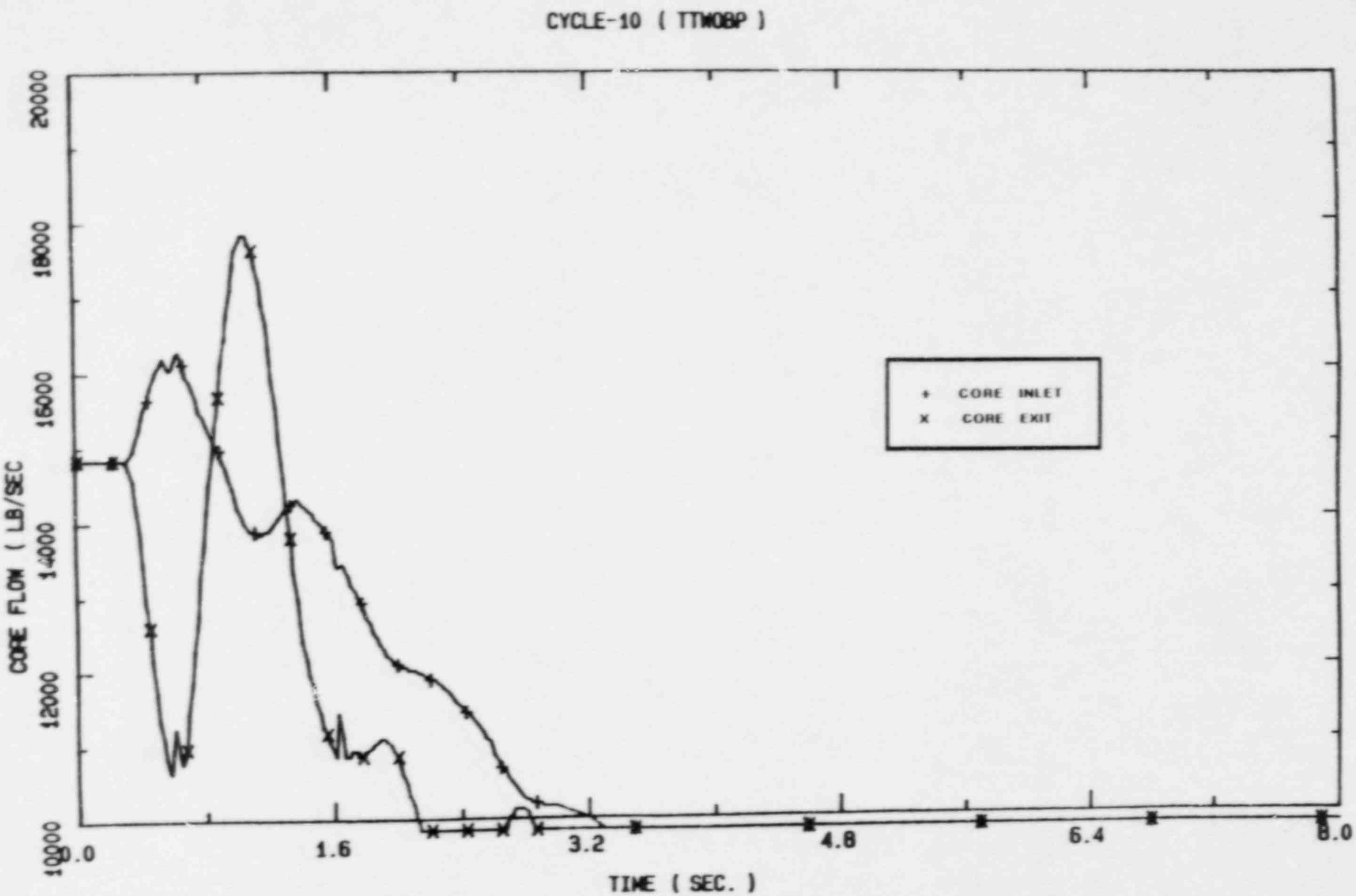


Figure 5.3 – Effect of pressure wave on core Inlet / Exit flow

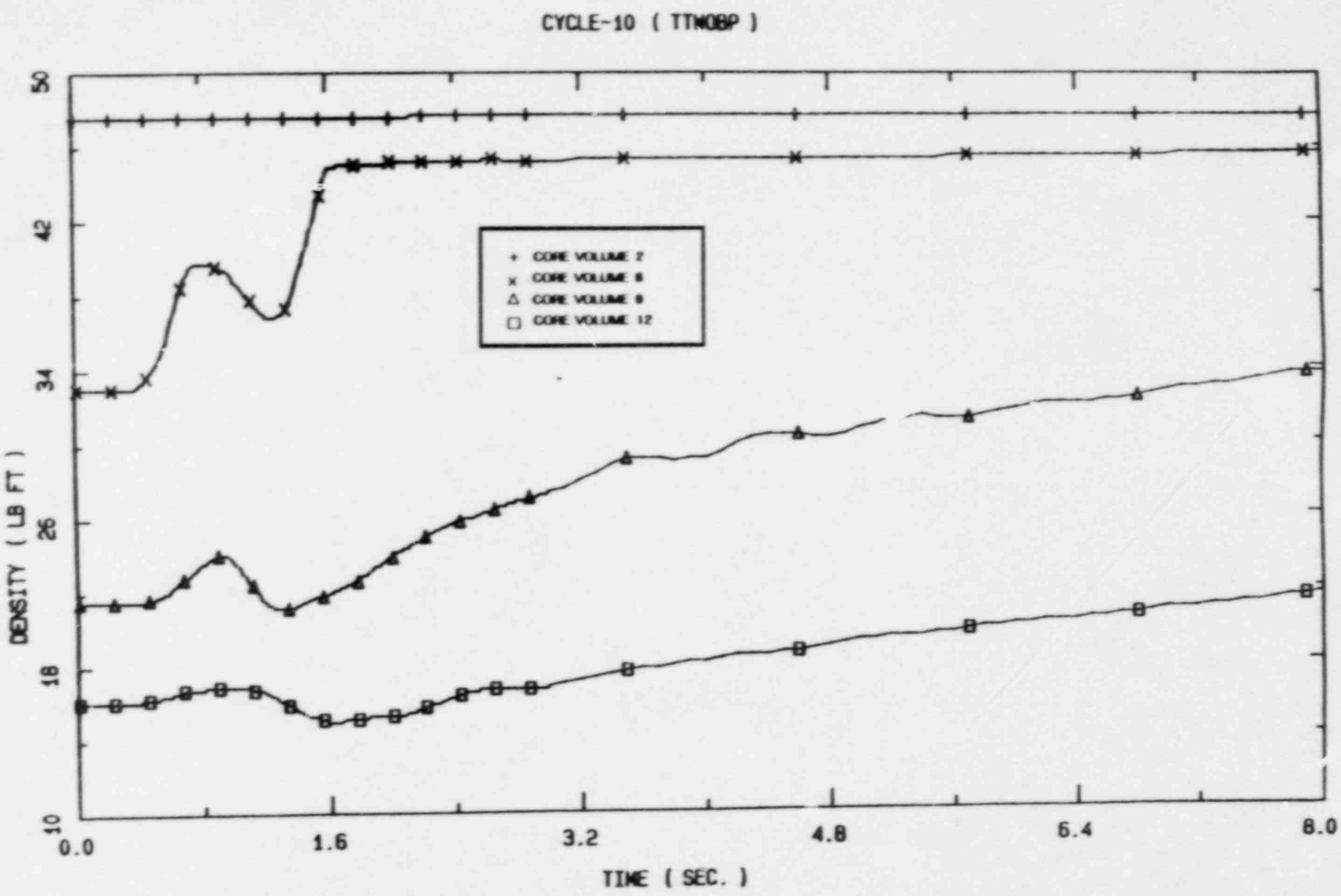


Figure 5.4 – Densification Due to wave Compression + Rarefraction

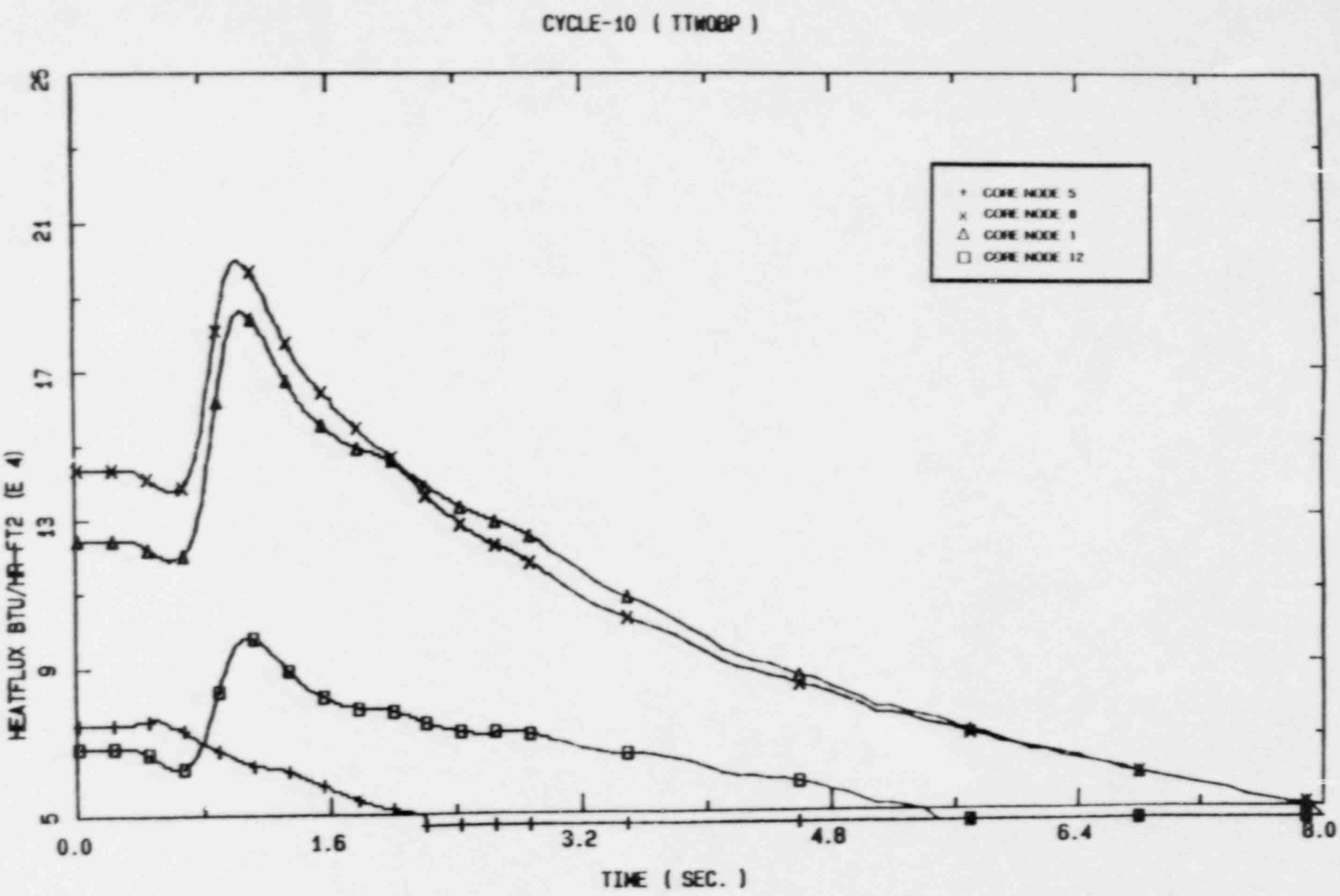


Figure 5.5 – Heat flux at Different Axial nodes

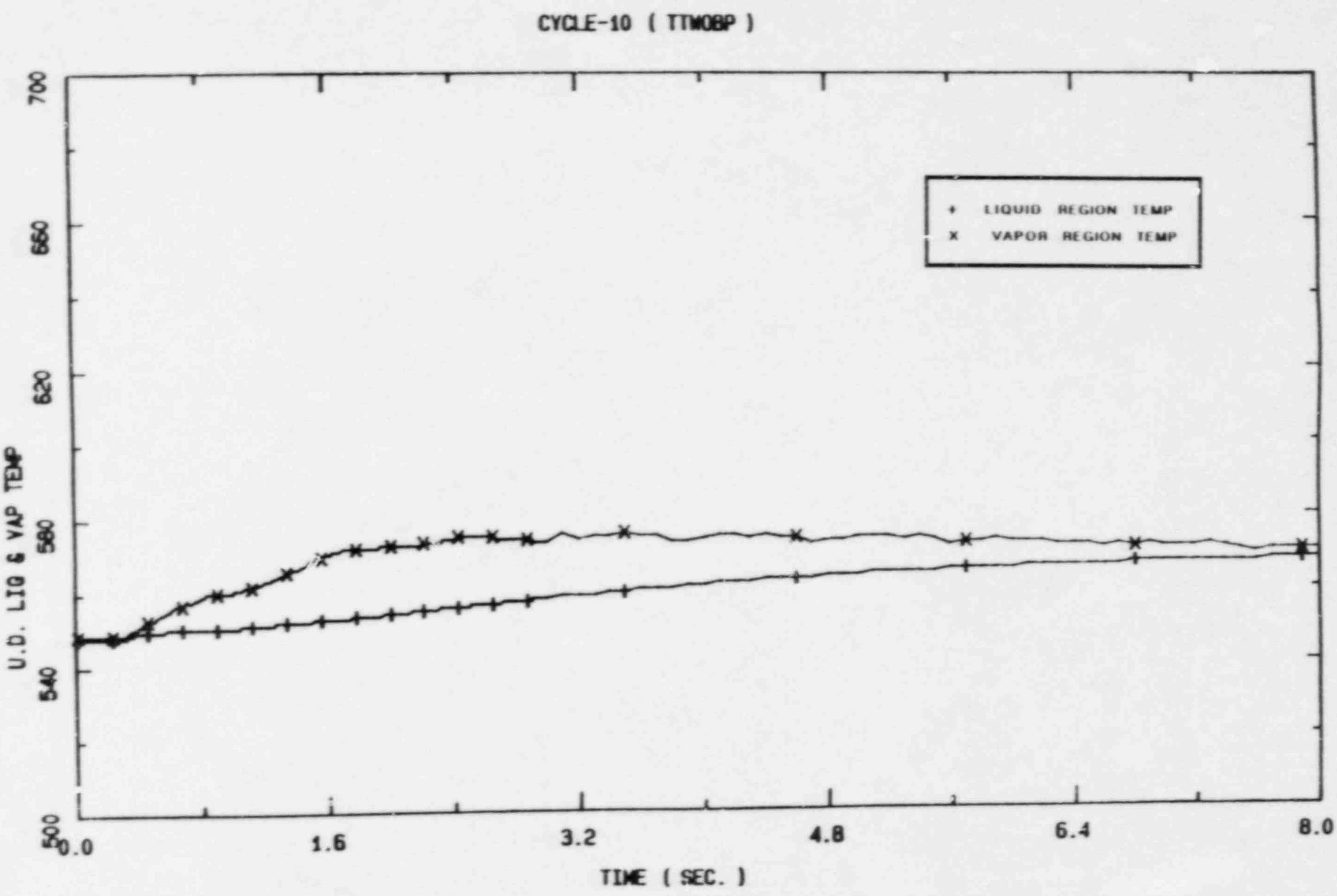


Figure 5.6 – Non-equilibrium effects on Upper Downcomer

Additional Information in Response to Question 10.

The use of the separator model is within the approved range of application. The limitations stated in the RETRAN SER are not applicable to any of the transients analyzed for the following reasons:

- The default carryover/carryunder tables were not used in any other transient or the startup tests. A constant carryunder was used throughout (0.1% for startup and 0.2% for reload transients). This is a justified approach because the transit time from the separator to the core through the downcomer is approximately 30 seconds under forced circulation and any change in carryunder will not be felt by the core until the transient is well over (8 sec. transients).

- The flow time through the separator is 0.225 sec. which is within the steady state flow times indicated by the SER (few tenths of a second) as the approved region.

- No reversed flow through separator inlet or recirculation junctions is encountered during any of these transients, hence SER restrictions under reverse flow conditions do not apply.

- SER restrictions on pressure wave attenuation at low flow/low quality conditions do not impact the CPR calculation in any of the reload transients analyzed because low quality is obtained when core power has already decayed and low flow is achieved when the recirculation pumps have coasted down; both conditions take place when the transients are over and finished. Even at that time, there is no impact on the pressure wave which was already over.

Additional Information in Response to Question 12.

It was quite possible to obtain better coastdown curve, which we did first, but the system inertia had to be adjusted in order to get the correct initial drop in flow immediately after the trip. This resulted in an inertia value which was quite different from the vendor's supplied data (40% more). It was our position that it is more appropriate to use the vendor's documented inertia (design value) which results in a conservative response for ΔCPR. This can be shown by the following argument. In the TTWOP and FWCF, peak power occurs prior to the recirc pump trip while peak heat flux will occur after the trip (see Figure 12.1). At the time of peak heat flux, the recirc flow would be less with the faster coastdown and hence a lower CPR. The same would be true for a transient such as a 5 recirculation pump flow. While a faster coastdown would give a faster power decrease, the heat transfer time constant is such that the heat flux would not decay as rapidly as the recirculation flow. This would result in a higher power and lower flow (higher ΔCPR) with a more rapid coastdown than with a slower coastdown.

The use of the non-equilibrium option is limited to pressurization transients only and the pump trip test involved a pressure and power decrease due to pump coastdown and hence this option is usually turned off. During depressurization the code is supposed to switch the calculation scheme in the upper downcomer, where this model is used, to the thermal equilibrium mode when vapor and liquid regions temperatures are equal. However, the RETRAN code cannot do that efficiently and although the code does not fail, it does not produce acceptable response when compared to plant data. This is a known behavior to RETRAN users. Switching this model off in transients where non-equilibrium effects are not present is necessary to correctly calculate the conditions in the upper downcomer. This was evident when the non-equilibrium model was used in the pump trip transient and the resulting incorrect model behavior was observed.

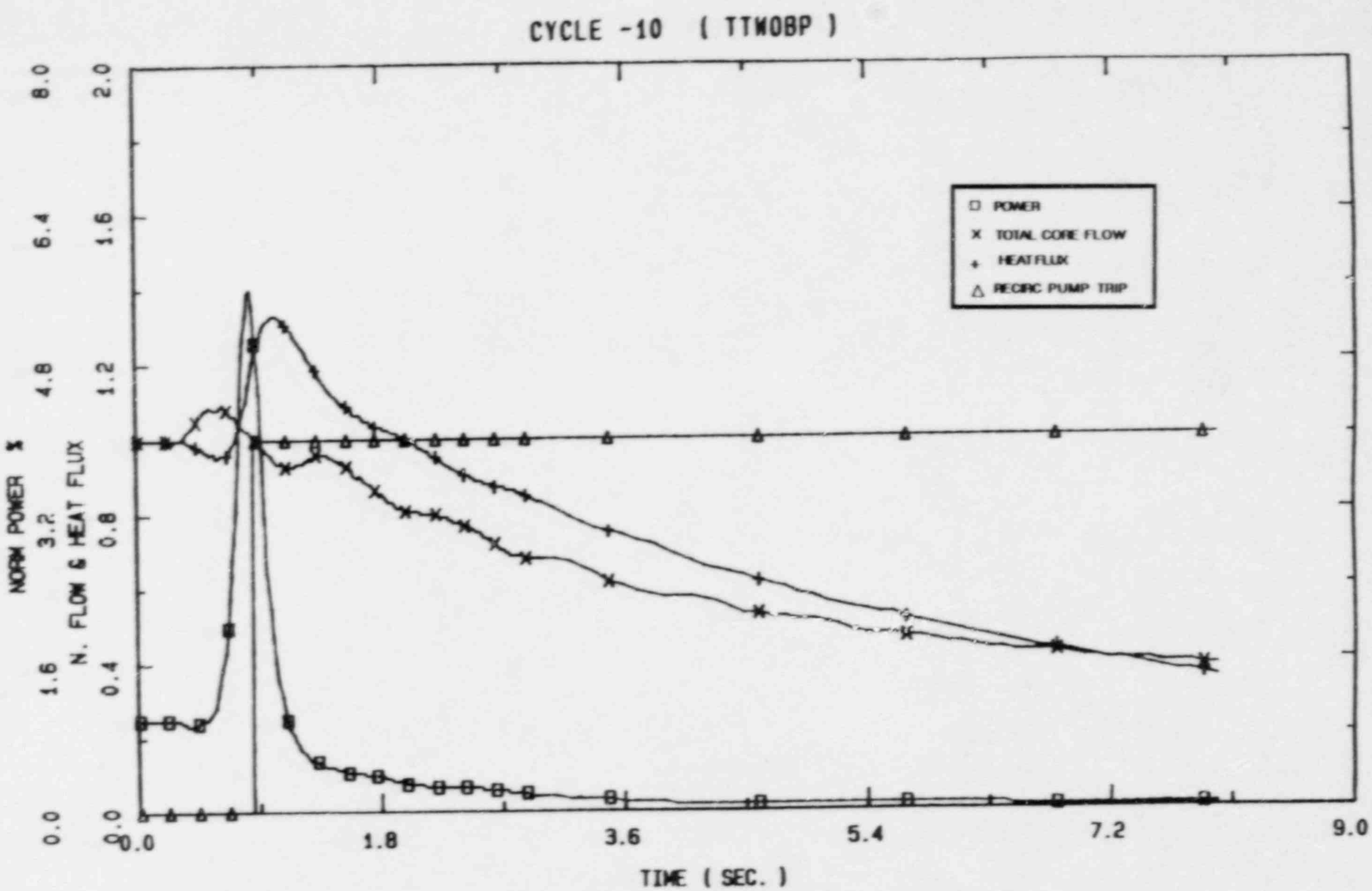

CYCLE -10 (TTWOBP)
NORM POWER %
N. FLOW & HEAT FLUX
0.0
1.6
3.2
4.8
6.4
8.0
0.0
0.4
0.8
1.2
1.6
2.0
POWER
TOTAL CORE FLOW
HEAT FLUX
RECIRC PUMP TRIP
0.0
1.8
3.6
5.4
7.2
9.0
TIME (SEC.)

Figure 12.1

Additional Information in Response to Question 13.

This test was basically a qualitative test to show our overall model works well; especially the cross-section polynomial void distribution, controllers, etc.. This was an integrated test and no benchmarking was carried out as a result of this test, i.e., nothing in the model was adjusted or changed. Its inclusion in the report is to give an overall picture and it has no impact on any of the reload transient.

Additional Information in Response to Questions 15 and 21.

The statistical analysis was based on a review of the inputs that would impact the results of the transient for each of the following systems; steam lines, vessel and core. For example, in the steam lines, the RETRAN parameters that influence pressure wave propagation are volume, inertia and pressure drop. The first two are dictated by length and flow area. While the latter by frictional losses which are dependent on steam line contours. Then the source of uncertainty in calculating these parameters were evaluated and an uncertainty was assigned which would be bounding. For the steam line, the flow area and length are well known and a smaller value would bound the uncertainty. For the steam dome, where vessel internals complicate the calculation of the volume, a larger uncertainty was used. In the case of steam line ΔP where measured data is available, the uncertainty in the loss coefficients covers the uncertainty in the measurement. This process was repeated for the vessel and the core. For the case where an input value was known to be conservative, such as the separator inertia, the uncertainty was not included in the model uncertainty.

The review did not include uncertainties for input variables to code correlations. A further review shows that the drift flux and heat transfer correlations require input. A sensitivity analysis has been conducted and an additional ΔRCPR of 0.0244 will be added to the values shown in Table 4.4. This would increase the overall uncertainty on page 98 of TR-045 from 0.042 to 0.049. The details of the uncertainties considered are shown in Table 15.1.

TABLE 15.1

RETRAN Correlation Uncertainties

* Drift flux equation VII-27 on page VII-30 of RETRAN theory manual:

parameter	range	ΔRCPR
Kappa 1 (Default = 0.8) Calculation of C_o	±0.2	0.0235
CGL (Default = 1.41) Calculation of V_{gj}	±30%	0.0038

* Heat Transfer Correlations on page VII-29a

C_D (Dittus-Boelter) Input value = 0.032	±20%	-0.0046
C_A (Hancock-Nicoll) Input value = 0.106	±20%	-0.0030
	TOTAL*	0.0244

* Values statistically combined as shown on page 98 of TR-045.

Additional Information for Question 16.

The impact of the separator mixture level on the course of the TTWOBP transient was found to be negligible (TR-045, page 86). This is primarily because the transit time from the separator recirculation junction to core entrance through the downcomer and recirculation loops is much higher than transient time and any change in coolant properties will not be felt by the core until the transient is over. This conclusion is also applicable to the MSIV ATWS transient (8 sec. duration) and the FWCF transient which is effectively a turbine trip with bypass with 8 sec. duration and, therefore, sensitivity of the separator inventory need not be revisited for each transient.

Additional Information in Response to Question 17.

A sensitivity study was carried out on courant limits of 0.2 and 0.1 for the limiting TTWOBP transient at the maximum time step size of 0.002 sec. There were no changes seen in any of the parameters calculated, including CPR, power, heat flux, flows, levels, pressures, etc. It is, therefore, concluded that the default courant limit with 0.002 sec. max. time step gives a converged numerical solution. The RVS are sized according to certified capacity at reference pressure.

The comparison of ODYN and RETRAN results are primarily to show the conservative ΔCPR calculated with RETRAN with respect to previous licensing calculations (ODYN).

Additional Information to Question 20.

The nodalization scheme adopted for Oyster Creek was based on the following consideration:

1. Steam Lines: The important phenomena to be captured in the steam line model during a pressurization transient is the proper tracking of pressure wave propagation as it reaches the steam dome and the core where it will collapse the void and generate a power spike before scram reactivity effects dominate the transient. The work done by EPRI on the RETRAN simulation of Peach Bottom Tests (Ref. 2 of TR-045) showed that a 6 node line is an adequate representation for pressurization transients; in addition Yankee Atomic (Ref. 13 of TR-045) showed any number of nodes beyond 6 will not significantly change the results. TVA (Ref. 14) and GE (Ref. 11 of TR-045) showed the same conclusions using different codes (RETRAN for TVA and ODYN for GE). The important parameter in deciding the noding pattern and nodes boundaries is the length per node and the proximity of the node to valves which will be actuated during the transient. Based on the above considerations, an 8 node steam line was used for Oyster Creek which has a length of approximately 240 feet as compared to 460 feet for Peach Bottom resulting in a more detailed scheme. In addition, a nodalization sensitivity analysis has been done for 6 and 16 nodes with negligible effects on the TTWOBP, MSIV ATWS and FWCF. The impact on the CPR is shown in Table 20.1, thus confirming our original choice.

2. Core: EPRI and TVA (cited above) showed that 12 hydraulic nodes are quite adequate to capture axial void distribution and subsequent void collapse in pressurization transient. Oyster Creek's choice of 12 hydraulic and 24 neutronic nodes is believed to be quite adequate and in addition, 24 hydraulic nodes were done showing that 12 nodes give more conservative results as seen in the attached table. All three transients (TTWOBP, MSIV ATWS and FWCF) were run with the 24 hydraulic and neutronic nodes. GPUN will be using the more conservative 12 hydraulic and 24 neutronic nodes for the reload transients.

3. Vessel: As the pressure wave reaches the steam dome, it has two paths to reach the core; namely, through the separators, standpipes, upper plenum, and through the downcomer, recirc. loop, lower plenum, i.e., part of the wave will reach through the top of the core while the other through the bottom. It is, therefore, apparent that the entry points to the two paths, i.e., separators for path 1 and upper downcomer for path 2 become important. They represent the coupling regions between the core and the steam dome. What is important about these two regions is that they should represent the pressure wave transfer from a pure steam environment in the dome to the mostly liquid region in the downcomer and the two phase mixture in the separators as realistically as possible especially through the steam/fluid interfaces in the above two regions. When the pressure wave reaches the interfaces (mixture levels in both regions), the

steam region immediately above the interface will be compressed against the fluid boundary causing its pressure (and temperature) to increase relative to the fluid, i.e., the existing thermal equilibrium between the two regions will disappear and a non-equilibrium (thermal) will be generated. This increase in pressure, due to the steam compression, will propagate to the core producing a greater void collapse and a higher power generation. The normal RETRAN equations (HEM, Algebraic Slip and Dynamic Slip) should not be used for these regions because they model only thermal equilibrium states and if used, will force the steam to have the same temperature (and pressure) as the fluid at the interface and the compression effect will not be captured. The impact, obviously, will be a less effective pressure wave reaching the core which will not collapse as much voids as before causing less power to be produced which is unrealistic and a non-conservative approach. From the above discussion, it is clear that a model which captures the non-equilibrium effect is required in those regions and this is available as a special model (non-equilibrium pressurizer) in RETRAN to be activated at selected regions (volumes) of the model. In order to show that the above arguments are correct, the above two regions (separators and upper downcomer) were modeled using the normal RETRAN equations (i.e., equilibrium) and using the non-equilibrium pressurizer for both regions and a combination of them, i.e., one region using equilibrium while the second using the non-equilibrium. The conclusion reached was the use of the non-equilibrium for both regions gives a more realistic response (as expected), a TTWOBP transient was used for this purpose. Once this is decided, the second issue was, is the RETRAN functional separator model, which uses the non-equilibrium model also required? This model can force, at user option, pure steam out of the separator steam junction, i.e., no carryover thus representing the steam dryers which are not explicitly modeled. This is a needed function and because the non-equilibrium option by itself does not guarantee pure steam, since it is based on mostly vapor and mostly liquid regions concept, the use of the functional separator is required. The result of the sensitivity work done at GPUN showed that the use of the functional separator model for the separators and the non-equilibrium model for the upper downcomer are the best options that produce the most realistic results. The following two nodalization schemes and model options were used:

a. Separators and upper downcomer combined in one volume.

Options Used

* Normal RETRAN solution using the equilibrium bubble rise model.

* Non-equilibrium pressurizer model.

b. Separator and upper downcomer as two separate values.

Options Used

- Normal RETRAN solution using the equilibrium bubble rise model in both volumes.
- Same as above with non-equilibrium pressurizer model in separator.
- Non-equilibrium pressurizer in both volumes.
- Functional separator model in separator and non-equilibrium pressurizer in upper downcomer.

The use of multi-nodes in the upper downcomer with the non-equilibrium option is not possible in RETRAN because of the "Pancake" effect, i.e., stacking of separated volumes. The use of the algebraic slip (as opposed to bubble rise separated volume) with multi-nodes is not recommended because the non-equilibrium effects will not be captured as explained above. The non-equilibrium effect due to subcooled voids in the core is not captured via the algebraic slip hydraulic equations, but rather through the subcooled void profile fit correlation which generates "neutronic voids" and not actual steam bubbles.

In addition to the above study, volumes 103 and 104 have been combined into one volume and negligible effects were seen on ΔRCPR as shown in Table 5.1

In conclusion, GPUN's choice of vessel nodalization and code options combination gives the more realistic response using the RETRAN-02 code.

4. Recirculation Loops: The number of nodes were doubled, from 2 to 4 (plus pump) with little effect (see Table 20.1).

Table 20.1

RETRAN Nodalization Study

	ΔRCPR TTWOBP	ΔRCPR FWCF
Steam Lines (Base = 8 Nodes)		
6 Nodes	-0.0045	-0.0038
16 Nodes	+0.0022	+0.0023
Recirculation Loop (Base = 3 Nodes)		
5 Nodes	-0.0038	-0.0038
Reactor Vessel		
Dryer-Dome Combined (V103 + V104)	-0.003	-0.005
Core (Base = 12 Nodes)		
24 Nodes	-0.0098	-0.0038