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THE B&W OWNERS GROUP

Transient Assessment Program

BASIS FOR RAISING ARMING THRESHOLD FOR ANTICIPATORY REACTOR TRIP ON TURBINE TRIP

Babcock & Wilcox
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1. Background

Prior to the TMI-2 accident, B&W plants responded to a turbine trip by initiating a plant runback. Successful runbacks from power levels as high as 100% were demonstrated for some B&W plants. After TMI-2, the NRC required that B&W plants implement an automatic reactor trip on turbine trip for the purpose of reducing challenges to the PORV. This Anticipatory Reactor Trip (ART) was installed in all B&W plants and set to function for power levels above 20%. This value was selected because it was anticipated that with a high pressure trip setpoint of 2300 psig and PORV setpoint of 2450 psig, runbacks attempted from higher initial power levels would result in reactor trips on high pressure.

A consequence of implementing the turbine trip ART is that all turbine trips which occur at initial power levels above 20% now result in reactor trips. The B&W Owners Group Transient Assessment Program (TAP) records show that during the period January 1, 1980 through January 1, 1985, anticipatory trips due to turbine trips occurred 52 times. Twelve of these trips occurred with the initial reactor power at or below 40% (see Figure 1-1). Operating experience and a recent study addressing the setpoint for reactor trip on high pressure (reference 1) indicate that tripping the reactor for all turbine trips which occur at power levels greater than 20 percent results in unnecessary challenges to plant safety systems. These challenges are considered unnecessary because:

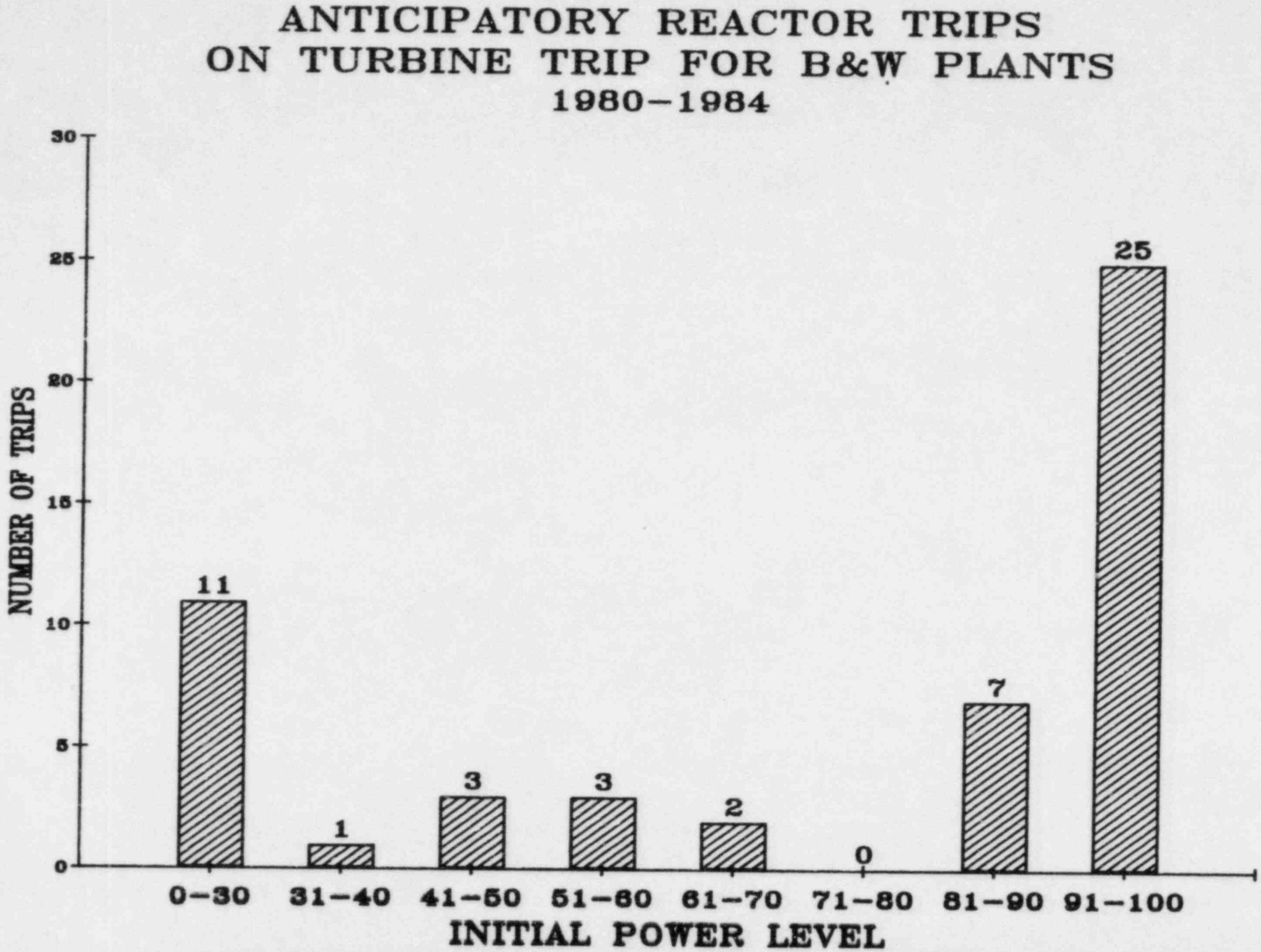
1. It is possible for B&W plants to accommodate a turbine trip from some power levels higher than 20 percent without a reactor trip on high pressure. Therefore, tripping the

reactor for those turbine trips which would not otherwise cause a reactor trip results in unnecessary challenges to safety systems.

2. The probability of opening the PORV as a consequence of a turbine trip from any power level is very small whether the ART is implemented or not. Therefore, tripping the reactor on every turbine trip for the purpose of reducing challenges to the PORV is unnecessary.

The B&WOG is committed to reducing reactor trips for the purpose of improving plant availability and safety. Raising the arming threshold for the turbine trip ART to a power level consistent with a plant's runback capability would result in fewer reactor trips. For this reason, the B&WOG initiated this study to determine the initial power level from which a successful runback on turbine trip could be accomplished.

Figure 1-1.


ANTICIPATORY REACTOR TRIPS
ON TURBINE TRIP FOR B&W PLANTS
1980–1984
NUMBER OF TRIPS
30
25
20
15
10
5
0
11
1
3
3
2
0
7
25
0–30
31–40
41–50
51–60
61–70
71–80
81–90
91–100
INITIAL POWER LEVEL

2. POTENTIAL BENEFITS

As noted in the previous section, raising the arming threshold for the turbine trip ART to a power level consistent with a plant's runback capability would result in a reduction in reactor trips. Section five of this report discusses the potential reduction in reactor trips which could be achieved. Based on assumptions of an ART arming threshold of 45 percent power and turbine trip frequency similar to previous years (1980-84), it is estimated that a reduction of .24 trips per reactor year could be achieved. This represents a reduction in average trip frequency for B&W plants of approximately five percent when compared to the 1980-84 average of 5.3 trips per reactor year.

3. ANALYSIS

3.1. Analysis Objectives

The primary purpose of this generic study was to determine an upper limit for initial power level from which a successful plant runback on turbine trip could be accomplished. The analysis was performed using the digital code POWER TRAIN configured to model a plant closely resembling Rancho Seco. In addition to investigating different power levels, cases were run with changes in various plant parameters. The objectives of this parameterization effort were to:

a. Determine which plant parameters are vital to a successful runback

b. Provide guidance relative to potential modifications which could enhance successful runback probability

c. Develop guidance for plant specific application of the results

3.2. Performance Criteria

The following criteria were established to define a successful runback on turbine trip:

Desired Performance	Limiting Parameter for runback transient
No reactor trip	High RC pressure
No AFW actuation	Low Steam Generator level
No OTSG overfill	Steam Quality
No loss of subcooled margin	RC pressure and temperature

3.3. Analysis Summary Description

A number of cases were investigated to predict maximum RC pressure during a turbine trip with reactor runback using the POWER TRAIN code. The parameters varied for these cases were:

a. Total bypass steam flow

b. Moderator coefficient (a function of burnup)

c. Initial power level

d. Runback rate

e. Pressurizer spray flow rate.

The cases analyzed are identified in Table 3-1. In all cases, the transient analyzed was a turbine trip with runback. Case numbers six and seven demonstrate the effect of variation in total bypass steam flow. Case number seven was also used to investigate the effect of ICS runback rate. Case numbers five and six demonstrate the effect of moderator coefficient. Case numbers one and two show the effect of initial power level. Case numbers three and four were run to investigate the effect of pressurizer spray.

3.4. Analysis Results

3.4.1. Total Bypass Flow

For this analysis, total bypass flow was defined as the sum of flow through all the open steam paths available prior to reaching the high pressure trip setpoint. Total bypass flow for the 2300 psig trip setpoint condition was the sum of turbine bypass plus atmospheric vent flow. When the RCS pressure was allowed to increase above 2300 psig (up to 2355 psig), steam pressure rose above 1050 psig and at least one bank of Main Steam Safety Valves (MSSVs) was open. Thus, at a 2355 psig trip setpoint, total bypass flow included at least one bank of MSSVs in addition to the turbine bypass and atmospheric vents.

The analysis showed that total bypass flow was one of the dominating parameters affecting successful runback. A typical RC pressure profile for the runback transient shows that pressure levels out and begins to decrease when the percent core thermal power is approximately equal to the total percent bypass flow. (See Figure 3-1). Thus,the higher the bypass flow prior to reaching the high pressure trip setpoint the higher the initial power level that can be tolerated.

For the cases analyzed, when the RCS pressure reached 2300 psig, the total rated bypass flow* was 15% (or 25%).** To avoid a high pressure trip at a 2300 psig trip setpoint, thermal power had to decrease to a value corresponding to the actual bypass flow before 2300 psig was reached. At a 2355 psig trip setpoint the total bypass included an additional 28% flow due to the opening of the first bank of MSSVs. This allowed for a much higher power level for a successful runback.

In this analysis, when the core thermal power decreased to a value corresponding to this total bypass (i.e., ~43% or ~53%) prior to reaching a 2355 psig RCS pressure, a sufficient primary to secondary heat balance existed and the RC pressure stopped increasing. Should a second bank of MSSVs open before a 2355 psig RCS pressure is reached, a higher initial power runback could be tolerated. In fact, any increase in bypass steam flow would increase the allowable initial power level.

Case numbers six and seven were analyzed to support the above conclusions. Case number six (59% power, 43%) resulted in a successful runback (at a 2355 psig setpoint) with RC pressure approaching 2350 psig about the same time the thermal power decreased below 46%. Case number seven was run to confirm that increasing the bypass flow would allow a higher initial power level. In case number seven, both the initial power level and bypass flow were increased by approximately 10%. The results for case numbers six and seven were similar, with RC pressure in

- - - - -

*Rated bypass flow is based on 900 psig. At higher steam pressure the actual bypass flow will be somewhat higher.

**Cases were run at 25% bypass since some B&W plants have 25% turbine bypass capacity.

both cases starting to decrease when the core thermal power and total bypass flow were approximately equal. Figure 3-2 shows a comparison of the RC pressure responses for case numbers six and seven.

3.4.2. Moderator Coefficient

As discussed in section 3.4.1, a successful runback requires that the percent core thermal power be reduced to the equivalent bypass capacity prior to reaching the high pressure trip setpoint. The reduction in core power is accomplished by negative reactivity insertion due to control rod movement and moderator temperature increase. The more negative the moderator temperature coefficient (as burnup increases) the faster the core thermal power decreases. Thus, for the same control rod insertion rate, a more rapid core thermal power decrease will occur at core End of Cycle (EOC), than at Beginning of Cycle (BOC).

Case numbers five and six illustrate the effect of moderator temperature coefficient. In case number six (EOC) thermal power decreased to 45% in the same time that thermal power decreased to 50% for case number five (MOC). The difference was enough to result in a high pressure trip (at 2355 psig) in case number five but not in case number six (EOC). Figure 3-3 compares the RC pressure response for case numbers five and six.

3.4.3. Initial Power Level

Initial power level was treated as an independent variable in the bypass capacity and moderator temperature coefficient discussions (sections 3.4.1 and 3.4.2). To confirm the conclusions drawn from those four cases, two additional cases were analyzed at lower power levels (case numbers one and two). Case number one (30% power, 15% turbine bypass, BOC) resulted in a peak RC pressure of 2256 psig. Thus, a successful runback was achieved without reaching the 2300 psig high pressure trip setpoint. It should be noted that the first bank of MSSVs did not open for this transient. Case number two (40% power, 15%

turbine bypass, BOC) resulted in a peak RC pressure of 2335 psig. Thus, a successful runback would not have been achieved at the 2300 psig trip setpoint but was achieved at a 2355 psig setpoint. The first bank of MSSVs did open for case number two demonstrating that as initial power is increased, more total bypass capacity is required to achieve a successful runback. Figure 3-4 compares the RC pressure responses for case numbers one and two.

3.4.4. ICS Runback Rate

This study included an effort to determine whether changes in Integrated Control System (ICS) runback rates could enhance the probability of successful runbacks.

In all cases analyzed, a maximum rod insertion rate was observed within a few seconds after the turbine trip and continued for 30 to 40 seconds. This rod movement started when the ICS put the unit into track (20% per minute runback rate) and continued (regardless of the power level) due to the ICS response to the increase in core average temperature (T_{ave}). Continuous rod insertion was observed for all cases until the core T_{ave} returned to the 582° setpoint, which was at least 30 to 40 seconds into the transients. Since the maximum transient RC pressure occurred well with in this time frame, it follows that an increased runback rate should not affect the peak RC pressure. Case number eight was analyzed to confirm this. When the runback rate was increased to 50% per minute the overall rod insertion rate did not change (in the first 30 seconds) and consequently the rate of core thermal power decrease did not change. Thus, increasing the ICS runback above 20% per minute would not improve the probability for a successful runback.

3.4.5. Pressurizer Spray

The influence of pressurizer spray on the runback transient was investigated to determine whether changes in spray flow or setpoint could contribute to successful runback.

Case numbers three and four were run to show the effect of a variation in pressurizer spray flow. The expected spray flow (of 191 gpm) was arbitrarily doubled in case number four to 382 gpm. Both cases reached 2275 psig RCS pressure at the same time (about eight seconds into the transient) indicating that the doubled spray had not yet affected the RCS pressure significantly. Case number three reached a 2327 psig pressure at 15 seconds into the transient. The same time in case number four (double spray flow) predicted a 2316 psig pressure. These results suggest that increasing the pressurizer spray flow would not significantly enhance the probability of a successful runback. This comparison is shown on Figure 3-5.

The pressurizer spray is initiated at 2200 psig RCS pressure which occurs about three seconds into the transient. Should this setpoint be reduced, the spray would come on one or two seconds sooner. Based on the previous results, this additional spray time would have an insignificant effect on the peak transient pressures.

Table 3-1. Tabulation of Power Train Cases

Case No	Burnup	Max. Pressurizer Spray flow (gpm)	Bypass Flow %	MSSV Flow (1st Bank) %	Runback Rate %/min	Initial Power %
1	BOC	191	15%	28%	20	30
2	BOC	191	15%	28%	20	40
3	EOC	191	15%	28%	20	40
4	EOC	382	15%	28%	20	40
5	MOC (100) EFPD	191	15%	28%	20	59
6	EOC	191	15%	28%	20	59
7	EOC	191	25%	28%	50	70

Figure 3-1.

POWERTRAIN RESULTS
TURBINE TRIP WITH RUNBACK
CASE #6 (15%BYPASS,59%POWER,EOC)

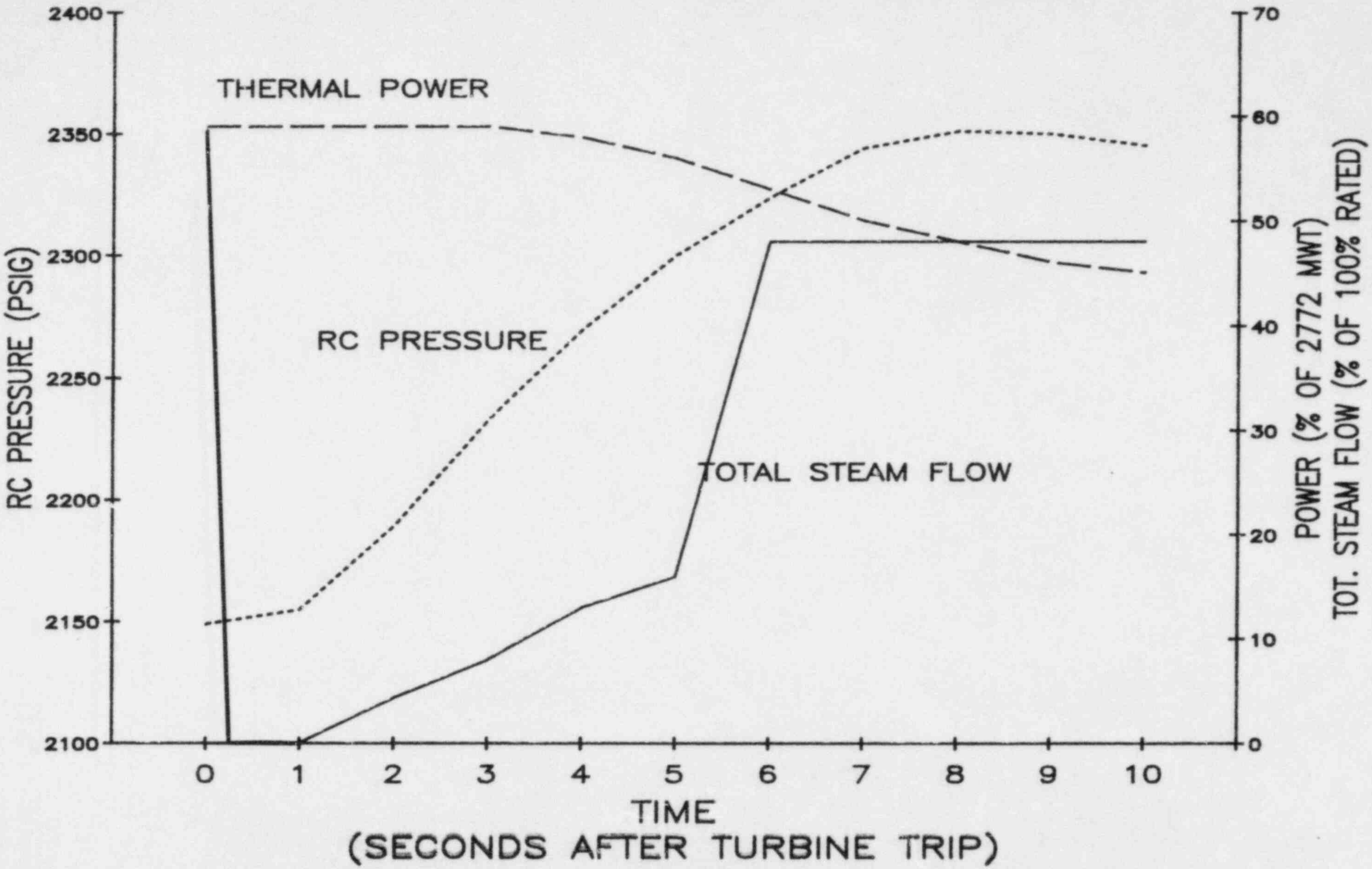
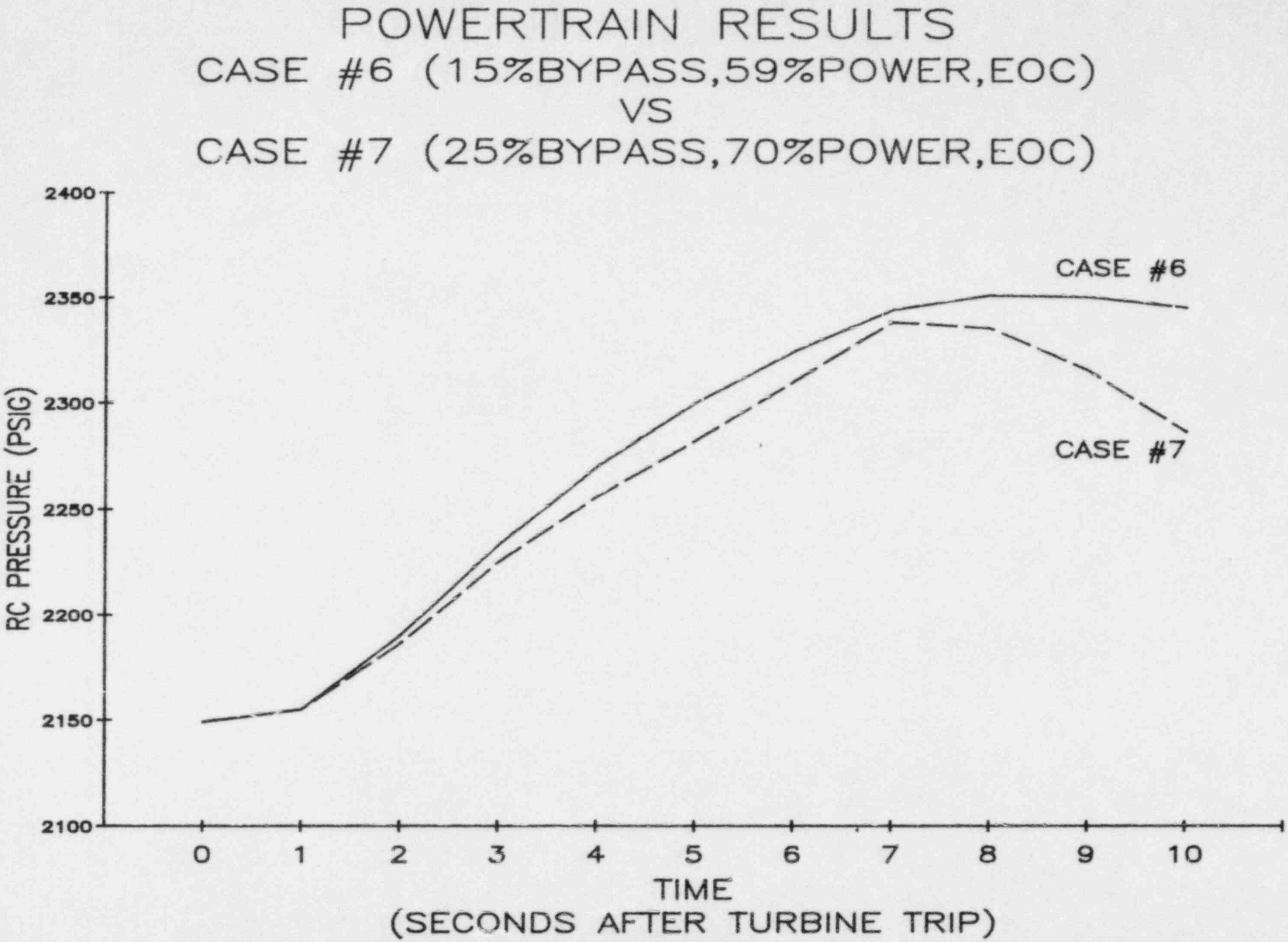


Figure 3-2.



POWERTRAIN RESULTS
CASE #6 (15%BYPASS,59%POWER,EOC)
VS
CASE #7 (25%BYPASS,70%POWER,EOC)
RC PRESSURE (PSIG)
2400
2350
2300
2250
2200
2150
2100
CASE #6
CASE #7
0
1
2
3
4
5
6
7
8
9
10
TIME
(SECONDS AFTER TURBINE TRIP)

Figure 3-3.

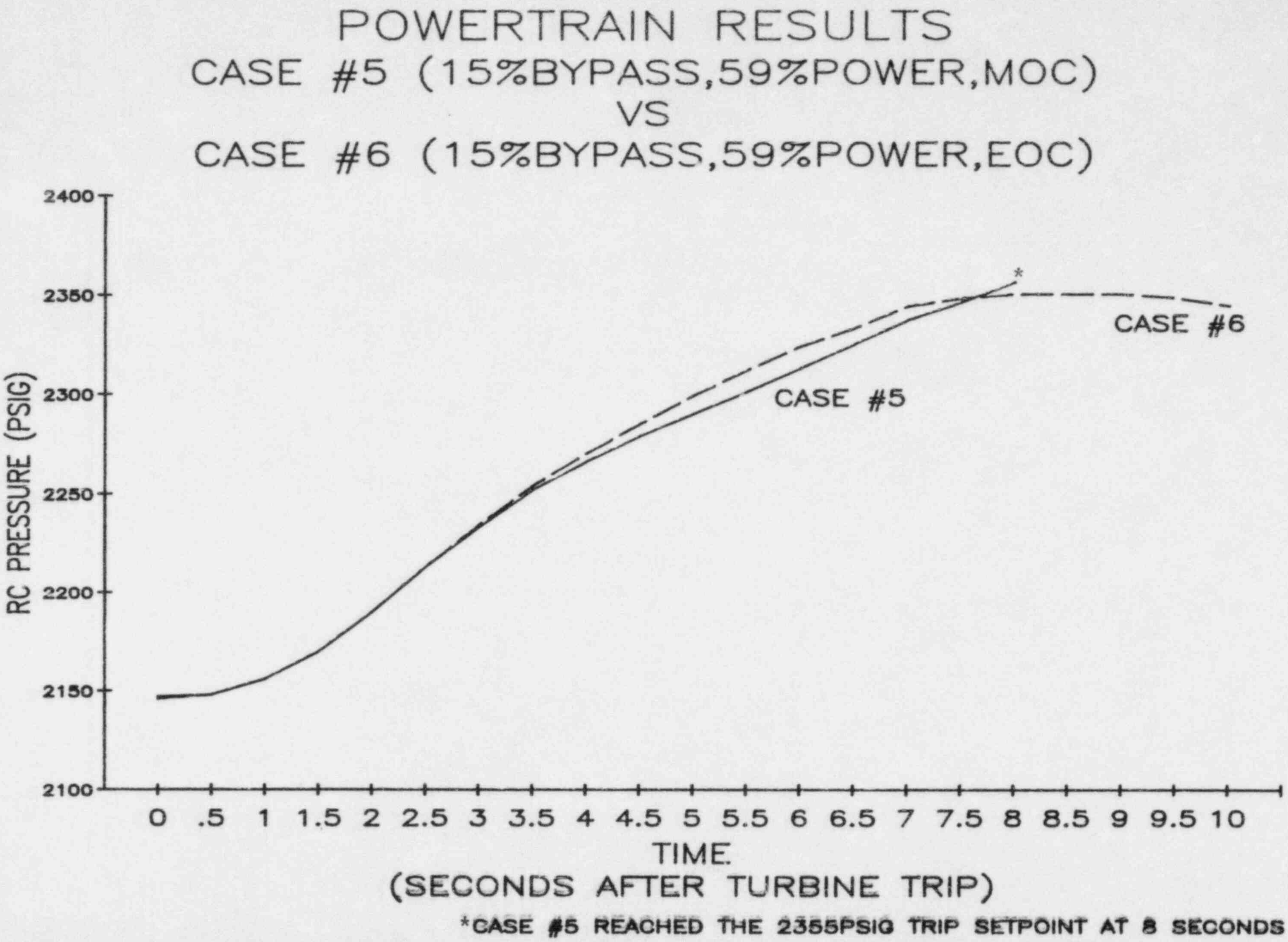

POWERTRAIN RESULTS
CASE #5 (15%BYPASS,59%POWER,MOC)
VS
CASE #6 (15%BYPASS,59%POWER,EOC)
RC PRESSURE (PSIG)
2400
2350
2300
2250
2200
2150
2100
CASE #6
CASE #5
*
0 .5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
TIME
(SECONDS AFTER TURBINE TRIP)
*CASE #5 REACHED THE 2355PSIG TRIP SETPOINT AT 8 SECONDS

Figure 3-4.

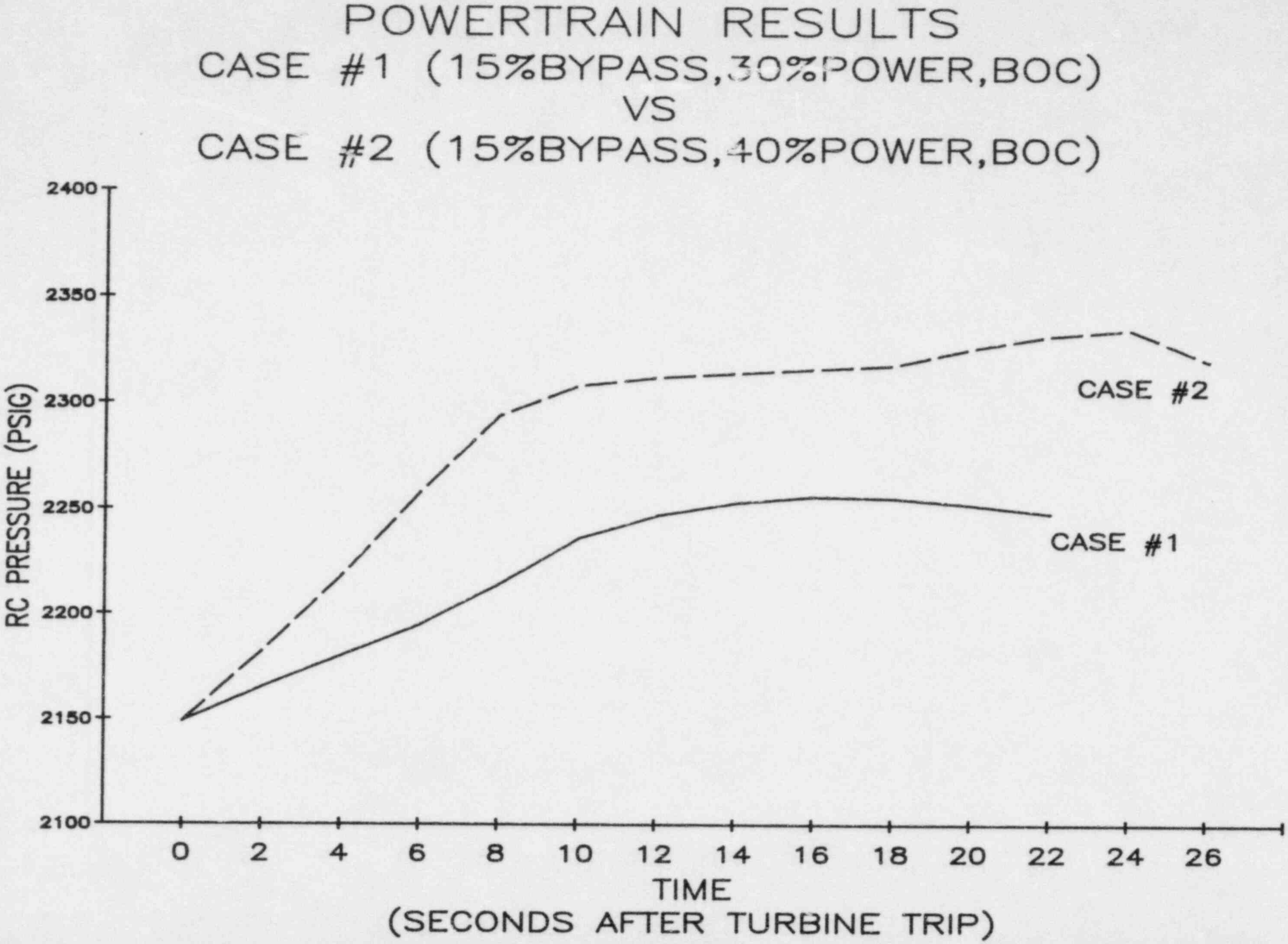
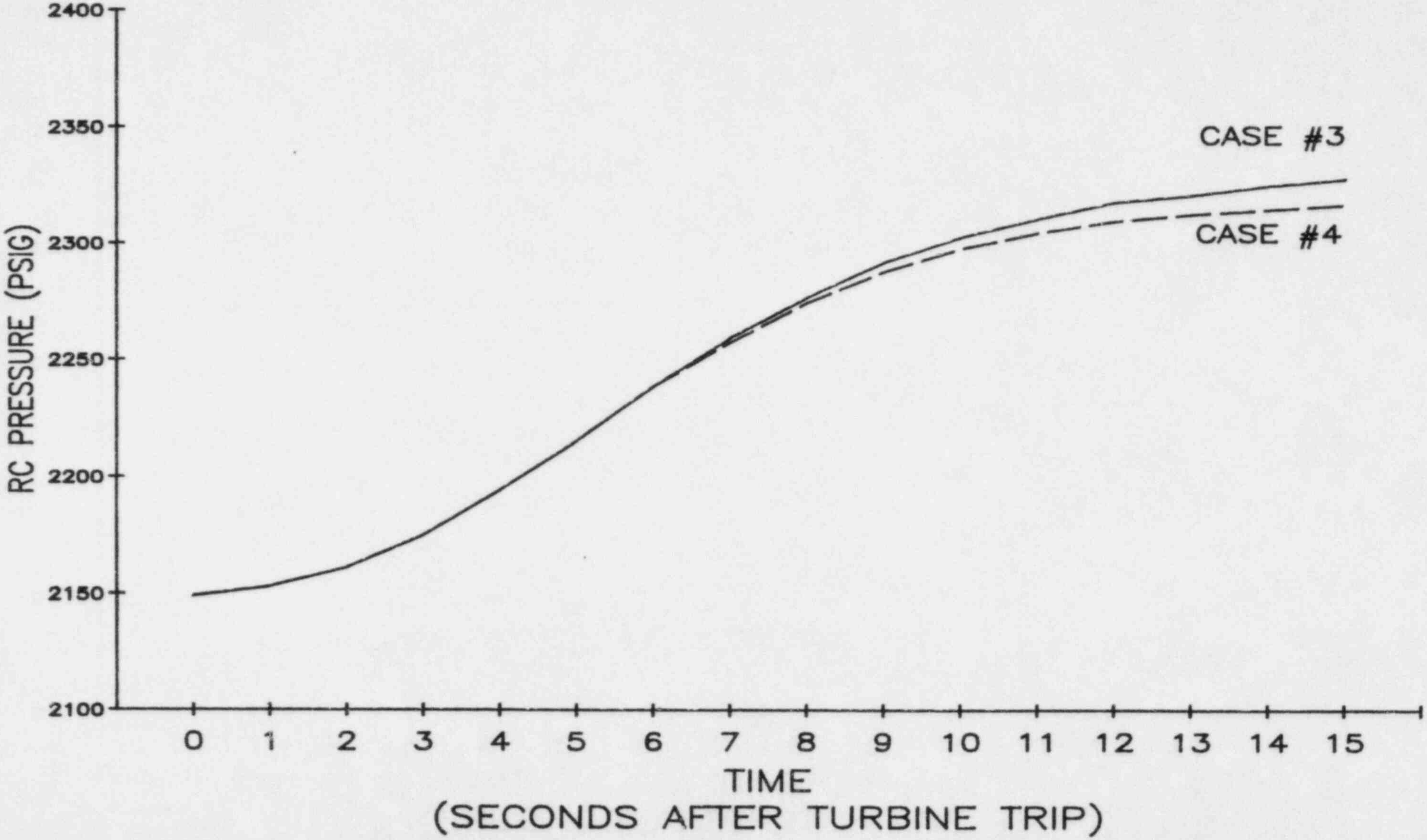

POWERTRAIN RESULTS
CASE #1 (15%BYPASS,30%POWER,BOC)
VS
CASE #2 (15%BYPASS,40%POWER,BOC)
RC PRESSURE (PSIG)
2400
2350
2300
2250
2200
2150
2100
CASE #2
CASE #1
0
2
4
6
8
10
12
14
16
18
20
22
24
26
TIME
(SECONDS AFTER TURBINE TRIP)

Figure 3-5.

POWERTRAIN RESULTS

CASE #3 (15%BP,40%PWR,191GPM PZR SPRAY)
VS
CASE #4 (15%BP,40%PWR,382GPM PZR SPRAY)



4. CONCLUSIONS FROM ANALYSIS

The power level from which a turbine trip can be followed by a successful reactor runback can be raised from its present level (20% power) to a higher power. This maximum power level from which a plant can successfully runback (without a high RC pressure trip and without the use of the PORV) varies for each plant depending on four plant parameters. These parameters are:

a. Total steam bypass capacity (including turbine bypass and atmospheric dumps)

b. Main steam safety valve (MSSV) setpoints and flow rates.

c. RPS high pressure trip setpoint

d. Moderator coefficient (burn-up)

In general, all B&W 177 FA plants should be capable of a successful turbine trip runback from 45% power at BOC (assuming a 2355 psig high pressure trip setpoint). This is based on all plants having at least 40% total bypass capacity and an approximately 5% power reduction prior to reaching the trip setpoint. At the current 2300 psig high pressure trip setpoint, all plants should be capable of a successful turbine trip runback from 30% power at BOC. This is based on analysis predictions showing successful runback from 30% power with 15% turbine bypass and no MSSVs opening. Any additional flow capabilities (in turbine bypass or MSSVs) will allow a higher initial power level for successful runback. This is discussed further in section 5.2.

The ICS controlled runback rate has little effect on this transient. This is because the maximum RC pressure occurs typically within 10 to 15 seconds. During this period the moderator coefficient dominates the core power decrease and core T_{ave}

dominates rod movement. These two effects override any "demand" from the ULD runback rate in the first 30 to 40 seconds.

Increasing the pressurizer spray flow rate or reducing the spray setpoint will have no effect on the peak RC pressure with a 2300 psig high pressure trip setpoint and only a very small effect (10 psi) assuming a 2355 psig setpoint.

5. APPLICATION OF RESULTS

5.1. Plant Specific Application

This study concluded that, for a given time in core life (moderator coefficient), the maximum initial power level for successful runback is constrained mainly by the total bypass flow available. It is important to note that only the flow that occurs prior to reaching the high pressure trip setpoint will affect the runback. This will include the flow through turbine bypass valves, atmospheric dump valves, and at least the first bank of MSSVs at a 2355 psig trip setpoint.

The total bypass flow available prior to trip is a plant specific parameter dependent on the configuration of turbine bypass, atmospheric dump and main steam safety valves (number, capacity and setpoints) and the main steam line volume. Tables 5-1 and 5-2 show the various bypass capacities and MSSV arrangements for B&W plants. The information in these tables indicates that the maximum initial power level from which a successful runback could be achieved will not be the same fcr all plants.

Table 5-3 is a compilation of the total bypass capacity available (prior to reaching a high pressure trip setpoint of 2355 psig) for all B&W plants.

Table 5-4 shows the estimated initial power levels for successful runback on turbine trip for each plant. These initial power levels are based on the total bypass capacities for the turbine bypass and MSSVs as shown in Table 5-3 and an approximately 5% power reduction prior to reaching the 2355 psig trip setpoint. These estimates are considered conservative in that no credit is taken for:

1. Bypass flow through the atmospheric dump valves
2. Power reduction due to moderator coefficient

5.2. Analysis Limitations

The analysis on which the conclusions of this study are based was performed using a model representing a typical B&W plant (similar to Rancho Seco). It is recognized that differences between the model and actual plants may exist (in addition to total bypass flow) which could cause plant performance to differ from analysis predictions. Examples of such differences are ICS tuning, feedwater pump speed response and feedwater valve response. Because of such differences, successful runbacks from initial power levels shown in Table 5-4 may not be achieved for every turbine trip. The consequence of an unsuccessful runback is a reactor trip on high pressure.

We believe that the possibility of unsuccessful runback for some turbine trips which could result if the turbine ART arming threshold were raised as described above is warranted for the following reasons:

a. The probability of opening the PORV would not be significantly increased. The turbine ART was implemented for the purpose of reducing challenges to the PORV. For successful runbacks, no challenge to the PORV would occur. For unsuccessful runbacks, a high pressure reactor trip would occur. Reference 1 showed that the probability of opening the PORV on a high pressure trip was small ($\sim 10^{-5}$ per event). Unsuccessful runbacks would result in an increased number of high pressure trips but no significant change in probability of opening the PORV. For example:

   Assuming that turbine trip frequency remains at 1980-84 levels (Figure 1-1), the ART arming point is set at 45% power, and 30% of the runbacks are unsuccessful, the average number of high pressure trips/reactor year due to this cause would be:

$$\frac{12 \text{ Turbine Trips* } \times .30}{5 \text{ years} \times 7 \text{ reactors}} = 0.10 \ \frac{\text{High Pressure Trips}}{\text{reactor year}}$$

This would increase the high pressure trip frequency average from 1.86/reactor year (reference 1) to (1.86 + .10) = 1.96 trip/ reactor year. PORV opening probability would change from:

$$\left(1.86 \ \frac{\text{Trips}}{\text{Reactor Year}}\right) \times \left(10^{-5} \ \frac{\text{Opening}}{\text{Trip}}\right) = 1.86\text{x}10^{-5}$$

to:

$$\left(1.96 \ \frac{\text{Trips}}{\text{Reactor Year}}\right) \times \left(10^{-5} \ \frac{\text{Opening}}{\text{Trip}}\right) = 1.96\text{x}10^{-5}$$

b. A net reduction in reactor trips would result. Figure 1-1 indicates the potential for reactor trip reduction which could be achieved by raising the ART arming point. Again, assuming turbine trip frequency to remain at the 1980-84 levels, an ART arming point of 45% power and successful runbacks for 70% of turbine trips at power ≤45%, the reduction in reactor trips due to this cause would be:

$$\frac{12 \text{ Turbine Trips* } \times .70}{5 \text{ years} \times 7 \text{ Reactors}} = \frac{.24 \text{ Trips}}{\text{Reactor year}}$$

*at power ≤ 45%

Table 5-1. Turbine Bypass Capacities

177 FA Plants

Unit	Steam flow at 100% FP (lb/hr)	Condenser dump capacity (% FP Stm. flow)	Modulating atmospheric dump capacity (% FP Stm. Flow)
ANO-1	10.5×10^6	15.8	6.2
CR-3	10.6×10^6	15.0	7.5
DB-1	11.8×10^6	25.0	15.0
ON-1	10.5×10^6	25.0	-
ON-2	10.5×10^6	25.0	-
ON-3	10.5×10^6	25.0	-
RS-1	11.7×10^6	15.7	7.5
TMI-1	10.6×10^6	22.5	6.4

Table 5-2. Main Steam Safety Valve Arrangements

177 FA Plants

Pressure (psig)	Number of valves set to lift at listed pressure								
	1040	1050	1060	1065	1070	1080	1090	1100	1104
Unit									
ANO-1	-	4	-	-	4	-	4	4	-
CR-3	-	4	-	-	4	-	4	4	-
DB-1	-	4	-	-	4	-	6	4	-
ON-1	-	2	-	2	-	2	2	4	4
ON-2	-	2	-	2	-	2	2	4	4
ON-3	-	2	-	2	-	2	2	4	4
RS-1	-	4	-	-	4	-	6	4	-
TMI-1	2	6	4	-	-	4	2	-	-

Table 5-3. Available Total Bypass Capacities Prior to Reaching 2355 psig Trip

Unit	Turbine bypass (% FP Stm. flow)	Atmospheric dump (% FP Stm. flow)	First bank MSSVs (% FP Stm. Flow)
ANO-1	15.8	6.2	28
CR-3	15.0	7.5	28
DB-1	25.0	15.0	25
ON-1	25.0	-	14
ON-2	25.0	-	14
ON-3	25.0	-	14
RS-1	15.7	7.5	25
TMI-1	22.5	6.4	48*

*Includes valves set at 1040 and 1050 psig

Table 5-4. Estimated Initial Power Levels for Runbacks on Turbine Trip

Unit	Initial Power Level
ANO-1	48
CR-3	48
DB-1	55
ON-1	45
ON-2	45
ON-3	45
RS-1	45
TMI-1	75

6. RECOMMENDATIONS

It is recommended that the Anticipatory Reactor Trip on Turbine Trip arming point be changed from its current setting of 20% power to a higher level based on the guidance provided in Section five above.

7. REFERENCES

1. "Justification for Raising Setpoint for Reactor Trip on High Pressure," BAW-1890, September 1980.