A Study of the ANO-1
Pressurizer Level Problem

By

R. W. Winks

Babcock & Wilcox Co.
Lynchburg, Virginia

8005290255

Table of Contents

List of Figures

List of Figures Continued

A STUDY OF THE ANO-1 PRESSURIZER LEVEL PROBLEM

Arkansas Power & Light Company has requested that B&W define what recommended actions should be taken to ensure that the indicated level of the pressurizer does not drop below zero inches on future major plant transients.

An additional request was made for B&W to clarify transient pressurizer system performance presented in the Reactor Coolant System Functional Specification in comparison with actual pressurizer performance.

Summary

A comparison of several pressurizer system parameters during the two reactor trips at ANO-1 and another similar reactor trip at TMI-1, an identical B&W plant, shows good agreement between all the pertinent parameters except the indicated pressurizer level. Plant data from these three reactor trip transients indicates that a change of 6 psi in the minimum steam pressure caused T_{ave} to vary by one degree F and that the minimum RC System temperature was 547 ± 1F and minimum steam pressure was 972 ± 13 psig. It is our recommendation that the final minimum unit average temperature should not decrease below 548 F during plant cooldown and the code steam relief valves should be re-adjusted so that the minimum steam pressure remains greater than 980 psig in order to keep the pressurizer level indication always greater than zero inches following a reactor trip from full power.

Due to the unusually large difference infinal pressurizer level for the two reactor trips (12/11/74 and 5/9/75) at ANO-1, it is our recommendation that AP&L thoroughly check the calibration and operation of the entire pressurizer level signal processing instrumentation system.

B&W also recommends that the Operator should no longer start the make up pump which is connected to the normally unused injection nozzle whenever RC pressure decreases below 1800 psig or pressurizer level approaches a zero indication.

To provide additional margin for future transients, B&W also recommends setting the pressurizer level setpoint at 190 or 195 inches depending on the nominal variation in pressurizer level. (Nominal variation of ±10 inches to ±5 inches is typical.) This technique will not contradict the normal upper operating limit of 200 inches for the pressurizer.

B&W has stated previously that the temporary loss of indication of pressurizer level is not equivalent to an unsatisfactory operating condition for the reactor coolant system. This study does not support changing this position. Minimum values of RC pressure at ANO-1 were 1750 ± 20 psig, well above the pressure at which the high pressure injection is initiated. In addition, automatic injection will protect the RCS and core if a true loss of pressurizer inventory exists.

1. Analysis of Pressurizer Performance

The performance of the ANO-1 pressurizer system has been compared to observed performance data from the TMI-1 and Oconee Unit #1 plants which are nearly identical to ANO-1. At TMI-1 the temperature-compensated pressurizer level for the full 400 inch range has been recorded on reactor trips from full power and the data can be directly compared to the pressurizer level indications for the 320 inch level at ANO-1. Related pressurizer system data has been observed at Oconee Unit #1 during reactor or turbine trips and this data has been used for comparison also.

Figure 1 compares the time rate of change of the ANO-1 pressurizer level (0 to 320 inch range) versus that for the 400 inch level range at TMI-1. These two plants were used in the comparison since they both record the temperature-compensated level indication. The curves show that parallel behavior of the two pressurizer level indications existed until 43 seconds after the reactor trip transient was started and that the change in level at ANO-1 was 180-30 or 150 inches versus 246-78 or 168 inches at TMI-1.

In the next twelve seconds, however, the ANO-1 pressurizer level dropped an additional 13 inches whereas the TMI-1 level only decreased another 2 inches, (A total change of 163 inches at ANO-1 versus 170 inches at TMI-1). It was speculated that a difference in the time rate of change of secondary side pressure could be the cause for the additional 13 inch decrease in the ANO-1 pressurizer level. Figure 2 exhibits the steam pressure profiles for ANO-1 and TMI-1. Very good agreement exists between the two secondary side pressures at a time later than 45 seconds into the reactor trip transient. The difference in the final minimum values of Tave for both plants was only 1.5 F and the difference in pressurizer level after adjusting for the unequal ranges was only 7 inches. During the initial portion of the transient, the ANO-1 steam pressure was approximately 15 psi lower than the TMI-1 steam pressure, consequently T_{ave} should have decreased more rapidly at ANO-1 than at TMI-1. Figures 3 and 4 reveal that the plot of the time rate of change of T_{ave} for both plants agreed within ±1.5 F during the entire transient and that the minimum value of T_{ave} is directly related to the minimum value of steam generator discharge pressure. Thus the pressurizer system performance for the first full power reactor trip at ANO-1 showed very good agreement with TMI-1 values of T_{ave}, level and minimum steam pressure.

As noted by AP&L personnel, the Arkansas plant pressurizer system performance was not constant for two nearly identical reactor trips from 100% power. Figure 5 displays the comparison of indicated pressurizer level for the reactor trips which occured on December 11, 1974 and May 9, 1975. The minimum pressurizer level on the second reactor trip has been estimated to be - 18 inches or an additional drop in level of approximately 35 inches compared to the first reactor trip from 100% power. In contrast, examination of other RC system parameters as shown in Figures 6 and 7 indicates only a slight change in the minimum value of T_{ave} and a small difference of approximately 10 psi in the steam generator discharge pressure.

Variation in makeup flow supplied to the reactor coolant system during the two reactor trip transients should be considered also. The current operator response of activating the makeup pump connected to the normally unused nozzle shortly after a reactor trip has a significant effect on maintaining RC pressure and pressurizer level. If the operator hesitates approximately one minute before initiating the additional makeup flow minimum RC pressure and pressurizer level values will have already been achieved and the extra flow will only hasten the recovery of the reactor coolant system. Investigation of operator response during the two reactor trips, (12/11/74 and 5/9/75), disclosed that the third makeup pump was activated earlier in the first transient than in the second, hence the pressurizer level probably indicated somewhat higher during the first transient due to the faster addition of makeup flow. B&W is concerned about the rapid utilization rate of allowable thermal cycles on the normally unused makeup nozzle at ANO-1 and we feel confident that a modified operating procedure or minor adjustment will enable the pressurizer water level to remain on scale throughout an entire reactor trip transient.

The different values of minimum T_{ave} for the three reactor trip transients have a singificant effect on the minimum value of RC pressure and Figures 8 and 9 show that a 1 degree fahrenheit deviation in unit average temperature is approximately equivalent to a 30 psi decrease in RC system pressure. A comparison of the three RC pressure profiles reveals that increased cooling of the primary side did occur between the first and second reactor trips at ANO-1 and hence minimum pressurizer level should have been slightly lower on the second transient than the first.

Figure 10 displays a comparison of the minimum unit average temperature and steam pressure at three similar B&W plants. The values of minimum steam pressure for the two reactor trips at ANO-1 are the lowest and the corresponding values of T_{ave} are also the lowest.

Since the first bank of steam code relief valves are set to open at a line pressure of 1050 psig and appear to finally reseat at a line pressure of 960 psig, it is our recommendation that the blowdown of the 1050 psig code relief valves be reset so that a minimum steam line pressure after reseating is 980 psig. Then the final minimum value for unit average temperature will be greater than 548°F and the minimum value of pressurizer level will be greater than zero inches.

2. Analysis of Makeup Pump Operation

The B&W training simulator was used to examine the change in RC pressure and indicated pressurizer level as different makeup pumps were operated following a reactor trip. Figures 11 and 12 illustrate the change in RC pressure and pressurizer level when the third makeup pump (which injects cold makeup water through the normally unused nozzles) is started twenty seconds after a reactor trip. When all three makeup pumps are started shortly after the reactor is tripped, an improvement of more than 100 psig in RC pressure and 50 inches in pressurizer level above typical minimum values can be realized. However, due to the limited number of allowable thermal cycles on the makeup nozzles, B&W does not recommend that the third makeup pump (connected to the normally unused nozzle) be started during each large transient in order to keep RC pressure and pressurizer level as high as possible. Even if the operator were to select and start the second makeup pump (which uses the same nozzle as the first makeup pump) Figure 11 and 12 show that negligible increase in both RC pressure and pressurizer level will be produced.

3. Analysis of Instrumentation Performance

Due to the inability of operating plant data to substantiate a 35 inch change in pressurizer level for two nearly identical reactor trips, it was appropriate to investigate and clarify the measuring and processing of the pressurizer level signal. The technique of converting a level signal measured at a hot operating temperature into an equivalent one at the calibrating temperature of 68°F is accomplished by using two function generators to develop the final signal voltage equivalent to the true level in the pressurizer. Without temperature compensation, the decreasing fluid density causes a smaller output signal hence the indicated pressurizer level would decrease with increasing pressurizer temperature. This is shown in Figure 13.

A standard method of compensating vessel level for temperature is displayed in a schematic in Figure 14. The fluid temperature signal is used to operate two function generators; one is a bias voltage signal added or subtracted from the measured differential pressure signal, and the other is a multiplicative correction factor to account for the ratio in fluid densities.

Specifically for the ANO-1 pressurizer, these two relationships are exhibited in Figures 15 and 16 and show during reactor trips the change in system temperature from 650°F to approximately 600°F covers a significant portion of the range of the two function generators. The correction factor (C.F.), relationship is a constant divided by the difference between pressurizer water density and pressurizer steam density for any pressurizer temperature between 68°F and 670°F.

Similarly, the bias voltage relationship is a voltage signal resulting from the difference between the density of water in the reference leg external to the pressurizer and the density of steam in the pressurizer. Figure 16 also shows the assumed reference leg temperature for particular values of presurizer temperature.

A study was performed to evaluate the effect of hotter reference leg temperatures on the indicated pressurizer level signal. Figure 17 exhibits the changes in bias voltage due to selected reference leg temperatures and Table I presents the resulting change in the final temperature-compensated level.

Table I

Variation in Pressurizer Level at 600°F
Due to Different Reference Leg Temperature

Ref Leg Temp - F	126	135	150
Bias Voltage	-1.32	-1.36	-1.45
Transmitter Voltage (for 40 inches)	-7.25	-7.25	-7.25
Corrected voltage	-8.57	-8.61	-8.70
Correction Factor	1.606	1.606	1.606
Deviation in Bias - %	0	0.2	.65
Total Deviation in Level-inches	0	1.0	3.3

Thus, the error in bias voltage due to the reference leg temperature being 126°F rather than the real temperature which may be approximately 150°F generates a pressurizer level signal which is greater than true level by only 3 inches. Hence, if a revised relationship of reference leg temperature versus pressurizer water temperature were developed and implemented for the ANO-1 pressurizer, it could not account for the 35 inch change in pressurizer level which occurred between the two reactor trips from full power.

One remaining possibility for non-repeatable pressurizer level indication is a change or abnormal operation in the signal processing circuit between the two reactor trips. The information given in Figure 13 shows that at full power (650°F) the transmitter output voltage varies from - 1.8 to -2.4 to -3.0 volts as true pressurizer level is varied from 200 to 180 to 160 inches. The full power value of correction factor voltage is +4.06 volts and the bias voltage is -2.15 as recorded on ANO-1 pressurizer calibration sheets. However, at a pressurizer water temperature of 600°F the corresponding transmitter output voltages for 200, 180, and 160 inches level are -1.0, -1.80 and -2.6 volts, the correction factor voltage is -1.34 volts and the bias voltage is -1.32 volts. It is our recommendation that AP&L check the complete temperature-compensated pressurizer level circuit for correct development of bias and correction factor voltages over the temperature range of 600 to 650°F.

4. Analysis of RCS Functional Spec

A review has been conducted of the pertinent sections of the B&W Reactor Coolant System Functional Specification for ANO-1 as requested by AP&L. It was their concern that actual pressurizer system performance did not agree with that stated in the above document and B&W should clarify any discrepancies.

The intent of the document is to define the limits of pressures, temperatures, and system flowrates during anticipated major transients for use in appropriate stress analyses of the components and piping comprising the reactor coolant system. The scope of the document is defined as the following:

"It provides general functional requirements for the design of RCS components."

"It is to be used in conjunction with individual component functional specs .... to obtain the complete functional requirements for a particular component."

The attempt to compare or match actual plant transient performance with that shown in the document is not consistent with directions contained in paragraph 4.1:

"The transient conditions are provided for equipment design purposes and are not intended to be actual transients or operating procedures."

The graphs of predicted system behavior for each transient were developed using a B&W hybrid analog-digital computer simulation of the Arkansas plant. The simulator was subjected to a large number of severe transients specifically to be conservative for subsequent design stress analyses on RCS components and the transients were not designed to accurately represent actual plant performance.

Related studies on the same simulator disclosed the very close relationship of RC system transient performance to the transient behavior of the secondary ide of the plant. The graphs developed for this document were prepared with a simulator having a very ideal and non-representative feedwater system, hence the corresponding variation in the reactor coolant system parameters will not necessarily agree with actual plant data from ANO-1. But the purpose is to define the maximum limits as stated in paragraph 6.1:

"The Reactor Coolant System components shall be designed to withstand the operating transients listed herein.... The intent of the transient conditions presented is to indicate the maximum rates of change of temperatures, pressure, flow etc."

However, the question whether or not actual plant data has exceeded the design limits needs to be answered. There are three categories of plant shutdown contained in this functional specification and each type of transient shall be examined.

Transient 7 - Step Load Rejection (100 to 8% Power Runback)

The performance curves for this transient are based on a turbine trip or electrical load rejection from 100% power with runback at approximately 30% per minute with power reduction to 8% power.

Figure 18 exhibits some of the information contained in Figures 7-1 and 7-2 of the RCS Spec 3-92 showing the predicted maximum deviation of RC pressure and pressurizer level for a turbine trip or load rejection transient. Comparison with actual plant data from two B&W plants (TMI-1 and SMUD) revealed that the predicted variation in pressure is in good agreement with the predicted values. For good component design it is important that the predicted pressures exceed the actual measured values at an operating plant, and they did.

Transient 8B - Reactor Trip due to High RC Pressure (no loss of feedwater system Operation

This transient is initiated by a turbine trip which will cause high RC pressure to trip the reactor a few seconds later. Feedwater flow is controlled and is responsible for significant cooldown of the RC system. Figure 19 again illustrates that the predicted peak RC system pressure is greater than the peak observed pressure at operating B&W plants. The variation in pressurizer water level has been predicted using a feedwater system that can satisfy an ideal feedwater flow profile following the reactor trip. This FW flow behavior is unlike the actual sudden decrease and rapid increase in feedwater flow generally occurring at the plant.

Transient 15 (or 8A) - Reactor Trip due to Loss of Station Power

This reactor trip transient can be initiated either by loss of all RC Flow (Pump Power) or by loss of station power. Without power, feedwater flow to the steam generators is terminated and RC pressure remains relatively high late in the transient. Figure 20 displays the predicted values of RC pressure and pressurizer level used as maximum values for stress analyses and, as before, the observed values of pressure have been less than predicted.

Comparison of ANO-1 Pressurizer Level With TMI-1 Full Range Pressurizer Level Following A Reactor Trip

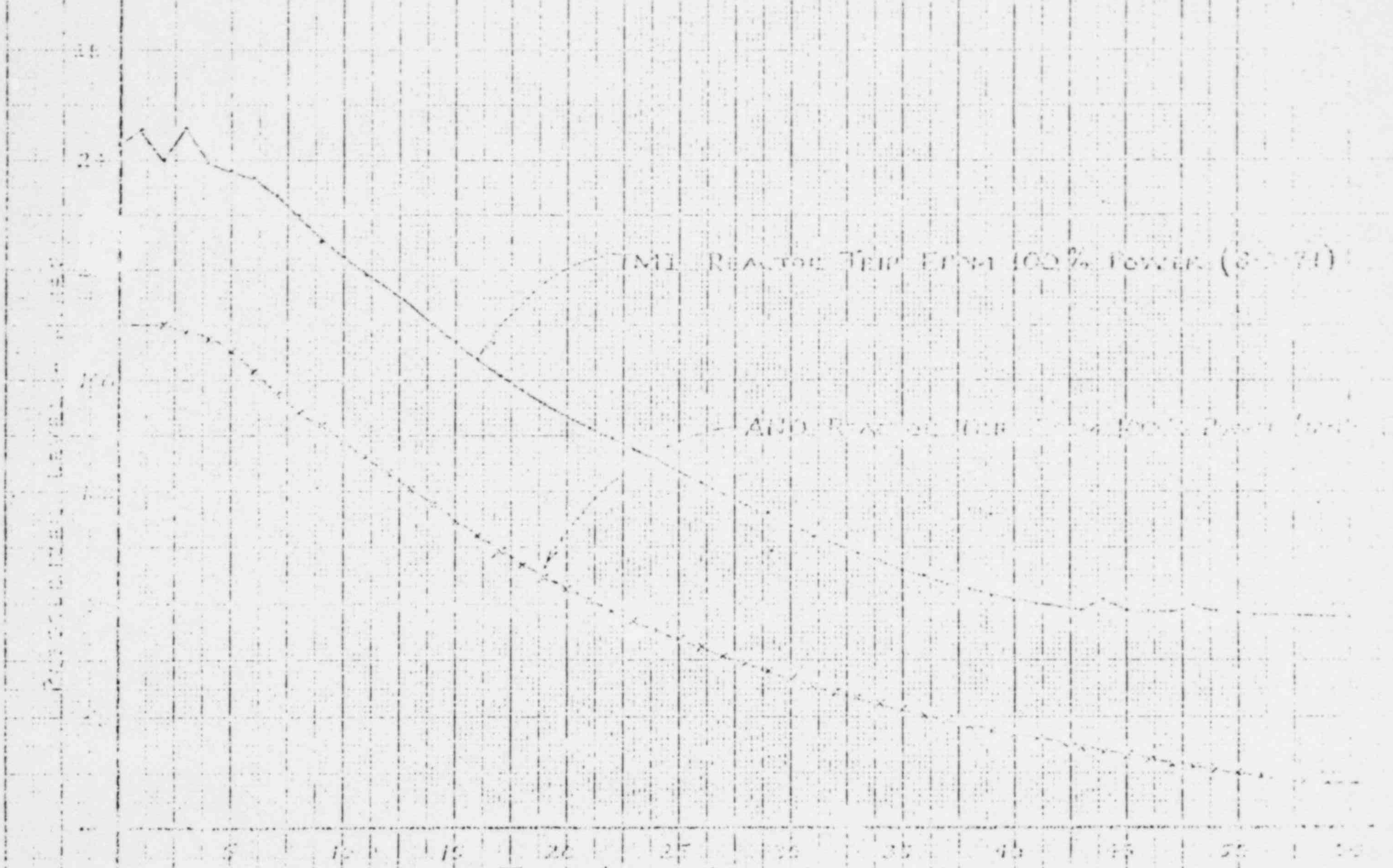


FIG 1

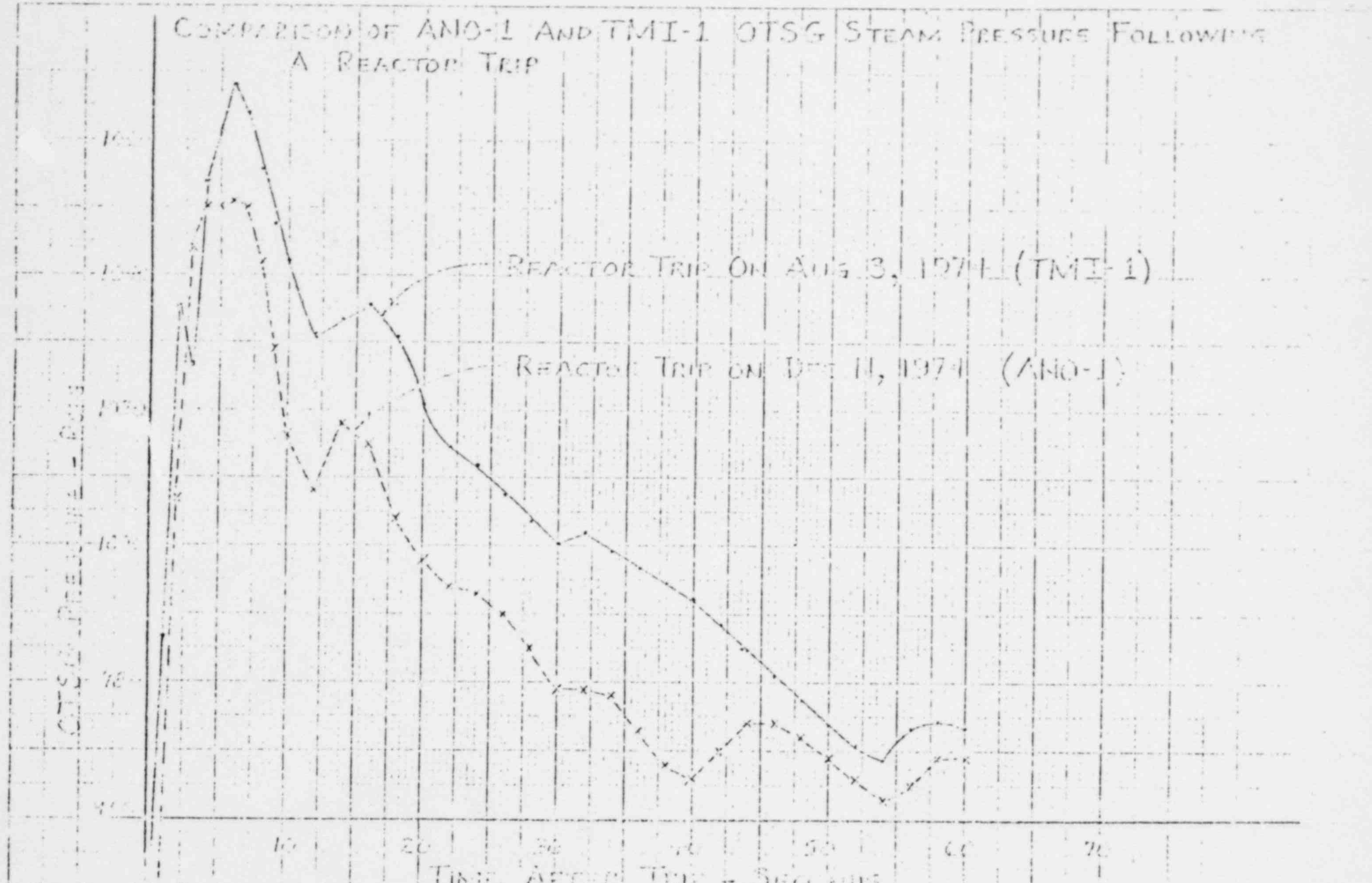
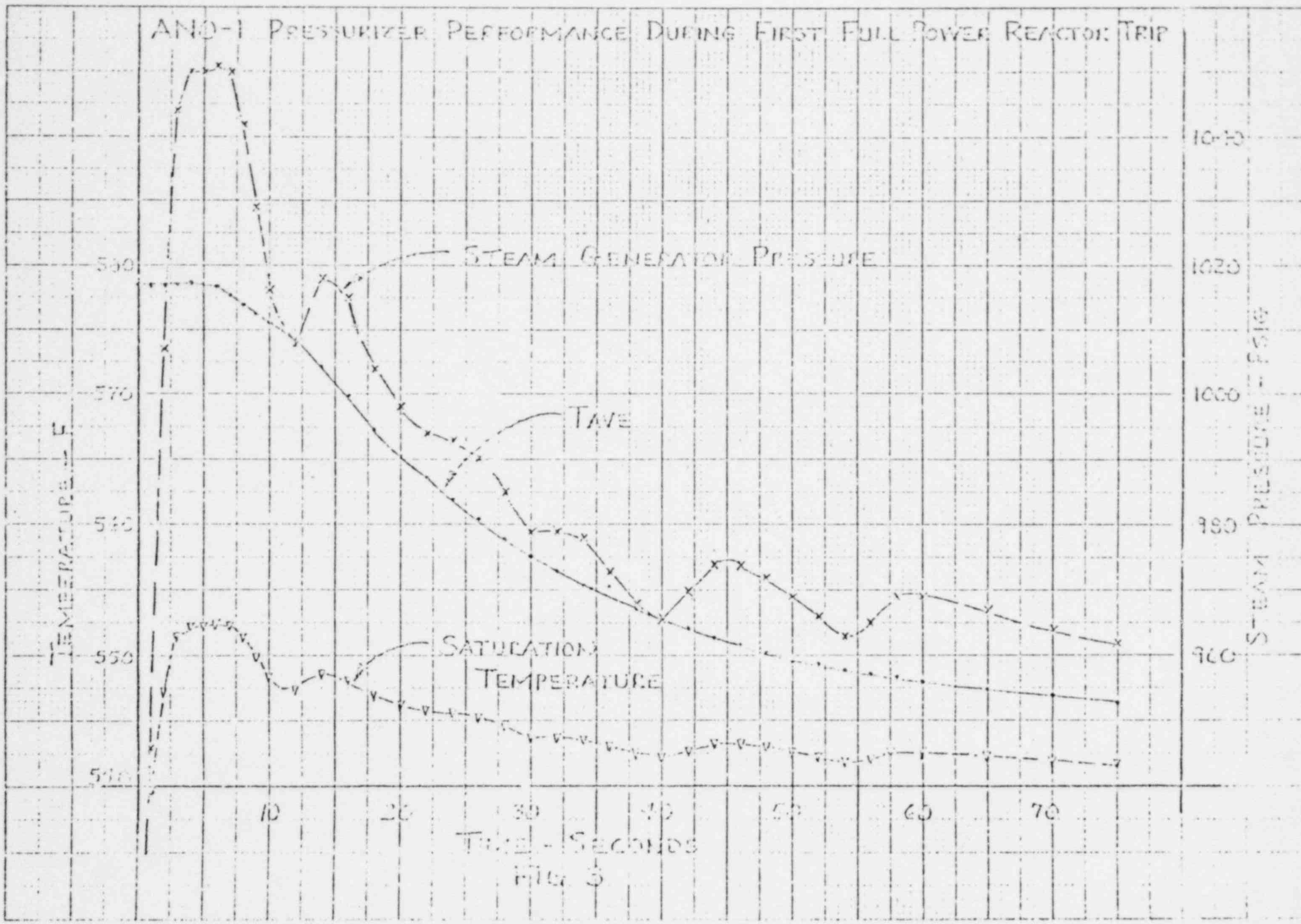
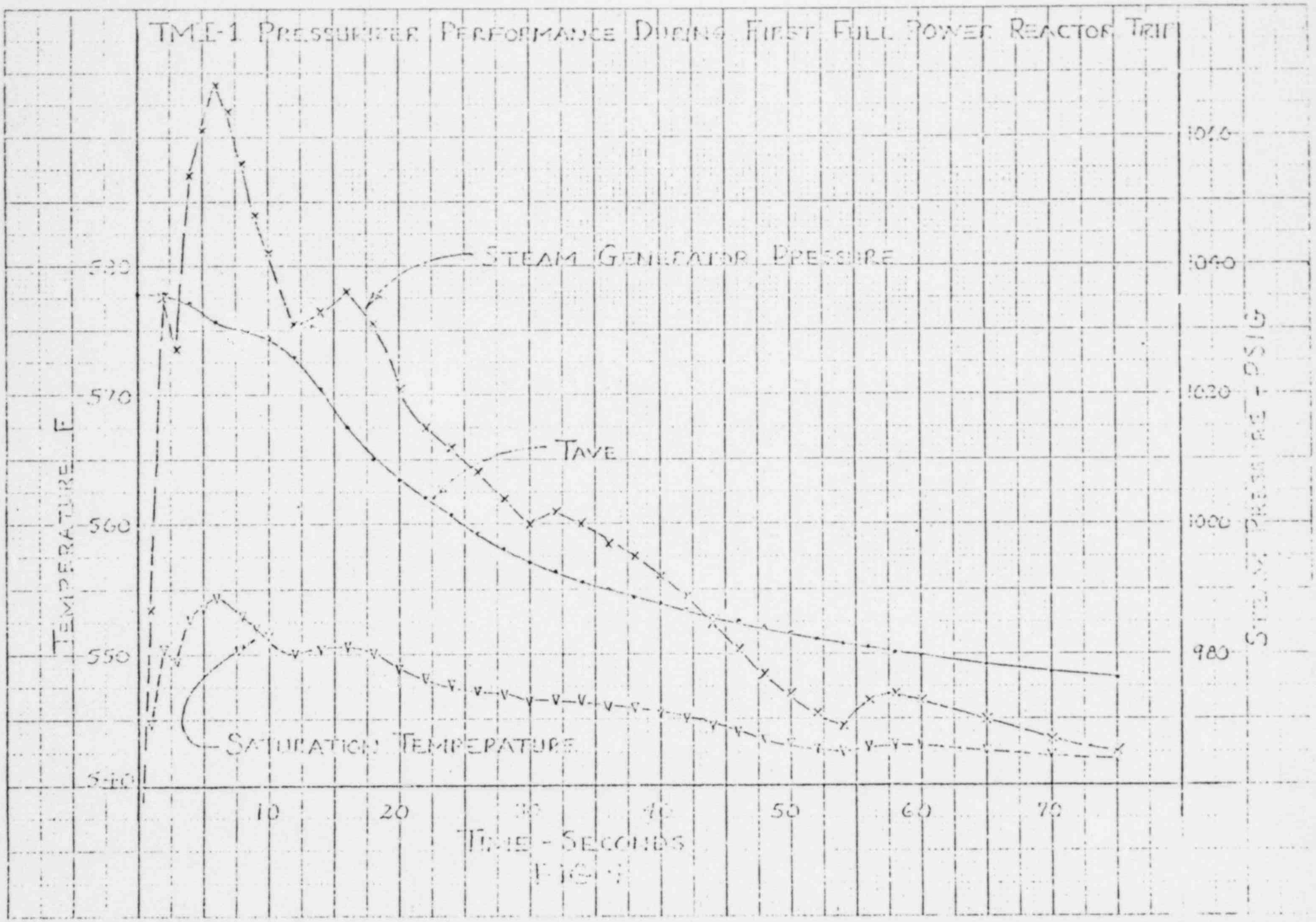
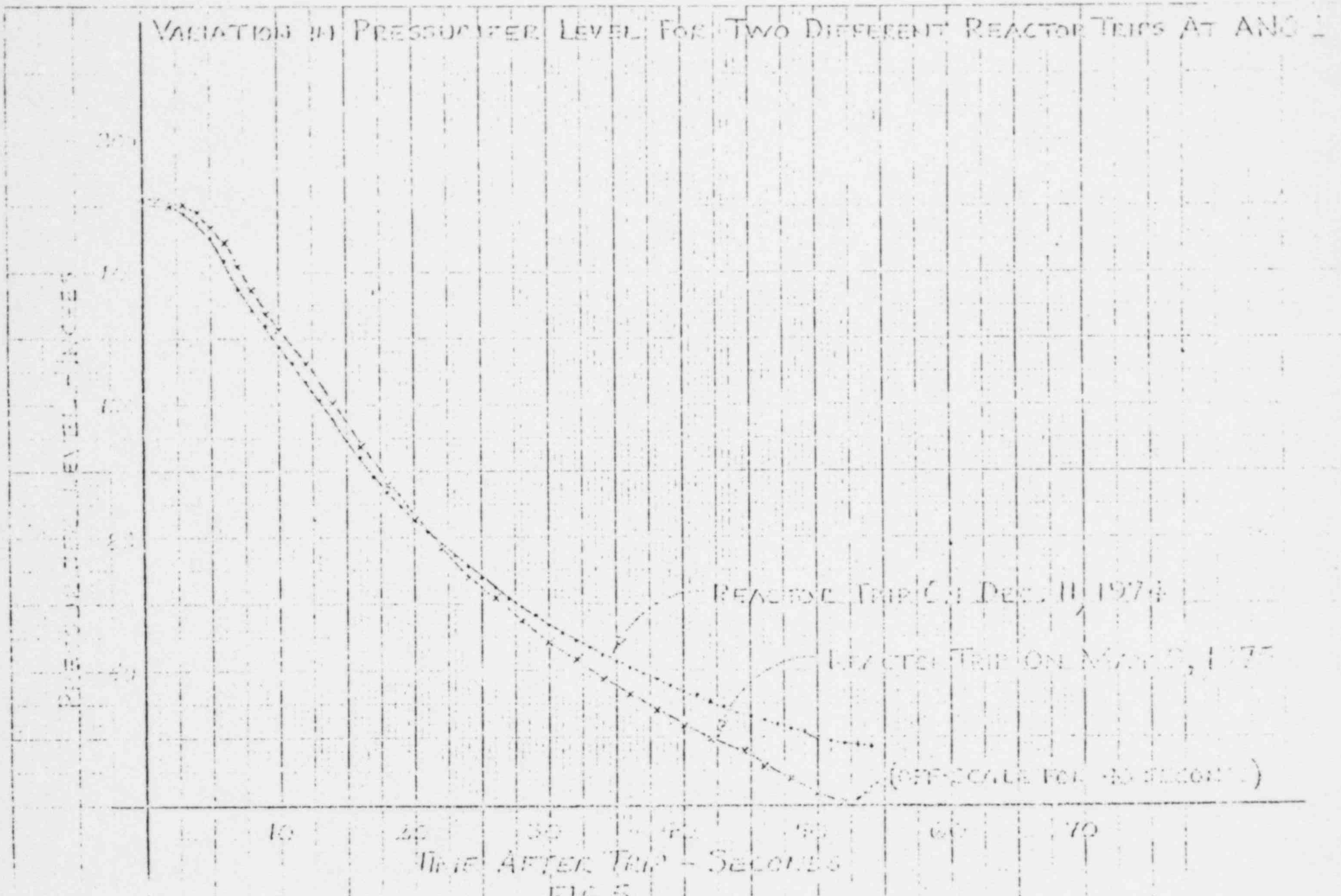

COMPARISON OF ANO-1 AND TMI-1 OTSG STEAM PRESSURE FOLLOWING A REACTOR TRIP
REACTOR TRIP ON AUG 3, 1974 (TMI-1)
REACTOR TRIP ON DEC 11, 1974 (ANO-1)
OTSG PRESSURE - PSIG
10
20
30
40
50
60
70
TIME AFTER TRIP - SECONDS

FIG 2


ANO-1 Pressurizer Performance During First Full Power Reactor Trip
Steam Generator Pressure
Tave
Saturation Temperature
Temperature - F
570
550
Steam Pressure - PSIG
1040
1020
1000
980
960
10
20
30
40
60
70
Time - Seconds
Fig. 5


TMI-1 Pressurizer Performance During First Full Power Reactor Trip
Steam Generator Pressure
Tave
Saturation Temperature
Temperature F
570
560
550
540
1040
1020
1000
980
10
20
30
40
50
60
70
Time - Seconds



VARIATION IN PRESSURIZER LEVEL FOR TWO DIFFERENT REACTOR TRIPS AT ANO
REACTOR TRIP ON DEC. 11, 1974
REACTOR TRIP ON MAY, 1975
(OFF SCALE FOR 40 SECONDS)
10
20
30
50
60
70
TIME AFTER TRIP - SECONDS
PRESSURIZER LEVEL - INCHES

FIG 5

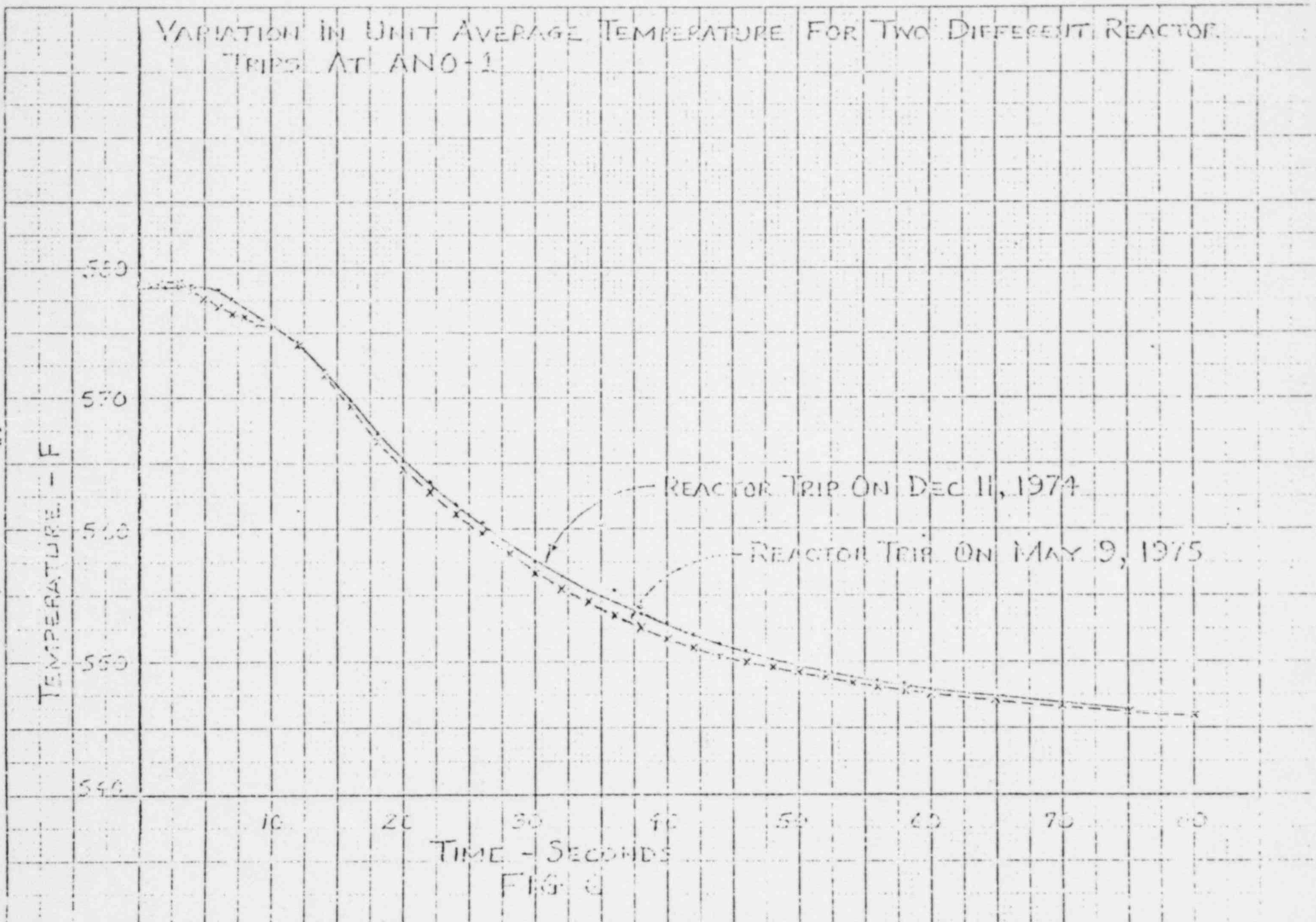
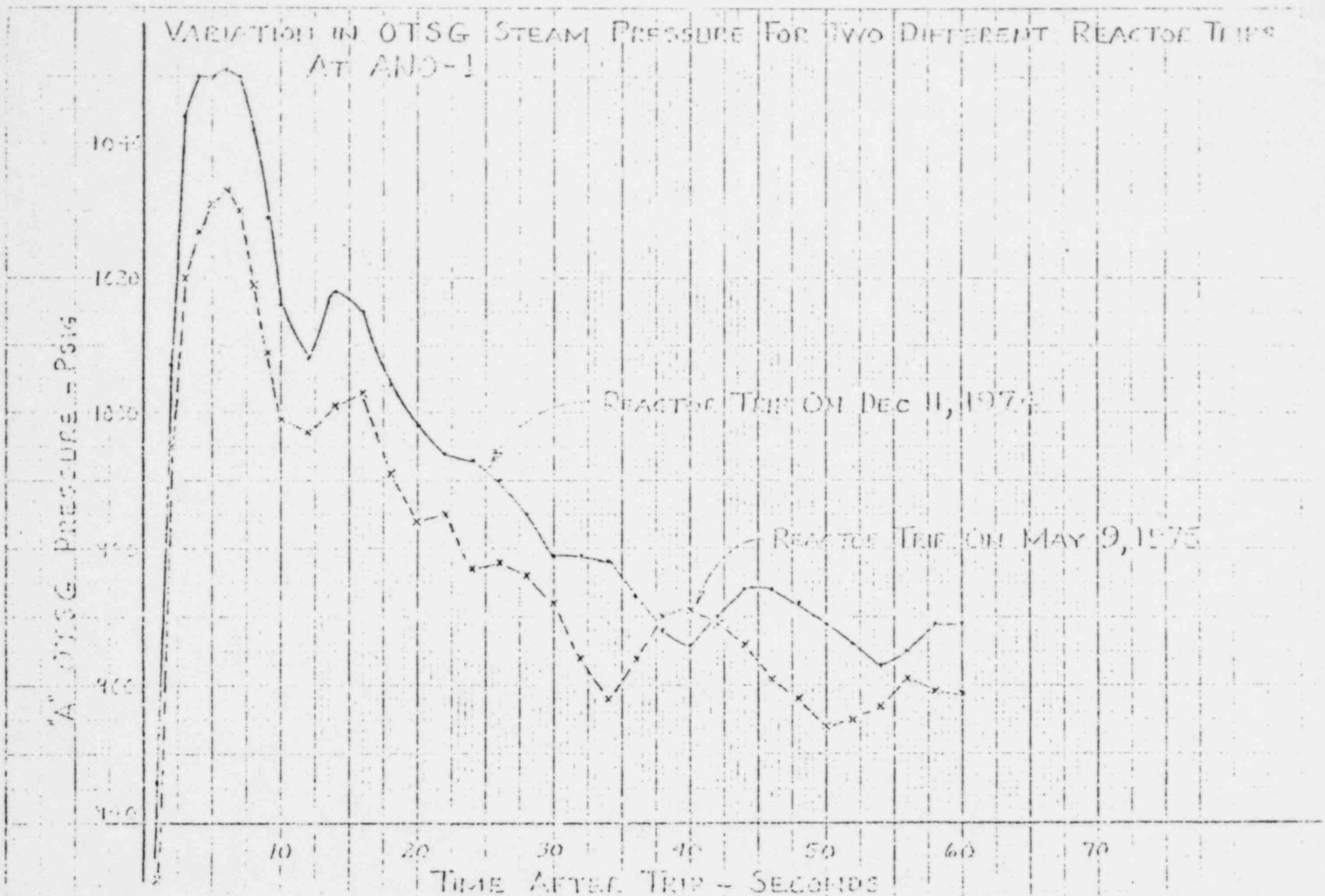

VARIATION IN UNIT AVERAGE TEMPERATURE FOR TWO DIFFERENT REACTOR TRIPS AT ANO-1
REACTOR TRIP ON DEC 11, 1974
REACTOR TRIP ON MAY 9, 1975
TEMPERATURE - F
580
570
560
550
540
10
20
30
40
50
60
70
80
TIME - SECONDS

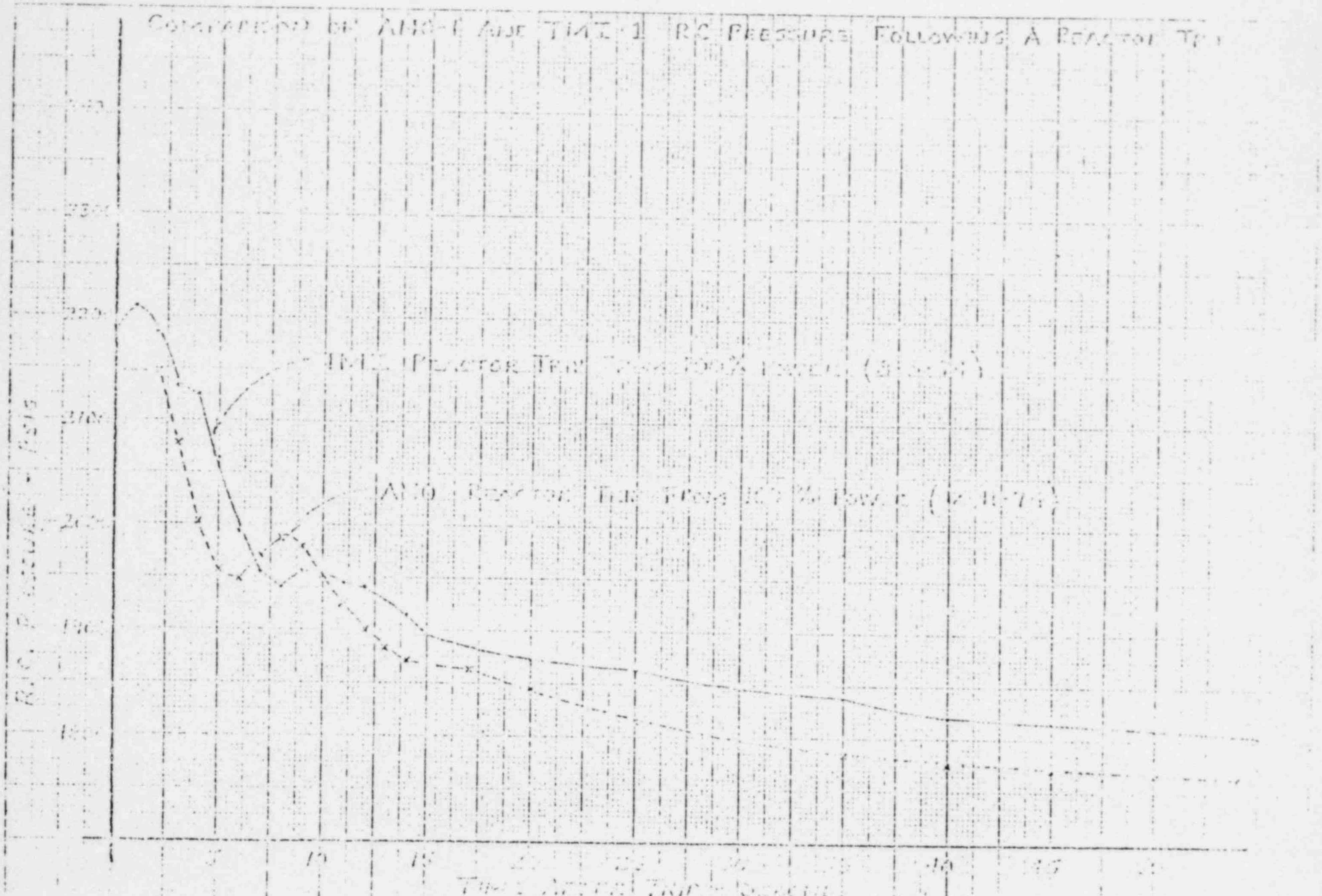
FIG. 6



VARIATION IN OTSG STEAM PRESSURE FOR TWO DIFFERENT REACTOR TRIPS
AT ANO-1
"A" OTSG PRESSURE - PSIG
1040
1020
1000
960
REACTOR TRIP ON DEC 11, 197
REACTOR TRIP ON MAY 9, 197
10
20
30
40
50
60
70
TIME AFTER TRIP - SECONDS

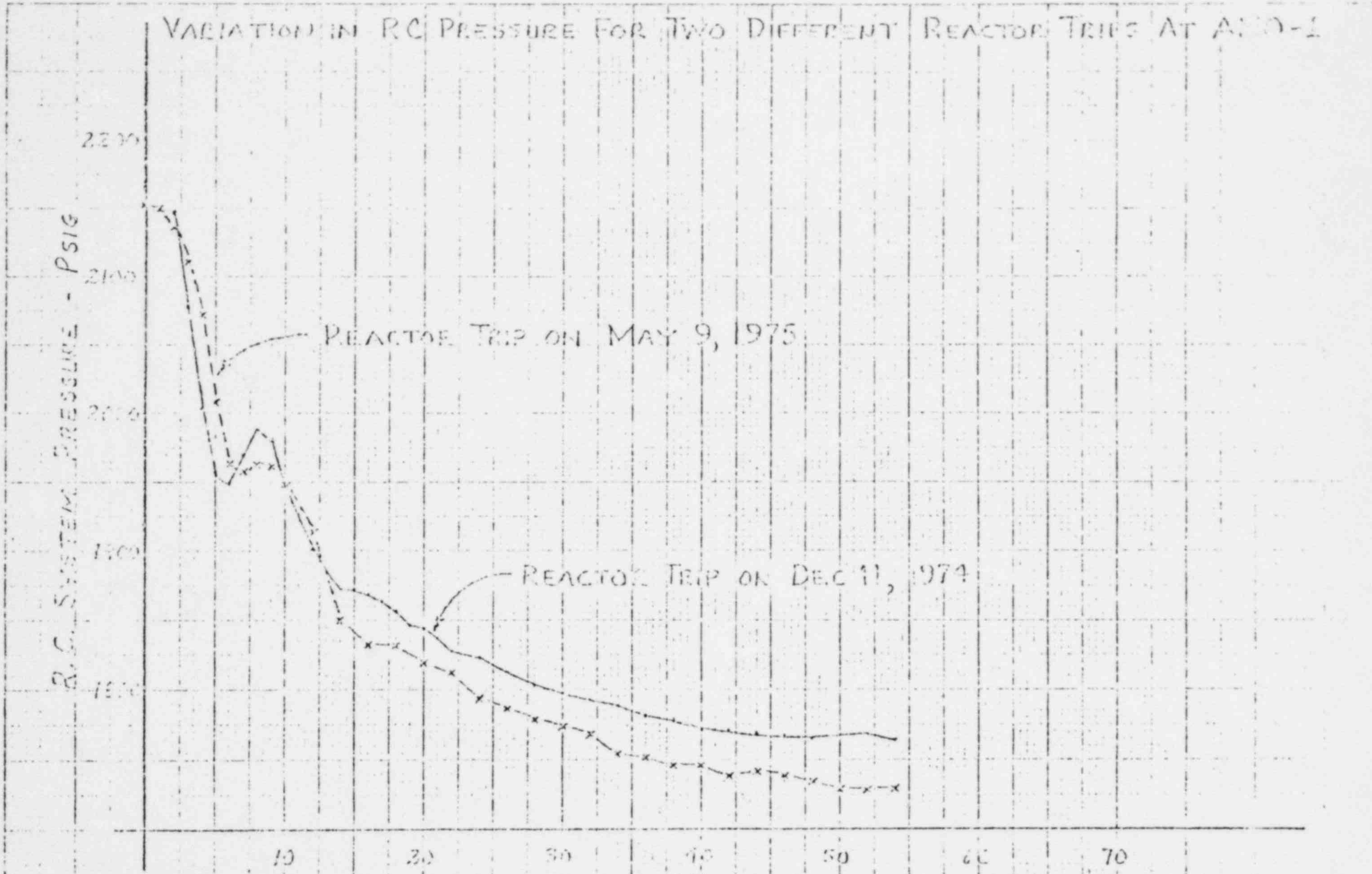
FIG 7

46 1512



COMPARISON OF ANO-1 AND TMI-1 RC PRESSURE FOLLOWING A REACTOR TRIP
TMI-1 REACTOR TRIP
ANO-1 REACTOR TRIP
R.C. PRESSURE - PSIG
2300
2200
2100
2000
1900
1800
5
10
15
40
45
TIME AFTER TRIP - SECONDS

FIG. 9



TIME AFTER TRIP - SECONDS

FIG.

Minimum Tave Versus Minimum Steam Pressure For Existing B & W Plants

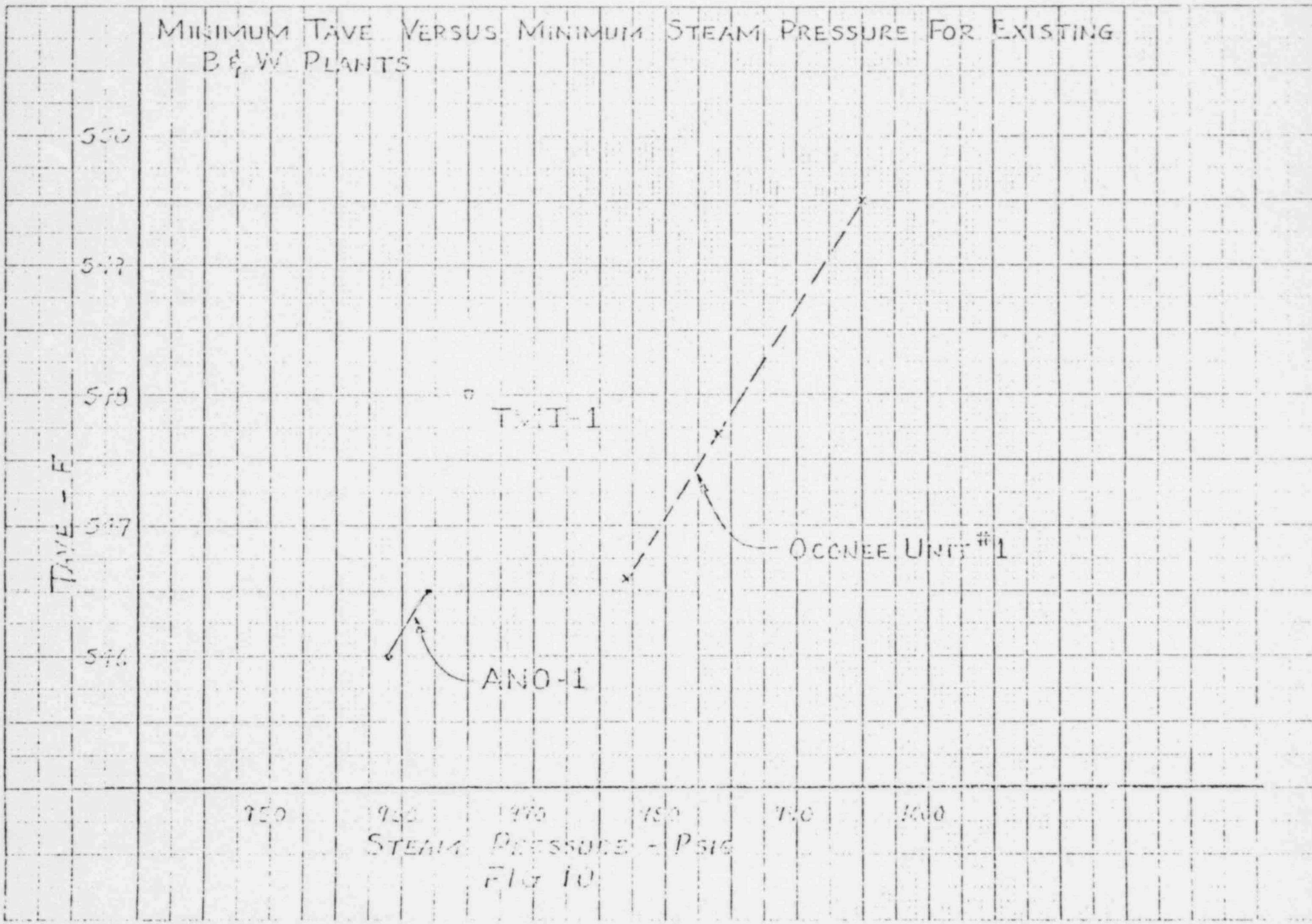


Fig 10

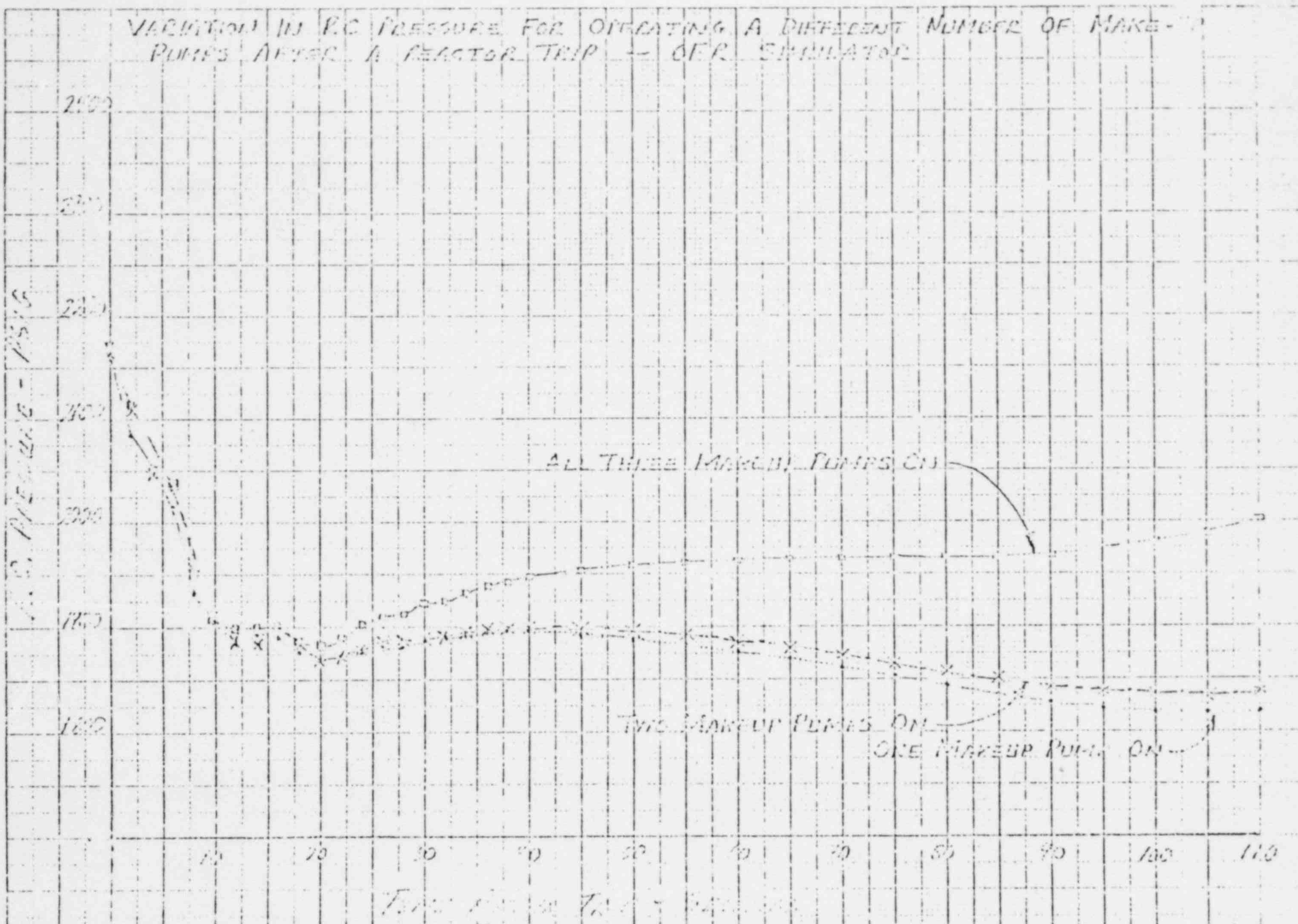

VARIATION IN R.C PRESSURE FOR OPERATING A DIFFERENT NUMBER OF MAKE-
PUMPS AFTER A REACTOR TRIP — OER SIMULATOR
ALL THREE MAKEUP PUMPS ON
TWO MAKEUP PUMPS ON
ONE MAKEUP PUMP ON

FIG. 11

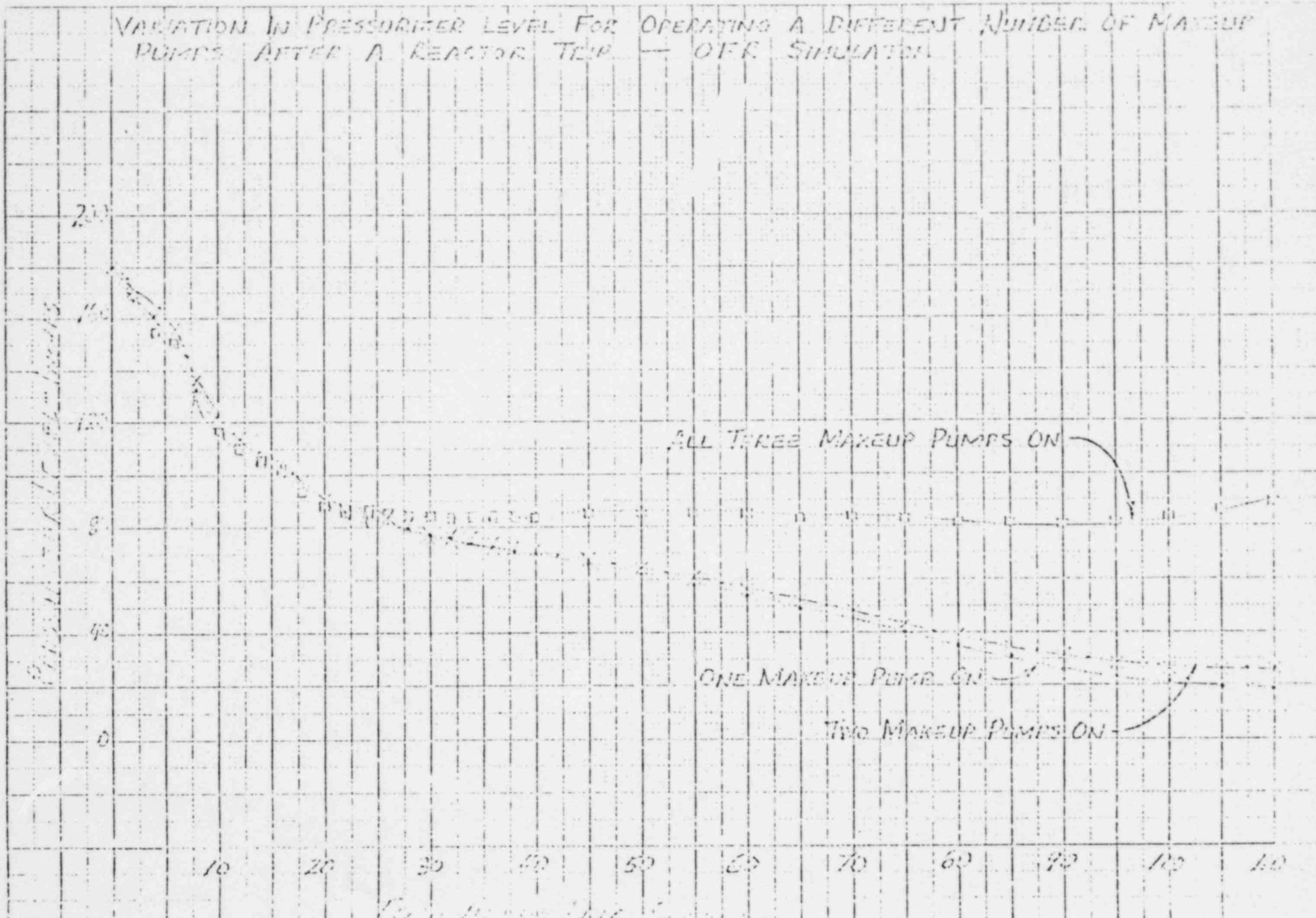

VARIATION IN PRESSURIZER LEVEL FOR OPERATING A DIFFERENT NUMBER OF MAKEUP PUMPS AFTER A REACTOR TRIP — OFF SIMULATOR
ALL THREE MAKEUP PUMPS ON
ONE MAKEUP PUMP ON
TWO MAKEUP PUMPS ON
0
10
20
30
50
70

FIG 12

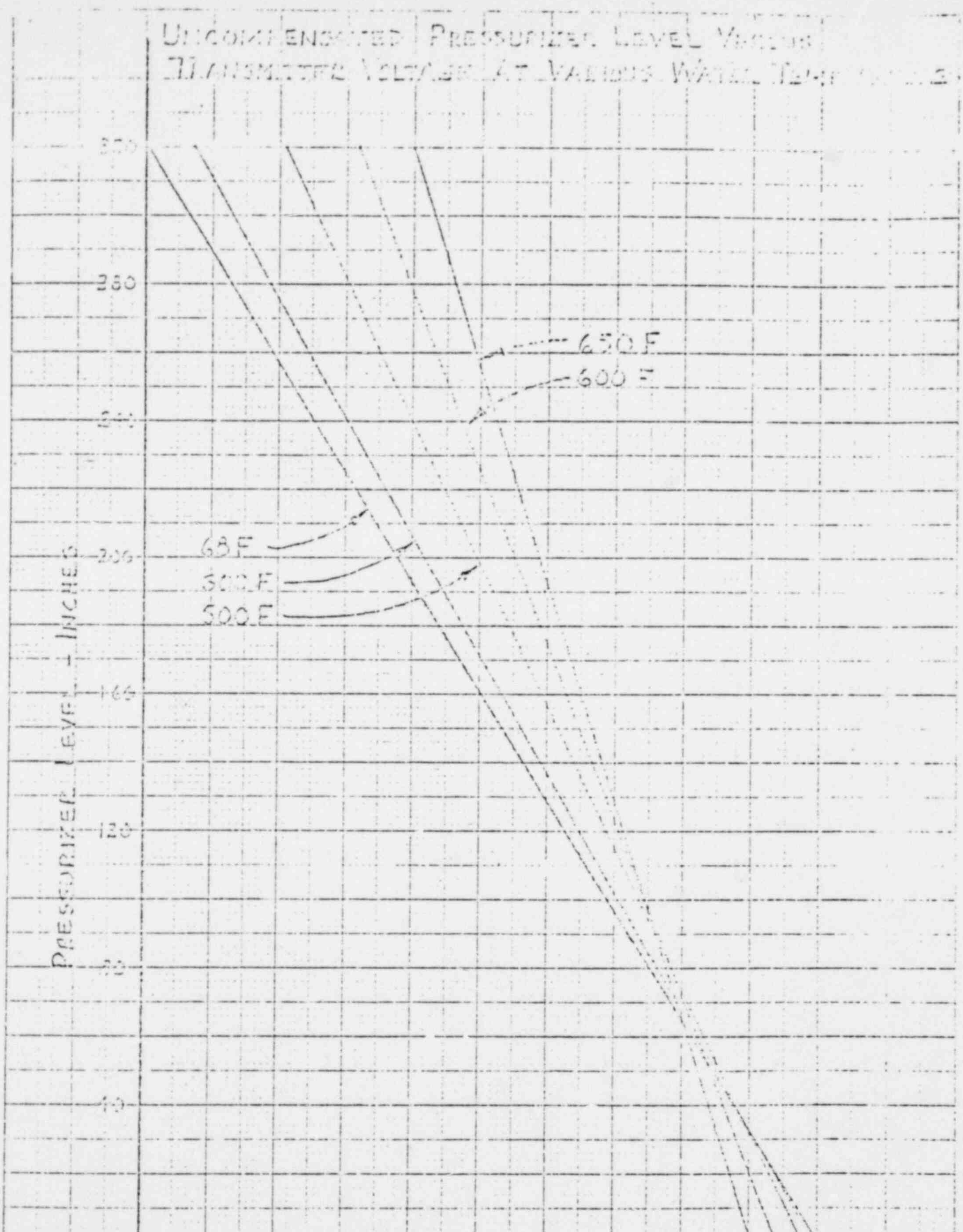


FIG 13

SCHEMATIC OF TEMPERATURE-COMPENSATED PRESSURIZER LEVEL CIRCUIT

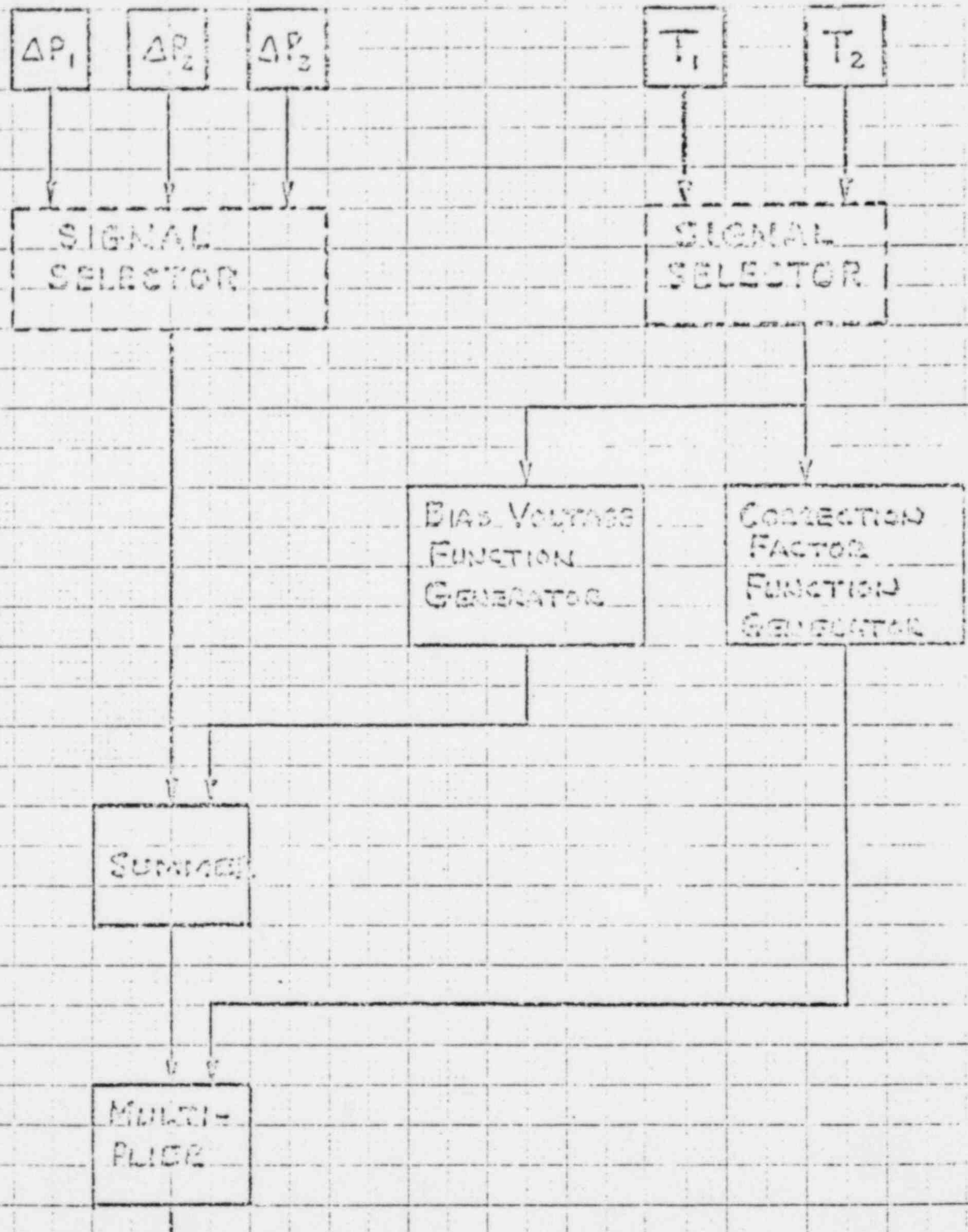


FIG 14

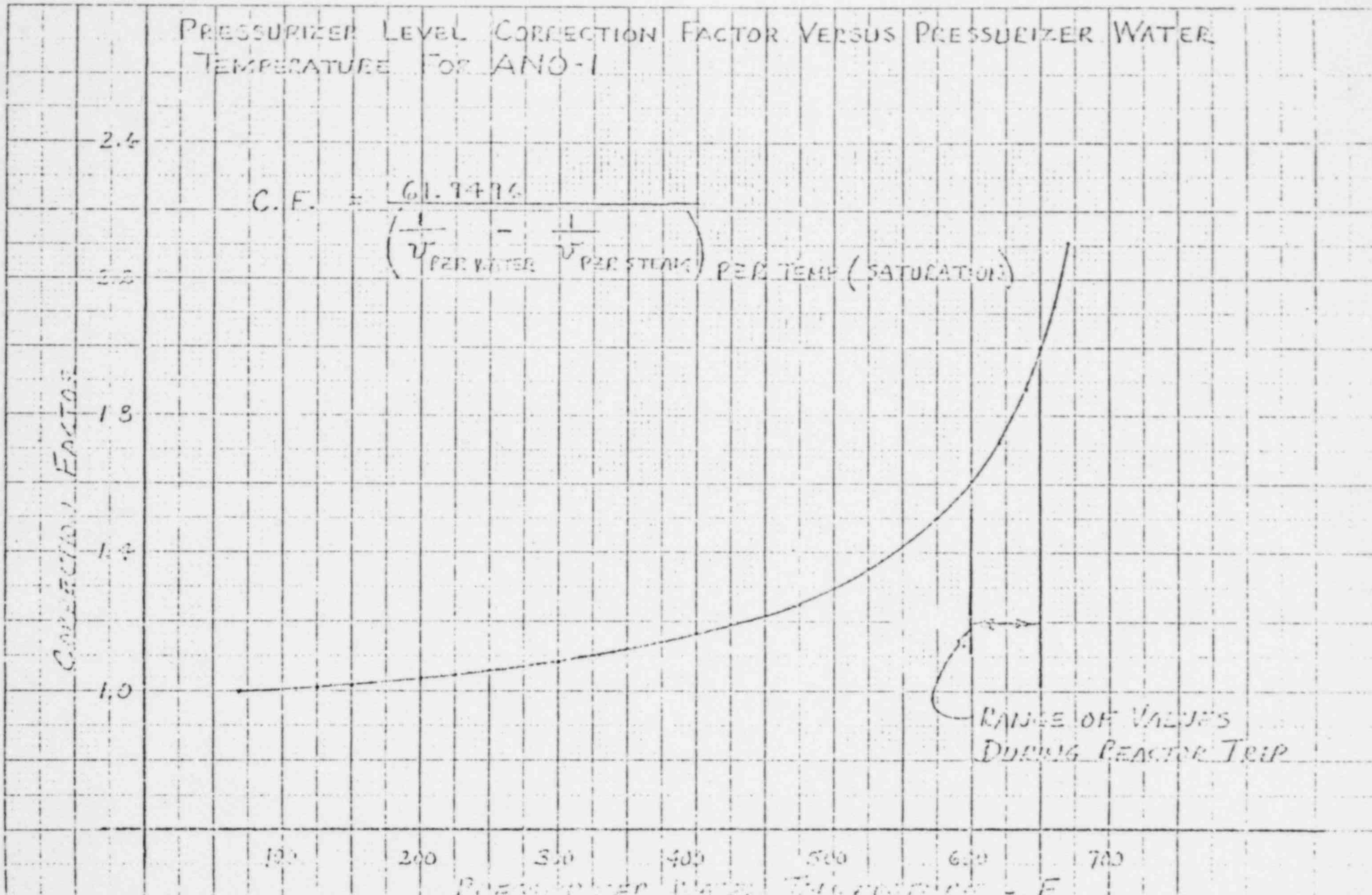

PRESSURIZER LEVEL CORRECTION FACTOR VERSUS PRESSURIZER WATER TEMPERATURE FOR ANO-1
$C.F. = \frac{61.7486}{\left(\frac{1}{v_{PZR\ WATER}} - \frac{1}{v_{PZR\ STEAM}}\right)_{PZR\ TEMP\ (SATURATION)}}$
2.4
1.8
1.4
1.0
CORRECTION FACTOR
200
400
600
700
RANGE OF VALUES
DURING REACTOR TRIP
- F

FIG 15

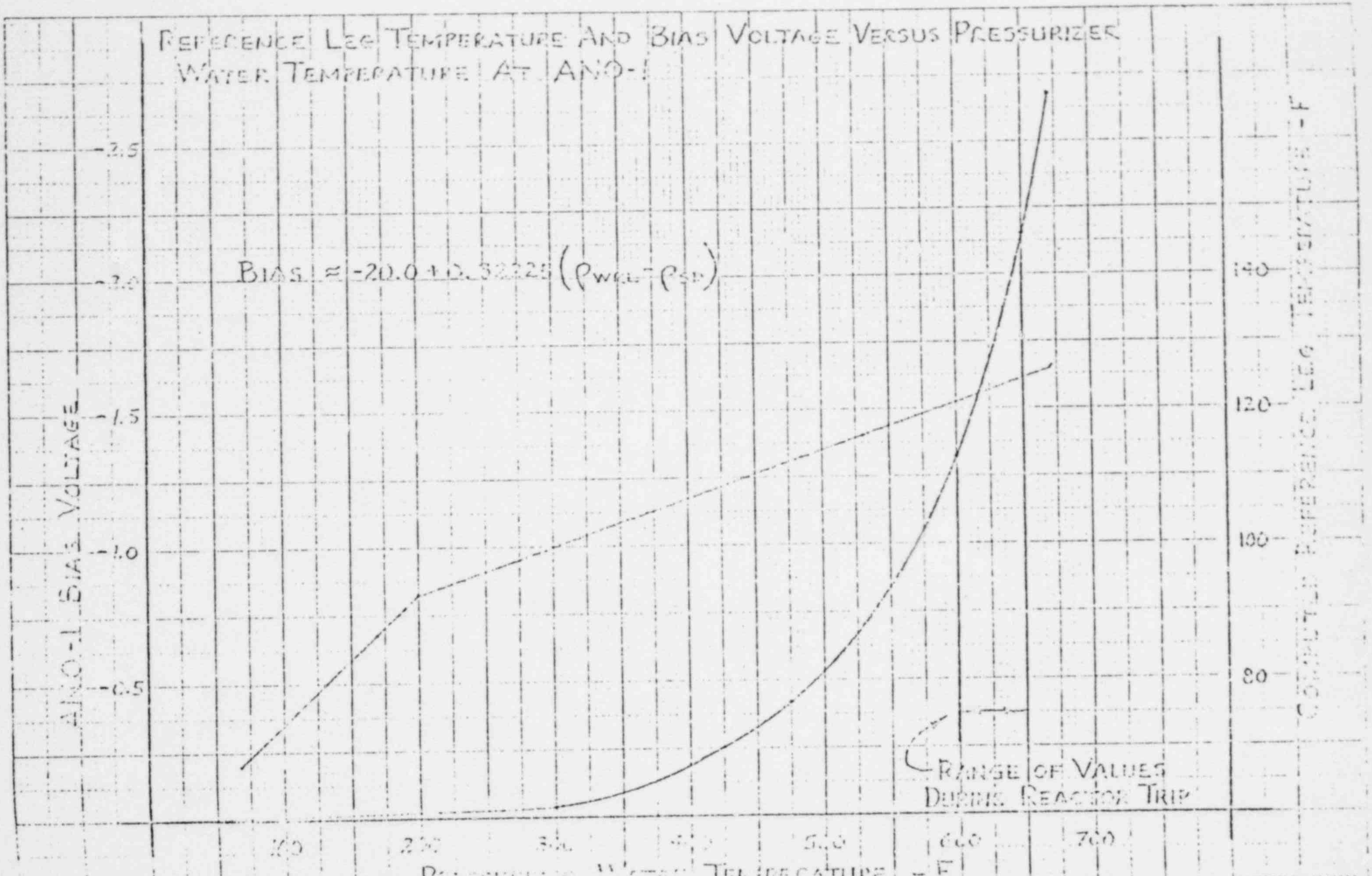

Reference Leg Temperature And Bias Voltage Versus Pressurizer Water Temperature At ANO-1
Bias = -20.0 + 0.32225 (ρ_{WELL} - ρ_{SP})
ANO-1 Bias Voltage
-2.5
-2.0
-1.5
-1.0
-0.5
Computed Reference Leg Temperature - F
140
120
100
80
Range of Values During Reactor Trip
700
Pressurizer Water Temperature - F

FIG 16

Variation in Bias Voltage Versus Water Temperature for Different Values of Reference Leg Temperature at ANO-1

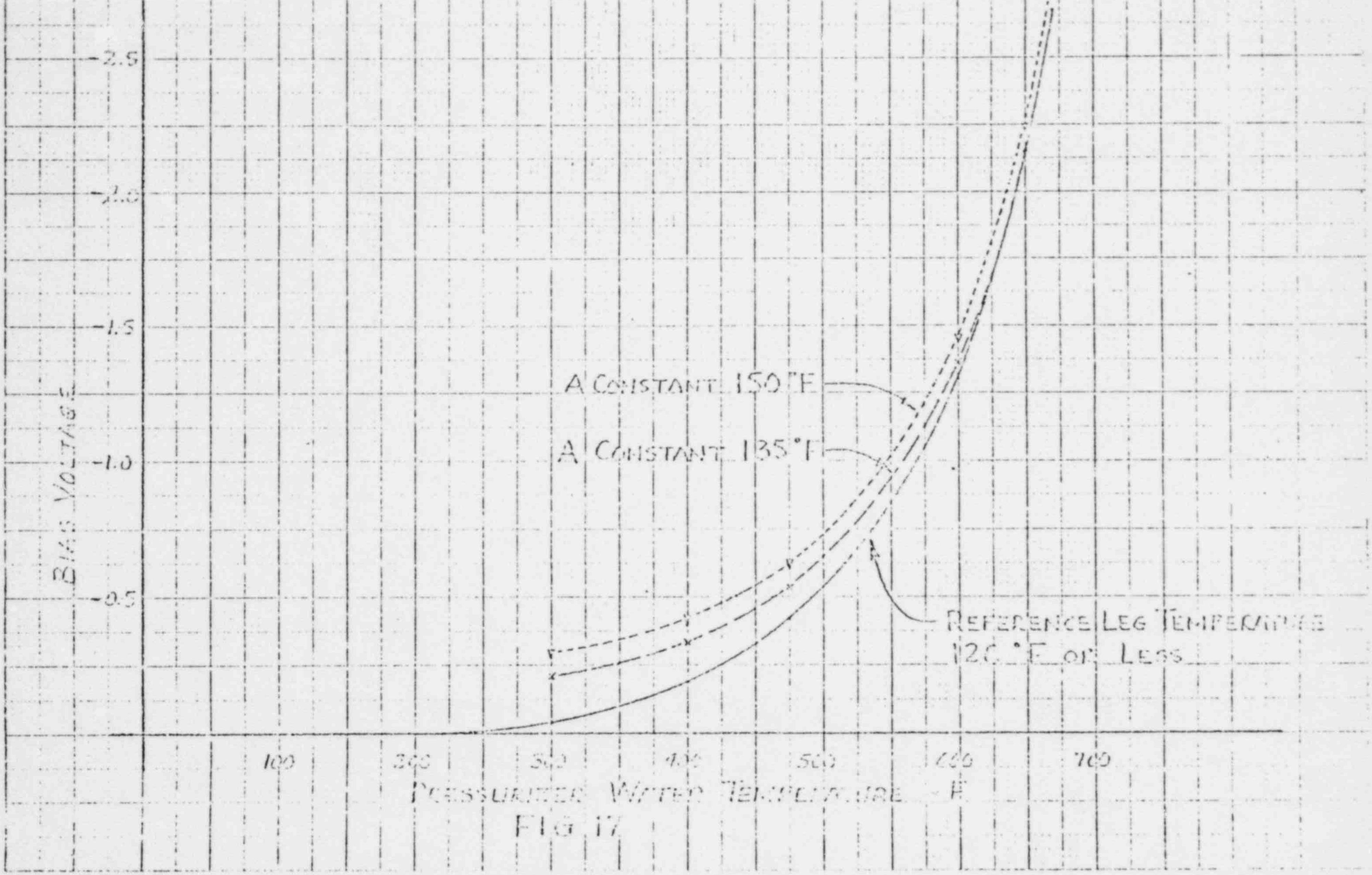
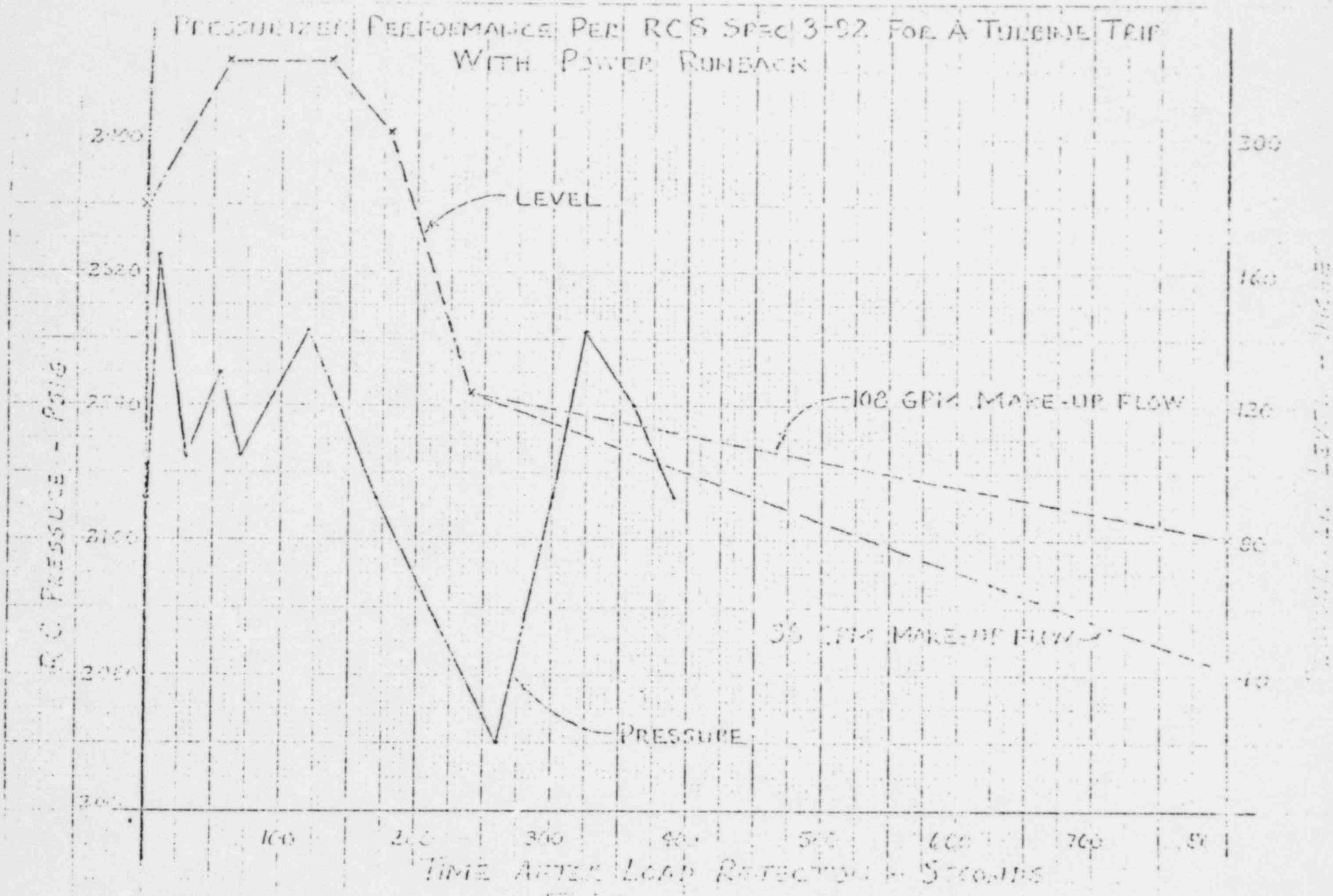


FIG 17


PRESSURIZER PERFORMANCE PER RCS SPEC 3-92 FOR A TURBINE TRIP
WITH POWER RUNBACK
LEVEL
108 GPM MAKE-UP FLOW
PRESSURE
R C PRESSURE - PSIG
2320
2100
100
300
TIME AFTER LOAD REJECTION - SECONDS

FIG

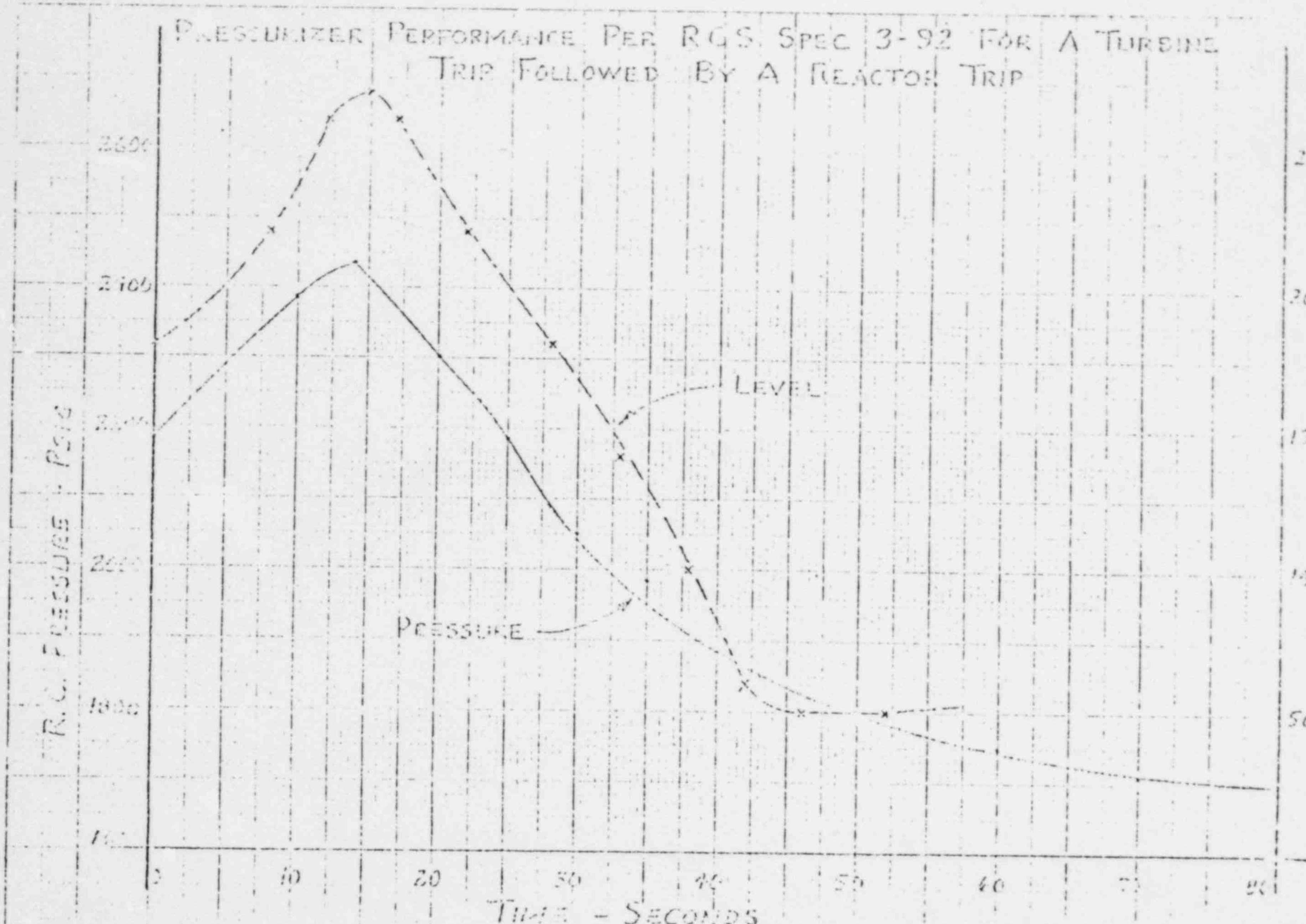

PRESSURIZER PERFORMANCE PER RCS SPEC 3-92 FOR A TURBINE TRIP FOLLOWED BY A REACTOR TRIP
LEVEL
PRESSURE
R.C. PRESSURE - PSIG
2400
2100
1800
50
TIME - SECONDS
0
10
20
40
60
80

FIG 19

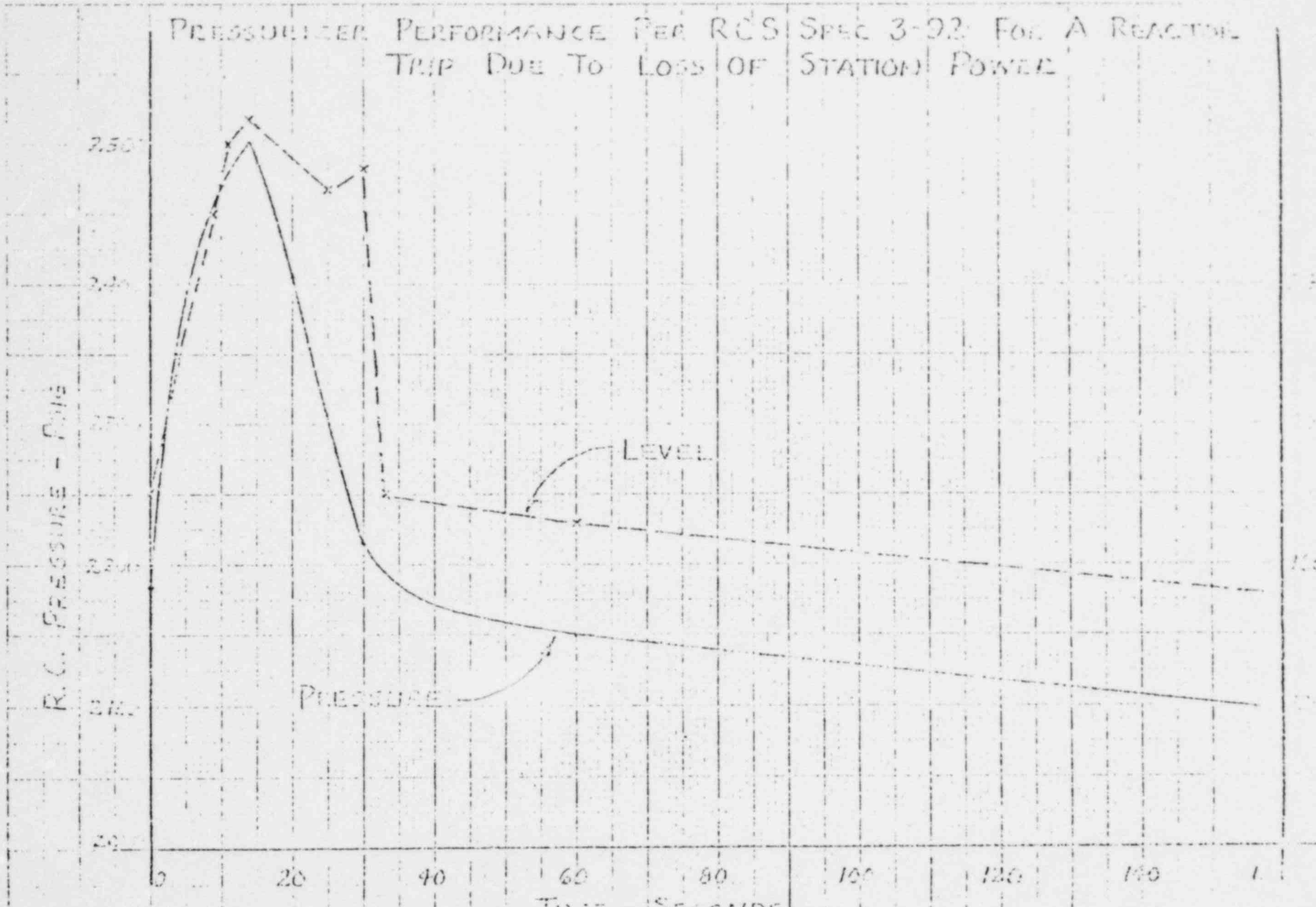

PRESSURIZER PERFORMANCE PER RCS SPEC 3-92 FOR A REACTOR TRIP DUE TO LOSS OF STATION POWER
R.C. PRESSURE - PSIG
2250
2200
LEVEL
PRESSURE
0
20
40
60
80
120
140
TIME - SECONDS

FIG. 20