Attachment 1

PRESSURE MITIGATING SYSTEMS TRANSIENT ANALYSIS RESULTS

Prepared by

WESTINGHOUSE ELECTRIC CORPORATION

for

THE WESTINGHOUSE OWNERS GROUP

ON REACTOR COOLANT SYSTEM

OVERPRESSURIZATION

JULY 1977

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ABSTRACT

The results of pressure transient analyses for the reactor coolant system of a pressurized water reactor during low-temperature, water solid operation are presented for particular cases of either mass or heat input to the system. The analyses were performed using conservative bounding input parameters plus parameter sensitivity studies to provide for results applicable to plant specific parameters. For the cases presented, the use of a nominal, two-inch air-operated relief valve, such as the pressurizer power operated relief valve, is shown to mitigate the pressure transient without the need for immediate operator intervention. A procedure is presented for selection of the relief valve setpoint to avoid violation of the 10CFR50 Appendix G pressure limitation for the reactor vessel.

SECTION 1
INTRODUCTION

1.1 PURPOSE OF STUDY

During the past few years (1972 to 1976) a number of events have occurred at operating PWR plants in which the reactor coolant pressure exceeded the allowable limit for the particular temperature as prescribed by the requirements of 10CFR50 Appendix G, during low-temperature, low-pressure, water solid modes of operation. These overpressure events were caused by either equipment malfunction, incorrect operator action or a combination of the two. In the vast majority of the events, the unscheduled pressure transient was recognized by the operator and terminated by manual action.

The purpose of this study was to evaluate the performance of a pressure mitigating system using pressurizer power operated relief valves for the causative events and plant parameters which bound the plants under consideration. The study included an evaluation of the overpressure events which have occurred and a review of the existing design features and operating practices to select for the analysis that group of causative events and pertinent plant parameters which encompass the operating plants within the W Owners Group.

1.2 REVIEW OF PAST EVENTS

Using the published records of Abnormal Occurrence Reports and information provided to the industry by the NRC in June 1976 (see Appendix C) an evaluation was made of the type of events which had occurred, their causative factors and the plant conditions at the time of the event. This review led to the general conclusion that 24 of the 29 reported events could be divided into the two major categories of either mass input or heat input to an isolated constant volume of reactor coolant. The other 5 events were either of unknown origin (3) or were caused by operators following inadequate procedures while controlling the reactor coolant pressure.

The review demonstrated that of the 18 events caused by mass input to the reactor coolant system, by far the greatest number (14) involved a mismatch between the charging and letdown flows. In all but one of the events, the mismatch was caused by a loss of letdown flow while the charging system remained in operation with a relatively low rate of mass input.

The remaining 4 mass input events were the result of an abnormal actuation of portions of the safety injection system. In the one event involving pumps, a single safety injection pump was started by an operator and flow inadvertently entered the reactor coolant system. In the other 3 events, the accumulator isolation valves were deliberately opened by the operator or inadvertently opened by a spurious signal from the engineered safety features actuation circuits. (Of course, pressurization caused by the accumulators is self limiting due to the relatively low gas pressure maintained in the accumulator.)

For the majority of the mass input caused pressure transients, the abnormal condition was recognized by the operator and terminated by operator action. However, the limit of the magnitude of the pressure transient in most cases was a direct result of the speed of the operator in recognizing the situation and taking remedial action.

Among the few (6) events attributed to the heat input case, five of the events reported were those in which a temperature asymmetry was allowed to develop in the reactor coolant system, generally due to insufficient mixing. Then, when a reactor coolant pump was started, the cooler volumes of reactor coolant would circulate around the system and be heated by warmer sections of the system, particularly the steam generators. These heat input events are self limiting in that the temperatures eventually equalize and past experience has indicated that the magnitude of the pressure transient is not great. One event was the result of removing heat from the coolant such that the temperature was allowed to decrease to a temperature too low for the coolant pressure being controlled at the time.

1.3 SELECTION OF PARAMETERS FOR STUDY

1.3.1 Relief Valve

The pressurizer power operated relief valves were selected as the logical mechanism for mitigating reactor coolant pressure transients because the hardware already exists on the operating plants. The valves are typically 2 inch nominal body size globe valves each located in a 3 inch line. Their normal function is to relieve reactor coolant pressure at operating plant conditions so the extension of the function to provide relief at a lower pressure is a natural utilization of the function. Since the power relief valve is controlled by an instrumentation system using electrical signals, the implementation of the function to a lower pressure range can be easily accomplished by electrical circuitry independent of the existing logic circuits which need not be affected. The reference relief valve model described in Section 2.2 was developed based on the general characteristics of a typical power operated relief valve.

1.3.2 Reactor Coolant Volume

The operating plants in the owners group to which this study is directed consist of 2, 3 and 4 loop plants with various designs of reactor vessels, steam generators and pressurizers such that reactor coolant volume enclosed varies widely. To bound all of the plants, the study considered the use of two extreme volumes; 6000 and 13,000 cu.ft. in all of the cases evaluated for both mass input and heat input.

1.3.3 Reactor Coolant Pressure

For the mass input cases, two initial reactor coolant pressures were considered but it was found that for the particular cases studied, the pressure transient was well defined at the time the relief valve setpoint was reached and there was a negligible effect on the relief valve performance due to the difference in starting pressure. Therefore for conservatism, the majority of the mass input cases were started from a coolant pressure of 50 psig to assure that the mass input mechanism was always at full performance before the mitigating relief valve came into operation.

The heat input cases which involved the operation of a reactor coolant pump were restricted to a minimum initial pressure of 300 psig because of a pump shaft seal requirement. Again for conservatism, this minimum pressure was used in all the analyses to assure that the pressure transient was allowed to become well established before the mitigating relief valve was brought into operation.

1.3.4 Reactor Coolant Temperature

The initial reactor coolant temperature selected for use in the analyses was based on a review of the credible operating conditions which might be experienced in a plant when in a low-temperature, low-pressure water solid condition. For all of the mass input cases, the reactor coolant was considered to be at a cold shutdown temperature of 100°F (see Section 5.3 for additional discussion of this parameter) and the pressurizer filled solid with water at 100°F (see Section 6.1 for additional discussion).

The heat input cases were studied with various values of initial reactor coolant temperature from 100°F to 250°F, the maximum range of temperature which might be expected for operation in a water solid condition. Over this range, as was expected, the heat input transients became more severe with the higher temperatures but the allowable coolant pressure, according to the 10CFR50 Appendix G rules, also increases.

1.3.5 Mass Input Mechanisms

The review of past experience indicated that the case of a loss of letdown while charging flow continued was the most likely cause of a pressure transient. Among the operating plants, there are charging system designs which consist of positive displacement pumps, centrifugal type pumps and combinations of the two. The lowest normal flow rate occurs in those plants with small positive displacement pumps where a representative flow rate is about 40 gpm.

The maximum normal charging flow rate occurs in those plants with centrifugal type pumps where a representative flow rate is about 120 gpm. The design mass input cases due to loss of letdown flow were therefore considered to be between 40 and 120 gpm.

Although there has been only one occurrence of inadvertent mass injection due to the operation of a safety injection pump, and these pumps are normally made inoperative during low-temperature low-pressure plant operation, the potential does exist for this type of mass input transient. Therefore, the analyses was extended to include the performance of the mitigating system for the case of a single safety injection pump being placed in operation (see Section 2.3).

The safety injection accumulators were not considered as a credible mass input mechanism for this study because there are multiple administrative controls to ensure isolation including de-energizing valve control circuits during plant shutdown operations.

1.3.6 Heat Input Mechanisms

The pressure transient events selected for study involved the cases where a temperature asymmetry was formed in the reactor coolant system in which the steam generators were at a higher temperature than the remainder of the system. The magnitude of the temperature difference between the steam generators and the reactor coolant system is dependent on the previous plant operations which allowed the asymmetry to develop. For the purpose of this study to bound the possible events, temperature differences between the steam generators and the reactor coolant system up to 100°F were evaluated. However, it is considered realistic to assume a maximum temperature difference of 50°F as the design case because much higher differences are difficult to develop and are easily recognized by the operator as abnormal conditions requiring special attention.

1.4 SUMMARY OF PARAMETERS

1.4.1 General

The plants represented by the W Owners Group comprise a group of 2, 3 and 4 loop pressurized water reactor plants, each with one steam generator and one reactor coolant pump per loop. Typical total reactor coolant system volumes for the plants under consideration range between about 6000 cu.ft. and 13,000 cu.ft., and these two volumes were therefore used for this study.

1.4.2 Reference Relief Valve

The relief valve selected for use in the study as described in Section 2.2 exhibits the following general characteristics:

1. Opening time; 3 seconds
2. Closing time; 5 or 20 seconds
3. Flow capacity; C_v = 50 gpm/$\sqrt{psi}$ per valve
4. Set pressures, various; 400, 500 and 600 psig

1.4.3 Mass Input Cases

The following two representative mass input cases as described in Section 2.3 were considered:

1. Charging flow with letdown isolated; 40 and 120 gpm
2. Inadvertent operation of one safety injection pump; 870 gpm at 500 psig

The following parameters were considered for the mass input cases:

1. Temperature of reactor coolant; 100°F
2. Temperature of injected water; 100°F
3. Initial pressure of coolant; 50 or 450 psig

1.4.4 Heat Input Cases

The temperature asymmetry conditions selected for study as heat input cases are discussed in Section 2.4. The following are the cases considered for both a 6000 and 13,000 cu.ft. plant size:

RCS/SG ΔT

Reactor Coolant Temperature / Steam Generator Temp.	100	140	180	250
150	50	---	---	---
190	---	50	---	---
200	100	---	20	---
230	---	---	50	---
240	---	100	---	---
250	---	---	---	---
280	---	---	100	---
300	---	---	---	50

SECTION 2
CALCULATION METHOD

2.1 LOFTRAN PROGRAM AND SPECIAL MODELING

The one loop version of the LOFTRAN † program was utilized to perform the mass input analyses and the four loop version was utilized for the heat input analyses. No changes to either version of the program were necessary for the studies. However, some input modeling, input additions and initialization changes were required as described in the following paragraphs.

2.1.1 Mass Input Analysis

No special features of LOFTRAN were required for the mass input cases. However, some input adjustments were made to ensure that the mass input model was representative of the conditions specified for analysis.

One such adjustment was made to ensure that an isothermal condition was maintained. Since LOFTRAN was not programmed to be initialized at zero power, a very small, constant power level was maintained and nominal, full reactor coolant flow was maintained. This initialization condition does not alter the resultant pressure increase for actual mass input cases where the reactor coolant pumps may not be running.

To minimize the pressure defect associated with the compressibility of a saturated (hot) water solid pressurizer (a representation required by LOFTRAN to maintain the specified reactor coolant pressure), the pressurizer water volume was reduced to 100 ft^3. The

† - WCAP-7907

volume difference between a nominal pressurizer and the 100 ft^3 was incorporated into the total system volume but at an initial temperature of 100°F.

2.1.2 Heat Input Analysis

Except for the decay heat (loss of RHRS) and pressurizer heater input cases, more extensive adjustments were necessary for modeling the heat input cases.

The heat input cases analyzed involved the startup of a pump in one loop with the plant in a cold shutdown condition and with temperature asymmetries in the reactor coolant loops. Two possible asymmetries were assumed. One was the RCS/SG case, in which the steam generators, primary and secondary, were at a higher temperature than the remainder of the reactor coolant. The second considered that the water in the loop seal piping from the steam generator outlet to the pump suction was at a lower temperature than the remainder of the coolant and steam generators. In both cases the temperature of the reactor coolant in the tubes was at a temperature equal to the saturated condition of the secondary water mass.

The multiloop version of the LOFTRAN program was used to obtain the capabilities for a reactor coolant pump startup in one loop and for the reverse flow simulation in the inactive loops. To circumvent a flow initialization problem, the LOFTRAN loop out of service option was used with a very small input power (LOFTRAN does not permit zero power initialization) to establish a very low natural circulation flowrate following the pump coastdown. After initialization for the natural circulation flow conditions, the code was returned to the normal program sequence to initiate the remainder of the heat input transient.

Before the heat input transient was initiated, however, it was necessary to input the required temperature profile.

For the case of the RCS/SG temperature asymmetry, the coolant temperature was made uniform everywhere except in the steam generator tubes. The steam generator secondary temperature and the coolant temperature in the steam generator tubes were input as equal but different than the reactor coolant temperature.

For the case of the loop seal temperature asymmetry, the temperature of the coolant volume in the loop seal was input different from the temperature throughout the remainder of the reactor coolant system (including the steam generator tubes) as well as the steam generator secondary temperature.

Also in the loop seal case, steam generator outlet plenum volume was set to a very small value to minimize mixing in the reverse flow loops before the cold slug from the loop seal entered the steam generator tubes.

After temperature initialization, the input parameters of core heat flux, steam flow and feed flow were stepped from their respective initial (natural circulation mode) conditions to zero during the first time step. Reactor coolant pump startup is initiated at t = 0 seconds using the default homologous data associated with the 93A pump model.

As in the mass input case, the pressurizer volume was minimized (set equal to 100 ft^3) and the difference in pressurizer volume (actual - 100 ft^3) was added to the inactive volume of the reactor coolant.

2.2 REFERENCE RELIEF VALVE MODEL

The relief valve model selected as the reference for use in the transient analyses describes a nominal two inch air-operated open-close valve with a linear plug characteristic. The capacity of the valve is based on a standard geometry globe-type valve with a flow coefficient C_v equal to 50; where the flow coefficient is defined as the flow of water at 60°F, in gallons per minute, at a pressure drop of one pound per square inch across the valve while the valve is in the full open position. (i.e., $C_v = Q/\sqrt{\Delta p}$)

Since the reference relief valve is considered to discharge into the pressurizer relief tank, there will be a backpressure at the valve discharge depending on the conditions in the relief tank at the time of valve actuation. The gas blanket pressure in the relief tank normally will not exceed 10 psig but the pressure can increase, due to repeated relief valve discharges, to a maximum of 100 psig at which time a rupture disk on the tank will open to prevent a further increase in pressure.

The flow capacity of the reference relief valve versus upstream pressure (reactor coolant pressure) is shown for various values of backpressure on Figure 2.2.1. All of the short-term transient analyses (one relief valve cycle) presented in this study were based on the flow capacity of the reference relief valve subjected to a constant backpressure of 10 psig. (See Section 6.2 for additional discussion.)

The reference relief valve was considered to have a linear flow characteristic; that is, the flow through the valve at a constant differential pressure is directly proportional to the lift of the stem. This selection is consistent with the type of valve used as the pressurizer power-operated relief valve in the operating nuclear plants. However, the effect of using a non-linear valve type (see Figure 2.2.2) was also investigated to see if the performance of the system would be improved by changing to a special plug-seat design. The opening and closing time characteristics of the non-linear valve were taken as the same as the reference linear valve.

The opening and closing characteristics of the reference relief valve used in the transient analyses were based on a particular but typical type of operator used to drive the valve stem. The reference operator was taken as an air diaphragm type with a stroke of 3/4 inch, a diaphragm area of 220 sq.in. and a compressed spring to hold the valve closed. The air pressure range required to stroke the valve was taken as 11 to 64 psig; that is, the valve stem starts to move with 11 psig pressure on the diaphragm and reaches the full stroke of 3/4 inch under a pressure of 64 psig.

When the relief valve is signalled to open, air is admitted into the piping to the valve and into the diaphragm chamber. The air continues to flow into this volume for a period of time, depending on the controlling restriction in the line, and increases the pressure until the unit pressure on the diaphragm reaches 11 psig. At this pressure, the force on the diaphragm equals the spring force holding the valve closed and a further increase in air pressure will cause the valve stem to begin to move and open the valve. For the reference valve model, this initial time delay, before the valve starts to move, is about 20% of the total time for the valve to act and is shown on Figure 2.2.3.

After the valve starts to move, the air flow into the diaphragm chamber continues to both increase the pressure to overcome the spring force and to fill the additional volume made available as the stem moves. When the valve reaches the full open position the air pressure in the diaphragm chamber is 64 psig, but since the supply pressure could be as high as 100 psig the air continues to flow into the diaphragm chamber after the valve movement has stopped until the chamber pressure equals the supply pressure. Figure 2.2.3 describes the valve stem movement (stroke) versus normalized time for the reference valve supplied from a normal 100 psig air system.

The valve is considered to be held open by the excess air pressure in the diaphragm chamber until receipt of a signal to close. Until the excess air has vented down from 100 psig to 64 psig, the valve stem will not move. This time delay of about 16% of the total time for the valve to act is shown on Figure 2.2.4. As the air pressure decreases below 64 psig, the stem begins to move under the action of the compressed spring and air flows out of the diaphragm chamber to both decrease the pressure and to remove a volume of air necessary to allow the diaphragm to move. At an air pressure of 11 psig, the valve will be in the full closed position but air will continue to vent from the diaphragm chamber until the pressure is equalized with the atmosphere. Figure 2.2.4 describes the valve stem movement (stroke) versus normalized time for the reference valve.

In the analyses presented in this study, the relief valve characteristics used to mitigate the pressure transients are described by the use of the three Figures 2.2.1, 2.2.3 and 2.2.4. For instance, if a reactor coolant pressure of 500 psig is reached during an increasing pressure transient at a time equal to 1/2 the valve stroke time, then the flow rate of water at 100°F through the valve at that instant is:

$$1107 \text{ gpm (Figure 2.2.1)} * \sqrt{\frac{62.4}{62.1}} * 0.395 \text{ (Figure 2.2.3)} = 438.3 \text{ gpm or } 60.5 \text{ lb/sec}$$

The total time for the reference relief valve to act in the opening direction was taken as 3.0 seconds which is about 1 second longer than a typical power operated relief valve in an operating plant. This total time includes a 0.6 second time delay (20% of total time) from the receipt of the signal until the relief valve starts to open. The time in the transient when the valve open signal was received was varied, to simulate different values of the valve setpoint between 400 and 600 psig, to obtain the effect of the setpoint on peak transient pressure.

After the reference relief valve has opened and turned the pressure transient from an increasing to a decreasing transient, the relief valve is assumed to receive a close signal when the pressure has decreased to a value 20 psi below the original setpoint. This value of the reset pressure was used in all of the analyses in which a full valve cycle was evaluated. Upon receipt of the signal to close at the time in the transient when the pressure was 20 psi below the valve setpoint pressure, the valve was closed using the characteristic shown by Figure 2.2.4 where the total time was taken as either 5 or 20 seconds.

In the transients which did not result in full opening of the reference relief valve (e.g., letdown isolation with continued charging pump operation) the stroke position in effect at the time the reset pressure was reached was the initial position used for the start of valve closure. If other than fully open, the time delay in Figure 2.2.4, associated with depressurization of the diaphragm chamber from 100 psi to 64 psi, is not in effect. Further, the total closing time is accordingly reduced in relation to the stroke position at reset pressure.

FIGURE 2.2.1

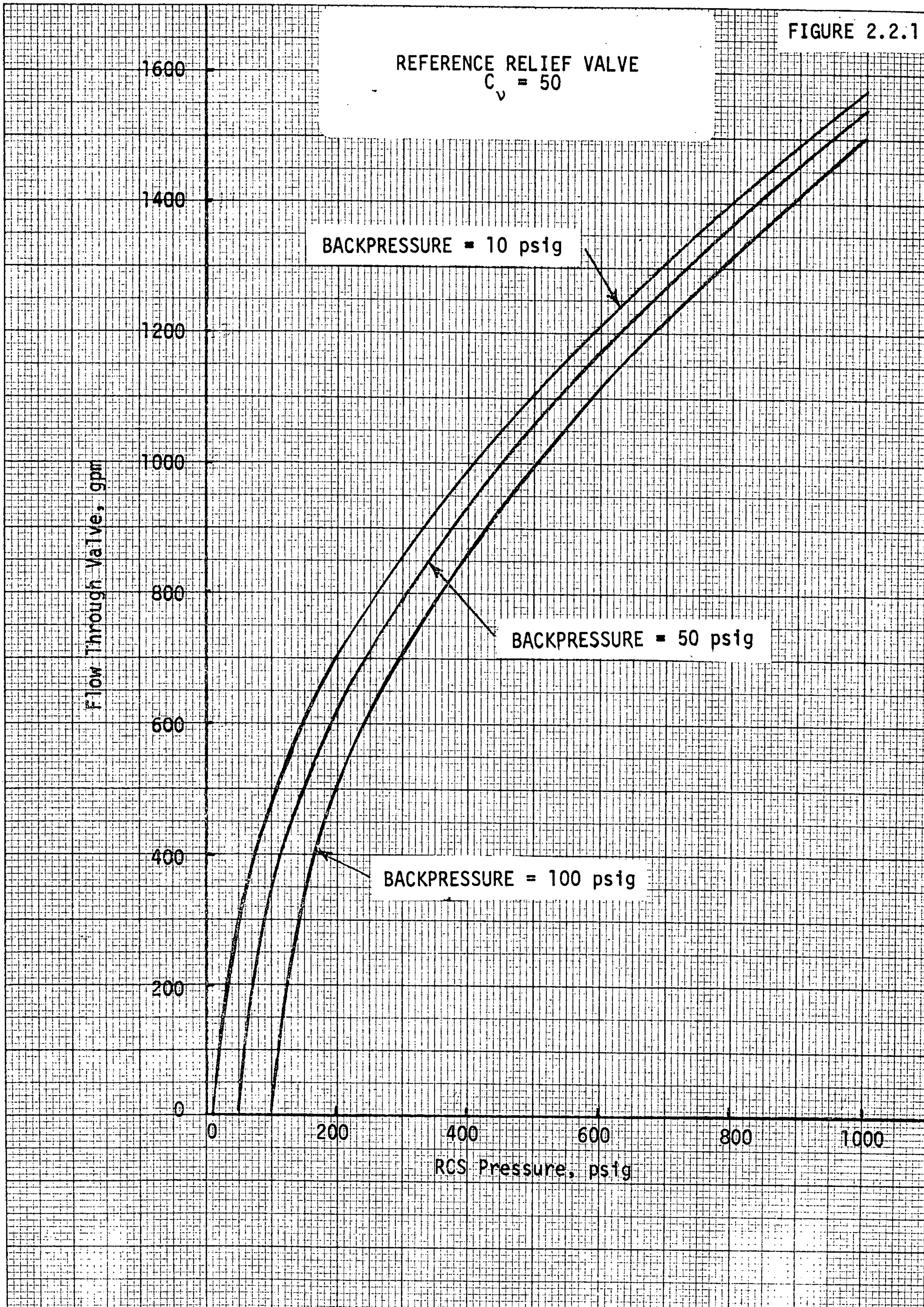
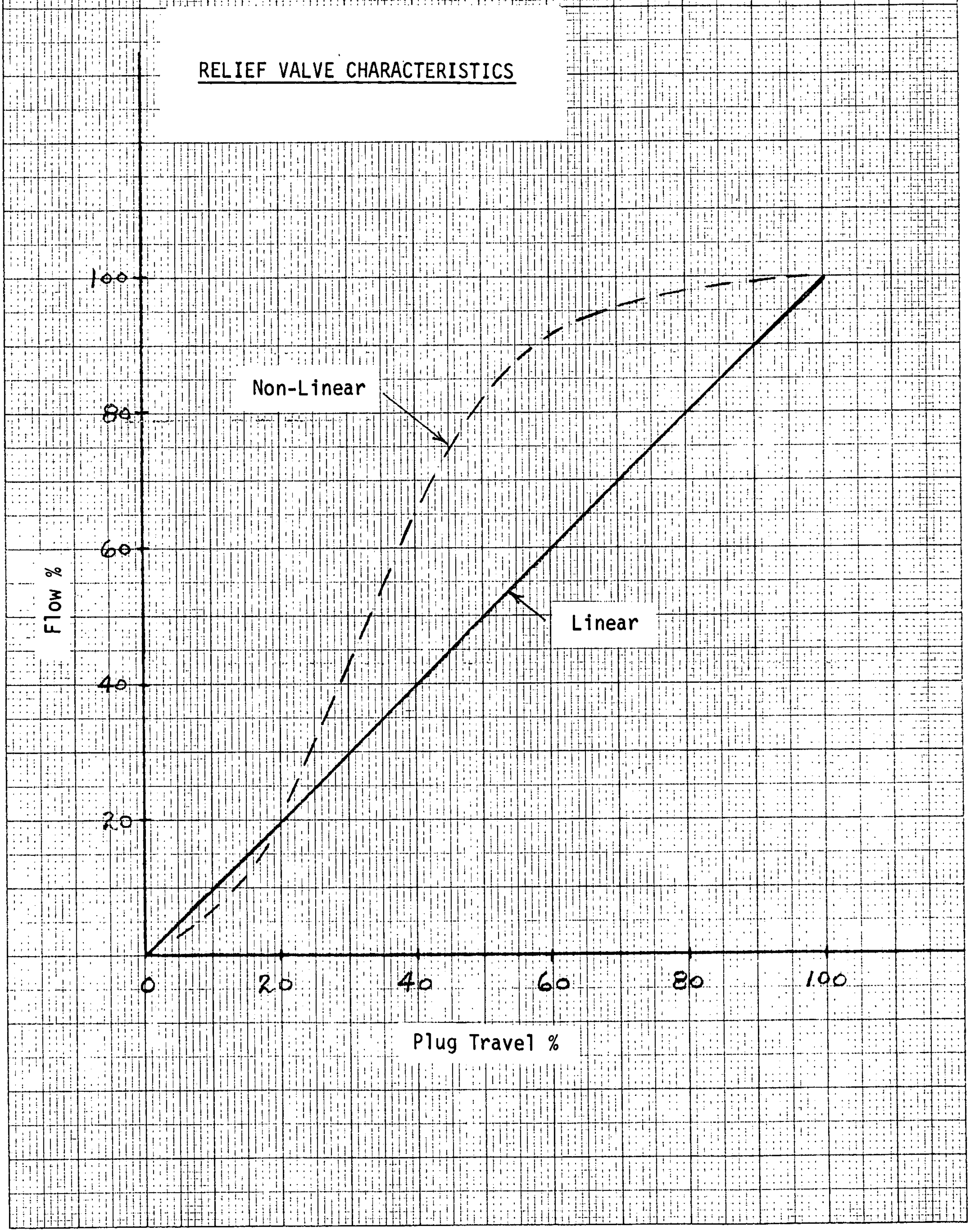

REFERENCE RELIEF VALVE
C_ν = 50
BACKPRESSURE = 10 psig
BACKPRESSURE = 50 psig
BACKPRESSURE = 100 psig
Flow Through Valve, gpm
RCS Pressure, psig
0
200
400
600
800
1000
1200
1400
1600
0
200
400
600
800
1000

FIGURE 2.2.2



RELIEF VALVE CHARACTERISTICS
Non-Linear
Linear
Flow %
Plug Travel %
100
80
60
40
20
0
20
40
60
80
100

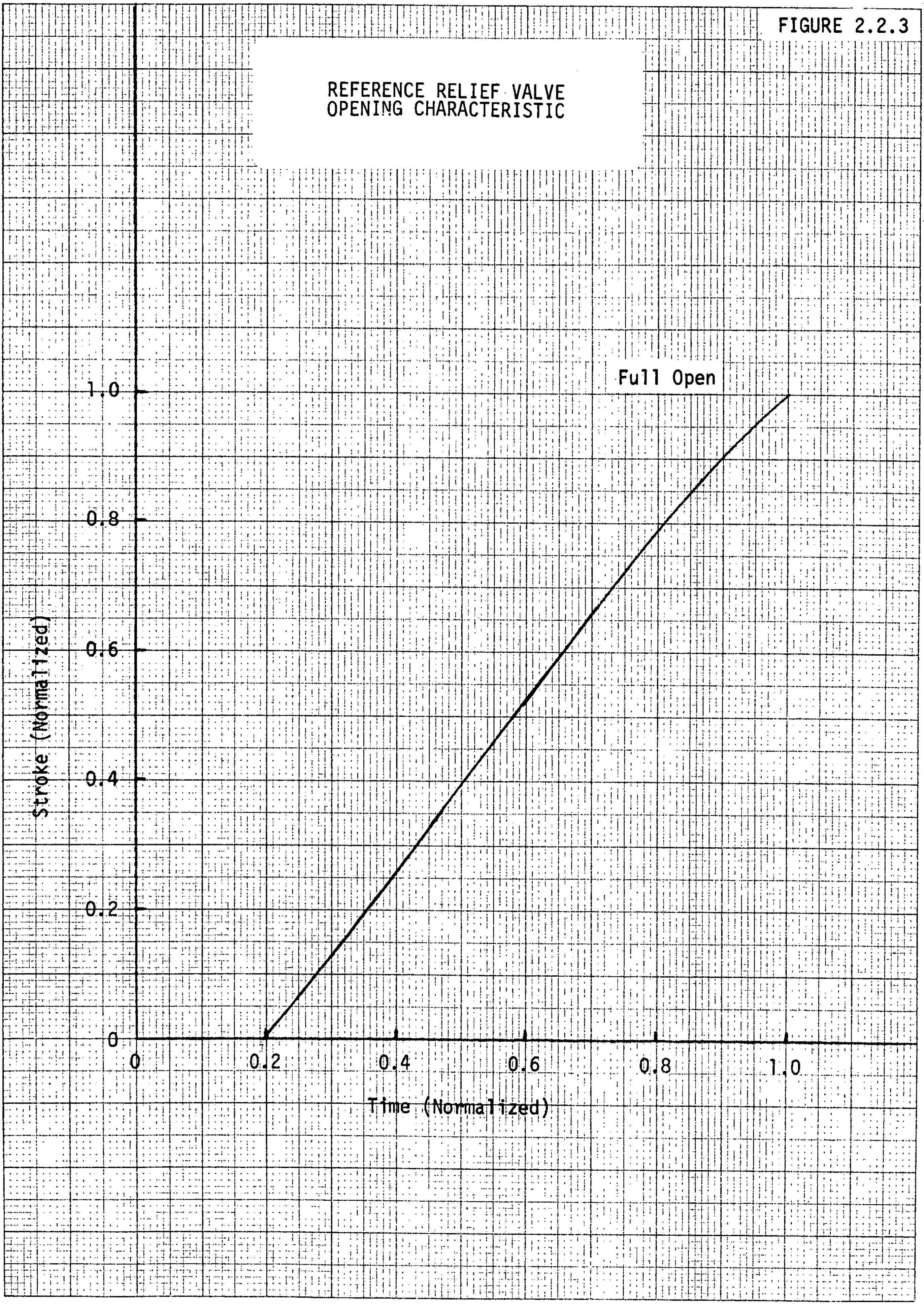


FIGURE 2.2.3
REFERENCE RELIEF VALVE
OPENING CHARACTERISTIC
Full Open
Stroke (Normalized)
1.0
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1.0
Time (Normalized)

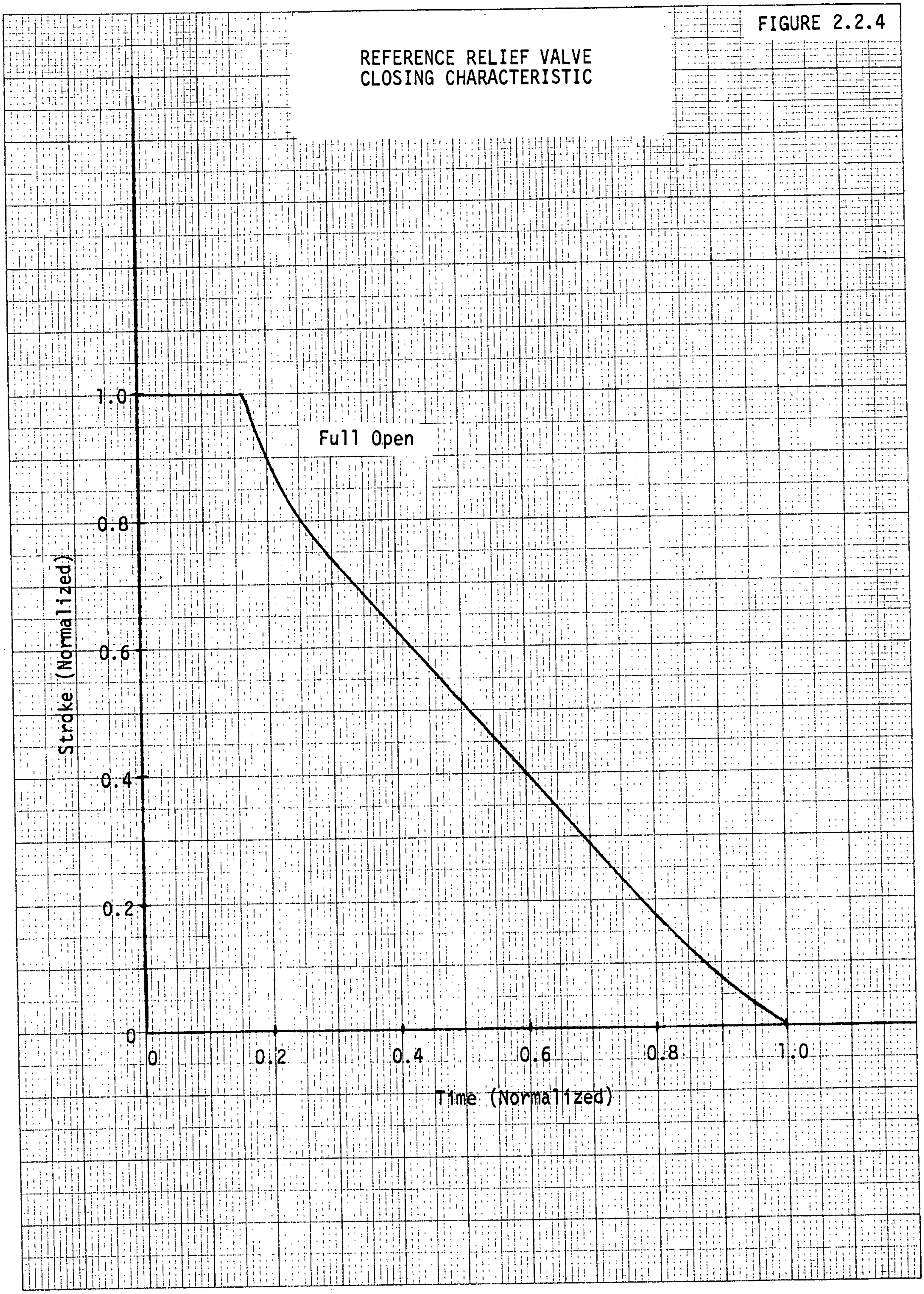


FIGURE 2.2.4
REFERENCE RELIEF VALVE
CLOSING CHARACTERISTIC
Full Open
Stroke (Normalized)
1.0
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1.0
Time (Normalized)

2.3 MASS INPUT MODEL

The two credible means of adding excess mass to the reactor coolant system while the plant is in a relatively cold (100°F) solid-water mode of operation are by creation of a mismatch between the charging and letdown flows or by inadvertently placing a safety injection pump in service. The most likely event as evidenced by the experience of the operating plants is the charging/letdown mismatch case. However, the inadvertent start of a safety injection pump has the potential for greater rates of mass input and hence more rapidly increasing coolant pressure transients. Therefore, the inadvertent start of a safety injection pump with the plant in a cold shutdown condition was selected as the limiting case.

Two particular cases of a mismatch between charging and letdown flows were evaluated; one considering the use of a positive displacement pump and the second a large centrifugal type pump. For both of these cases, the transient was initiated from the steady state condition of equal charging and letdown flows by terminating the letdown flow in a ramp fashion, as would occur if a valve in the letdown line was inadvertently closed. For the positive displacement pump case, the charging flow was considered to remain constant as the backpressure increased, while for the centrifugal pump case, the flow was considered to decrease with increasing backpressure as the flow was passed through a piping system with a constant resistance (Figure 2.3.1).

The flow from the positive displacement pump was taken as 40 gpm, a relatively typical low charging flow rate for a plant shutdown condition, while for the centrifugal pump case the charging flow was taken as 120 gpm, a relatively high value for normal charging service.

In the operating nuclear plants, there are various designs of safety injection systems and several types of pumps in use. A survey of the various systems and pumps resulted in the selection of four typical system delivery characteristics and these are shown on Figure 2.3.2. Each of the characteristics shown on Figure 2.3.2 represents the maximum expected flows into the reactor coolant system against various backpressures for the case of a single, new, non-degraded pump delivering through all the available injection flow paths.

From an inspection of Figure 2.3.2, it is evident that the system represented by Curve C is the worst case in that the system delivery into the reactor coolant system is the greatest of all the systems shown over the reactor coolant pressure range of 400 to 600 psig, the range of most interest for the transient analyses. Therefore, the system delivery described by Curve C was used in the study and is referred to as the reference safety injection pump startup case.

From test data on typical safety injection pumps, it was determined that the motors under full voltage will bring the pumps to full speed in a little over 2 seconds. Therefore, in the study, the reference SI pump was considered to reach full speed in 2 seconds. The flow from the pump does not begin immediately because the pump first must be brought up to a speed sufficient to develop a discharge head greater than the backpressure to which it is attempting to deliver. This delayed flow initiation is shown graphically on Figure 2.3.3 for two values of reactor coolant backpressure. This figure shows the flow rate into the reactor coolant system increases from zero to its equilibrium value in less than one second for the particular case of a 450 psig reactor coolant backpressure.

Although the startup characteristics shown by Figure 2.3.3 were used in the analyses of the pressure transients for the reference SI pump start cases, it was determined that the volume of water injected during these short pump startup periods is relatively insignificant in the analyses. Only for a specific case where the initial coolant pressure is very near the relief valve setpoint will the startup transient of the pump affect the pressure transient. For such a case, the relief valve would start to open as the pump came up to speed and the pressure transient would be mitigated earlier and more effectively.

In all mass input cases, reference SI pump startup and charging flow from either the positive displacement or centrifugal pumps, the temperature of the injected water was taken equal to the reactor coolant so that the resultant pressure transient is due to the addition of mass only and is not affected by the mixing of the injection water into the reactor coolant. (See Section 5.3 for additional discussion.)

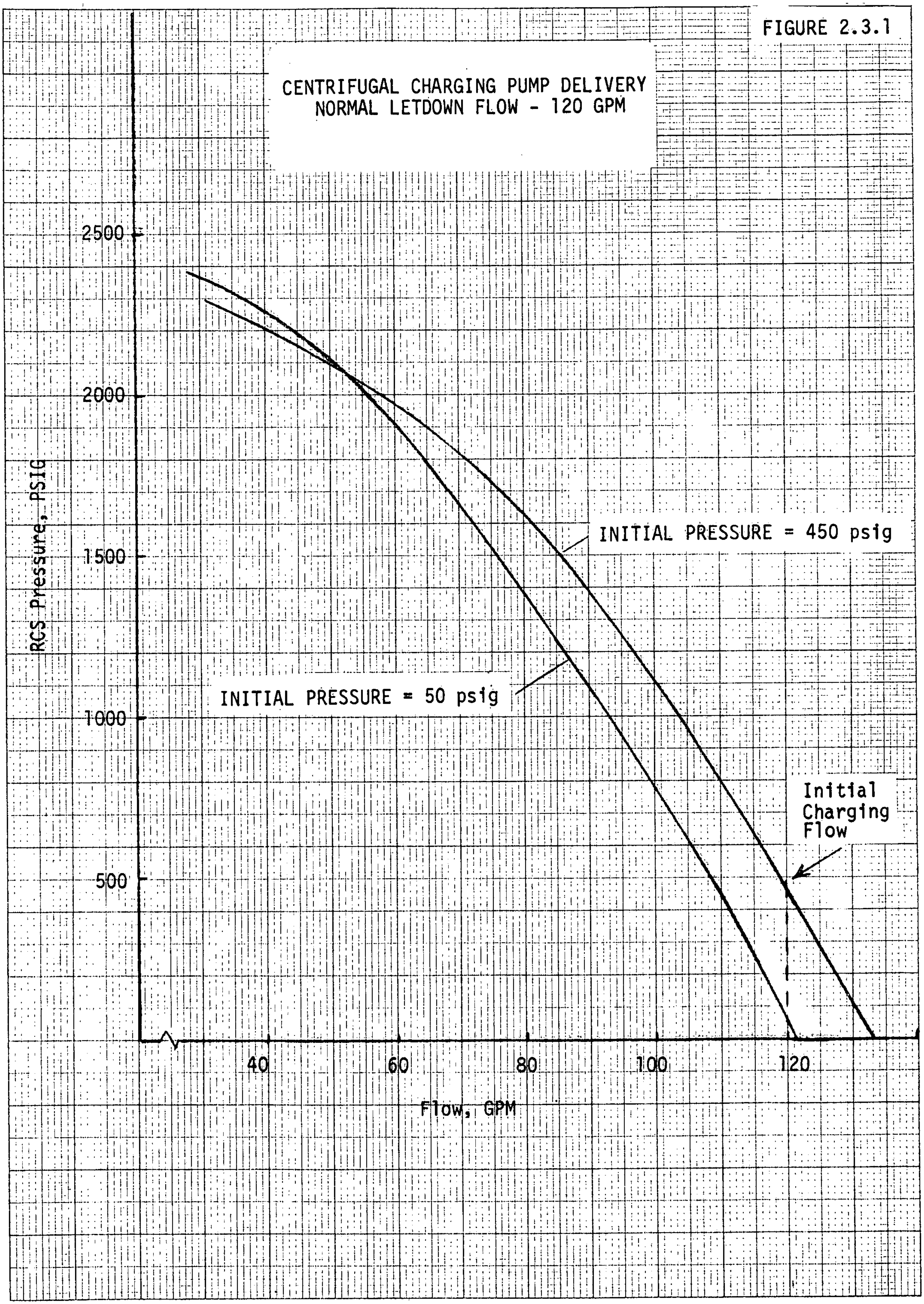
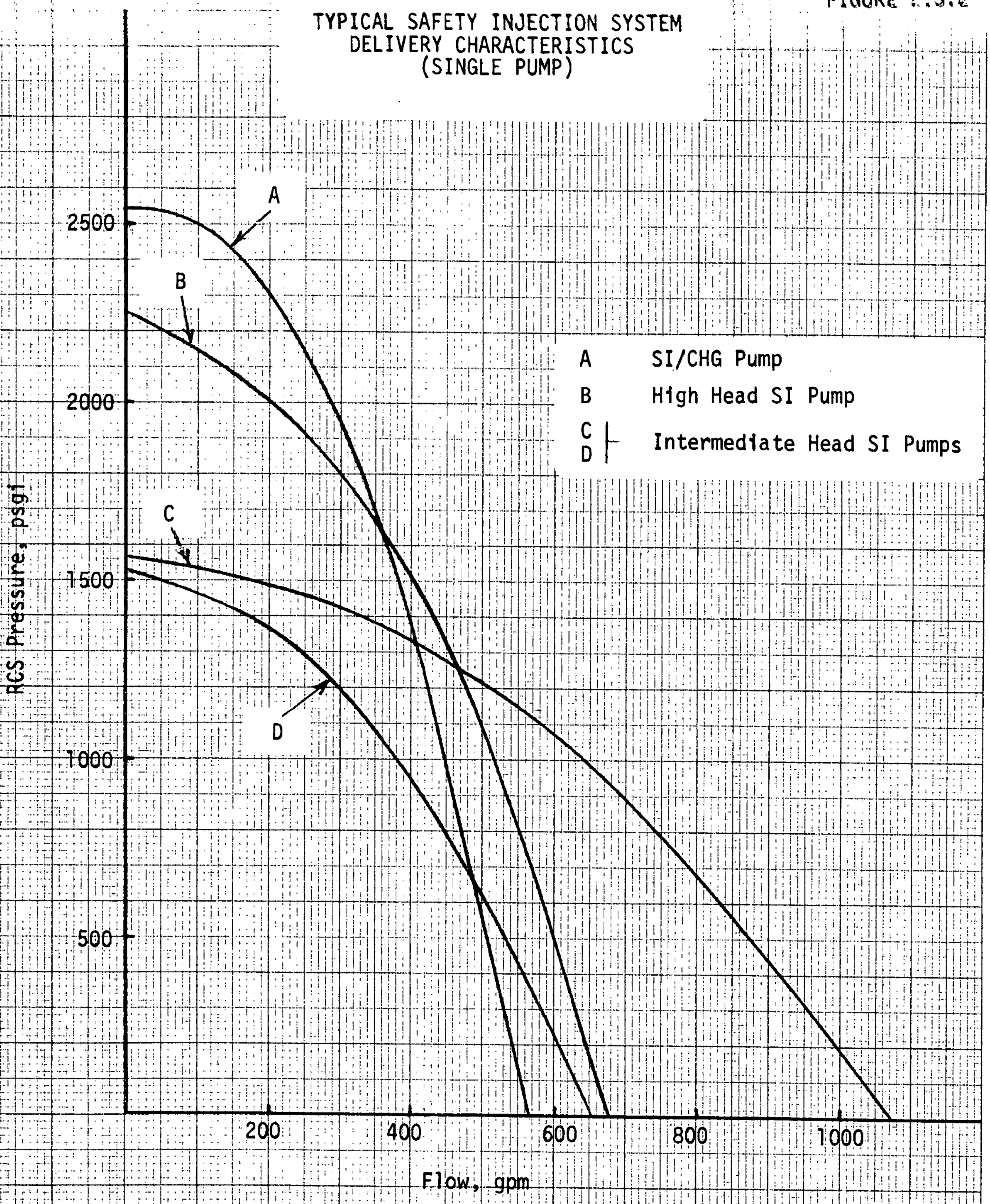


FIGURE 2.3.1
CENTRIFUGAL CHARGING PUMP DELIVERY
NORMAL LETDOWN FLOW - 120 GPM
RCS Pressure, PSIG
2500
2000
1500
1000
500
INITIAL PRESSURE = 450 psig
INITIAL PRESSURE = 50 psig
Initial Charging Flow
40
60
80
100
120
Flow, GPM

FIGURE 2.3.2

TYPICAL SAFETY INJECTION SYSTEM
DELIVERY CHARACTERISTICS
(SINGLE PUMP)

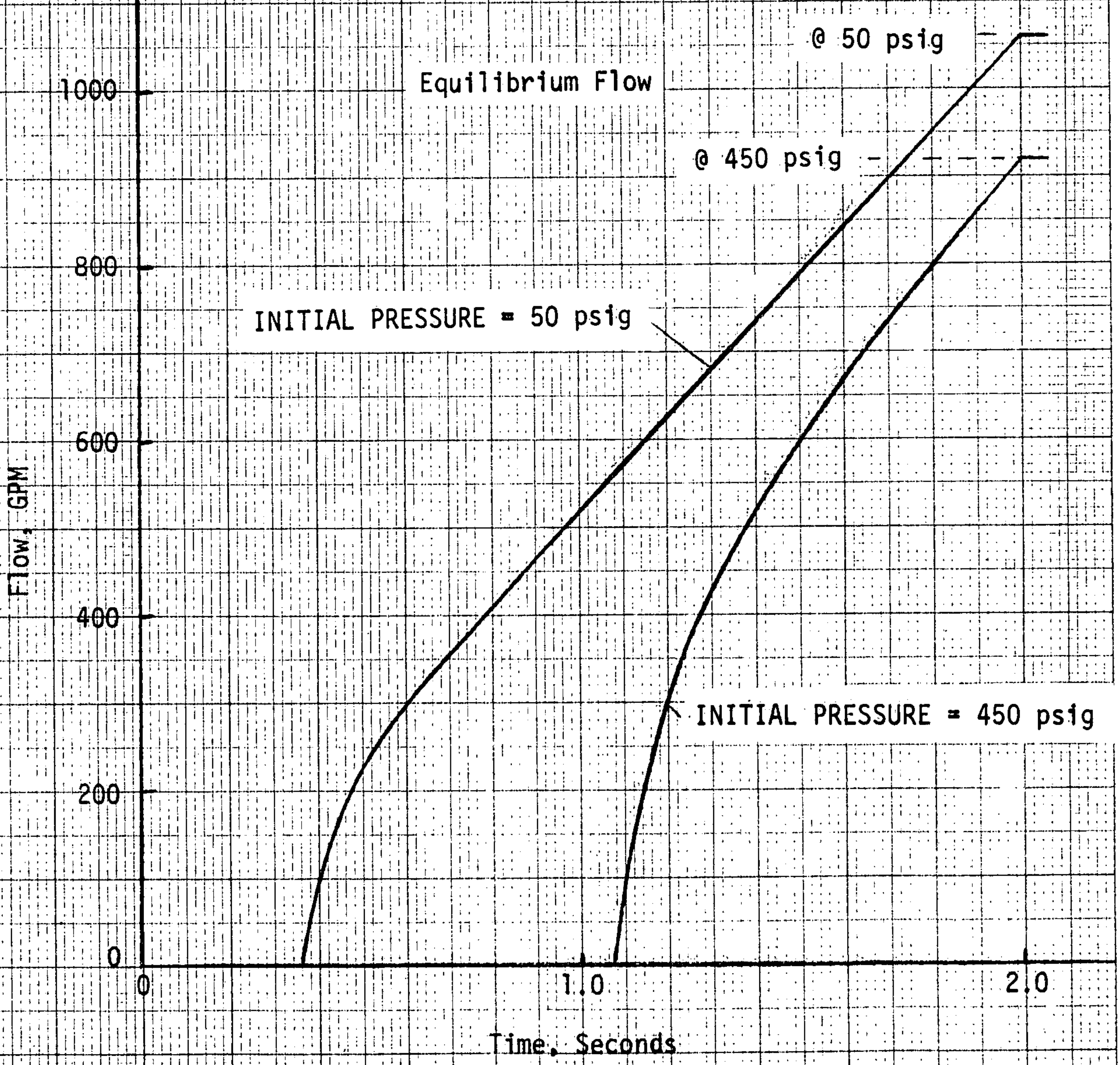


46 1320

10 X 10 TO 1/2 INCH 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 2.3.3

REFERENCE SAFETY INJECTION PUMP
STARTUP TRANSIENT



46 1320

K+E 10 X 10 TO ½ INCH 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

2.4 HEAT INPUT MODEL

The investigation of the reported events of reactor coolant pressure transients and of current plant operating practices led to the conclusion that four credible heat addition mechanisms should be studied: pressurizer heaters, core decay heat and two types of reactor coolant loop temperature asymmetry.

For the pressurizer heater case the reactor coolant system is considered to be water solid and completely isolated so that any heat input to the water in the pressurizer results in an attempt to expand the system with a consequent increase in system pressure. The reference case considered the operation of 1800 KW of heaters, the design value for a large 4 loop plant, in a relatively small pressurizer of 1000 cu.ft. volume. † This large heat input to a small liquid volume results in a conservatively high rate of change of pressure but is not significant compared with other heat input cases studied as shown by Figure 2.4.1.

The case of heat input from core decay heat was investigated considering the decay heat from an 1882 MWt design core added to a small system volume of 6000 cu.ft. 12 hours after plant shutdown from an extended high power run. This is a conservatively large relative value of heat addition, but the magnitude of the unrelieved transient pressure response still is not significant compared to other cases of heat input studied as shown by Figure 2.4.1.

The first of the two types of temperature asymmetry considered in the study occurs when the reactor coolant is at a relatively uniform warm temperature with little or no natural circulation and the cold reactor coolant pump seal injection water continues to enter the system. The cooler injection water will settle as a pool in the loop seal below the

---

† Typically there is 1 KW of pressurizer heaters for each 1 cu.ft. of pressurizer volume.

pump inlet formed by the piping from the steam generator outlet and the pump inlet (see Figure 2.4.2). The volume of cold water which can be trapped in the loop seal is determined by the piping layout and the typical volume used in the study was 140 cu.ft. in each loop. To fill this volume with cold water would require 3 to 4 hours of normal seal injection with the plant in a stagnant condition; i.e., no reactor coolant flow.

The coolant pressure transient is initiated upon starting one reactor coolant pump. As the pump comes up to speed, the coolant flow rate slowly increases in the active loop and the pool of cold water will be drawn up into the pump and discharged out to the cold leg piping and reactor vessel where it mixes with the warmer coolant. Simultaneously the cold pool of water in the inactive loop(s) will flow backward through the steam generator(s) at a flow rate significantly less than in the active loop. As each of the cold pools of water flow through their steam generators, their temperatures will be increased by the heat transferred from the secondary side, and since the coolant cannot expand in the isolated reactor coolant system volume, the coolant pressure will increase. The coolant pressure will continue to increase until the temperatures of the reactor coolant and steam generator water are equalized (see Figure 2.4.1) or the excess coolant volume due to the added heat is relieved through a relief valve.

The second type of temperature asymmetry occurs when the reactor coolant has been cooled down without sufficient circulation, for instance by use of the residual heat removal loop not augmented by the flow from a reactor coolant pump, and the steam generators remain at an average temperature higher than that of the reactor coolant. For this case, the steam generator shell, tubes, secondary water at the no-load level and reactor coolant enclosed in the tubes are assumed to be at a uniform temperature (see Figure 2.4.3). When the pressure transient is initiated by starting one reactor coolant pump, the reactor coolant flow rate increases, washing the warm water out of the tubes and replacing it with relatively cold water from the loops. The rate of flow in the active loop is significantly higher than that in the inactive loops which are subjected to reverse flow, but in all steam generators heat is transferred to the cooler reactor coolant causing an increase in pressure. The transient pressure increase will continue until the reactor coolant and steam generator water temperatures are equalized (see Figure 2.4.1) or the excess coolant is relieved through a relief valve.

For the cases with each type of temperature asymmetry, the reference steam generators were considered to have 58,000 sq.ft. of heat transfer area and a secondary water volume of 3580 cu.ft.; both parameters being significantly greater than those for any of the operating plants, so that the rate of heat transfer and total stored heat available for transfer were conservative in this study.

Heat transfer across the steam generator tubes was assumed to be controlled by free convection on the secondary side. The heat transfer coefficient associated with this mechanism was determined from the McAdams † correlation for turbulent boundary layers on a vertical surface, or:

$$h_{sec} = 0.13\ K \left[\frac{\rho^2 g \beta}{\mu^2} * P_r \right]^{1/3} \left[\Delta T_{wall} \right]^{1/3}$$

---

† McAdams, W. H., "Heat Transmission", 3rd Edition, McGraw-Hill, New York, 1954

where:

h_{sec} = secondary film coefficient of heat transfer, BTU/hr ft^2 °F

ρ = density of secondary water at film temperature, lbm/ft^3

μ = viscosity of secondary water at film temperature, lbm/ft hr

ΔT_{wall} = secondary to primary temperature difference, °F

g = acceleration of gravity, ft/hr^2

β = temperature coefficient of volume expansion, (°F)$^{-1}$

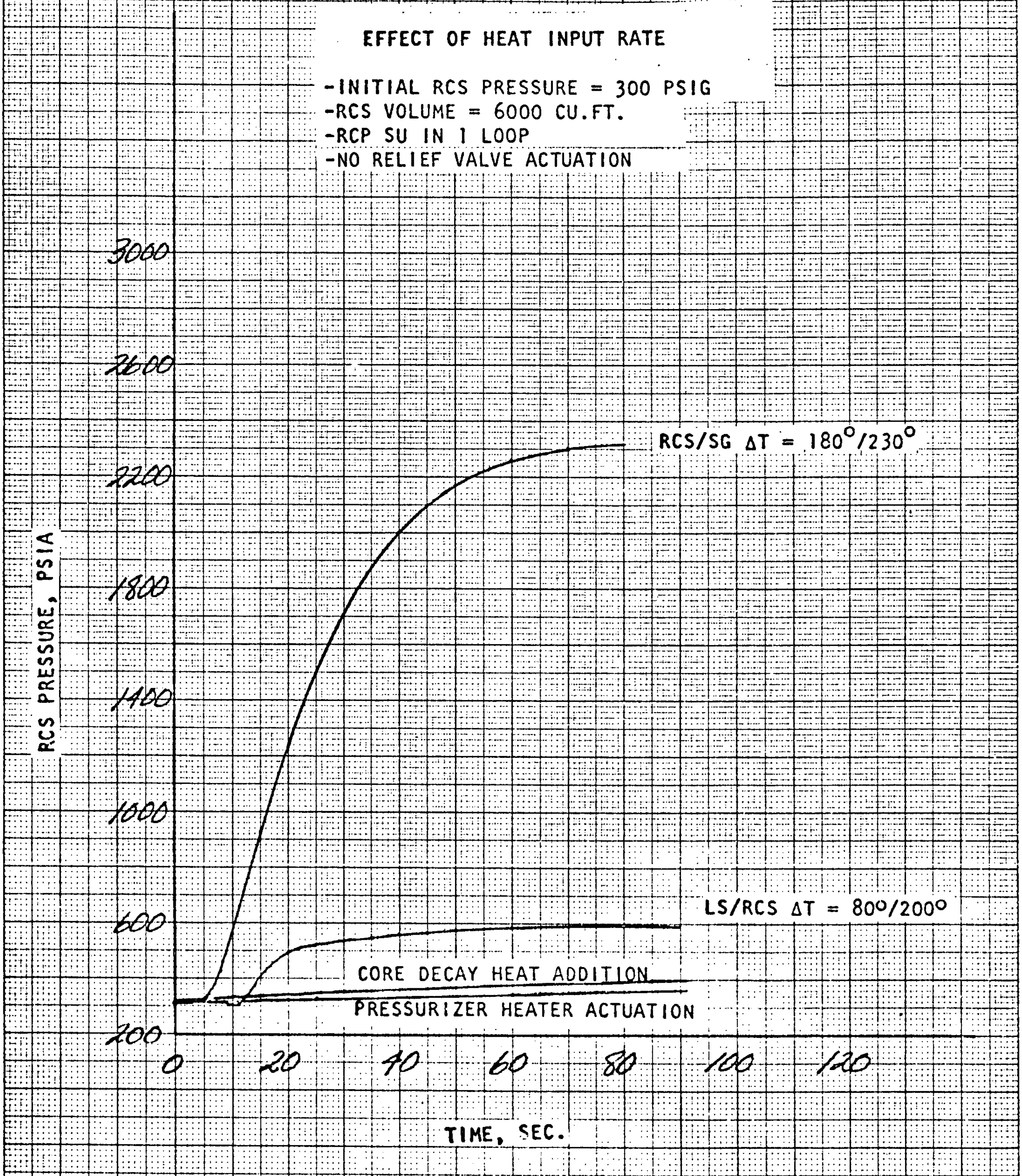
k = conductivity of secondary water, BTU/hr ft °F

P_r = Prandtl Number evaluated at secondary film temperature

The reactor coolant pump characteristics used in the heat input studies were those representative of a controlled leakage sealed pump with a flow rate of about 95,000 gpm at normal plant conditions and a startup time of about 10 seconds.

From an inspection of Figure 2.4.1, it is evident that the heat input cases from pressurizer heaters and decay heat are not as significant as those for the cases with a loop temperature asymmetry. Therefore, these less significant cases were not studied further. Similarly, the loop seal asymmetry case is seen to give a relatively small pressure transient compared to the potential excursion possible from the RCS/SG temperature asymmetry cases and was not considered further in the study of heat input transients.

FIGURE 2.4.1



EFFECT OF HEAT INPUT RATE
-INITIAL RCS PRESSURE = 300 PSIG
-RCS VOLUME = 6000 CU.FT.
-RCP SU IN 1 LOOP
-NO RELIEF VALVE ACTUATION
RCS/SG ΔT = 180°/230°
LS/RCS ΔT = 80°/200°
CORE DECAY HEAT ADDITION
PRESSURIZER HEATER ACTUATION
RCS PRESSURE, PSIA
3000
2600
2200
1800
1400
1000
600
200
0
20
40
60
80
100
120
TIME, SEC.

FIGURE 2.4.2

LOOP SEAL VOLUME

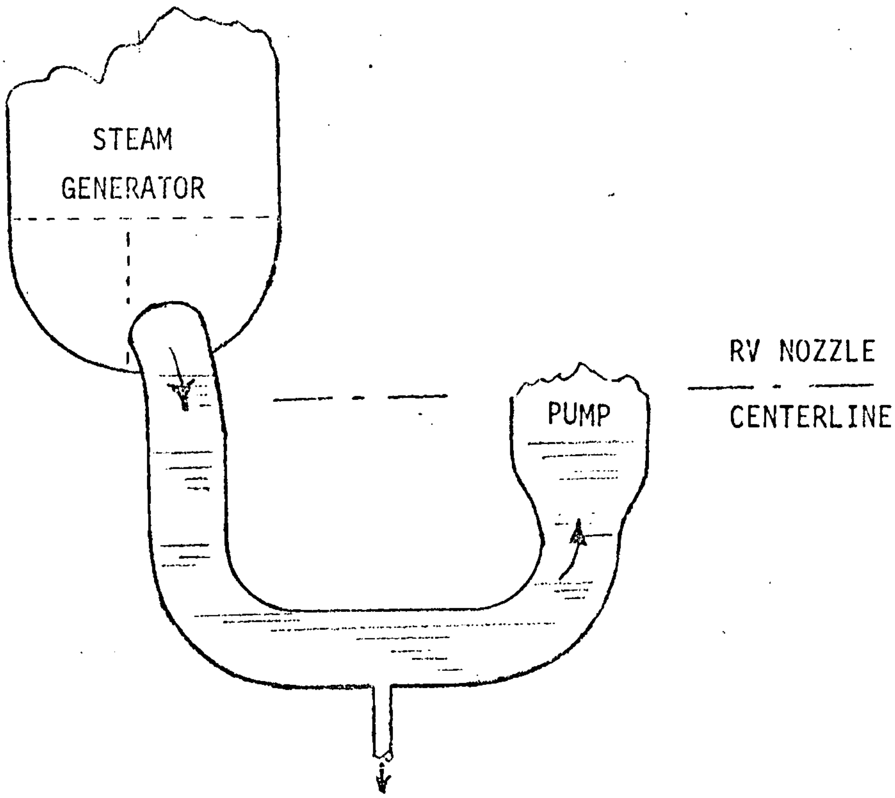
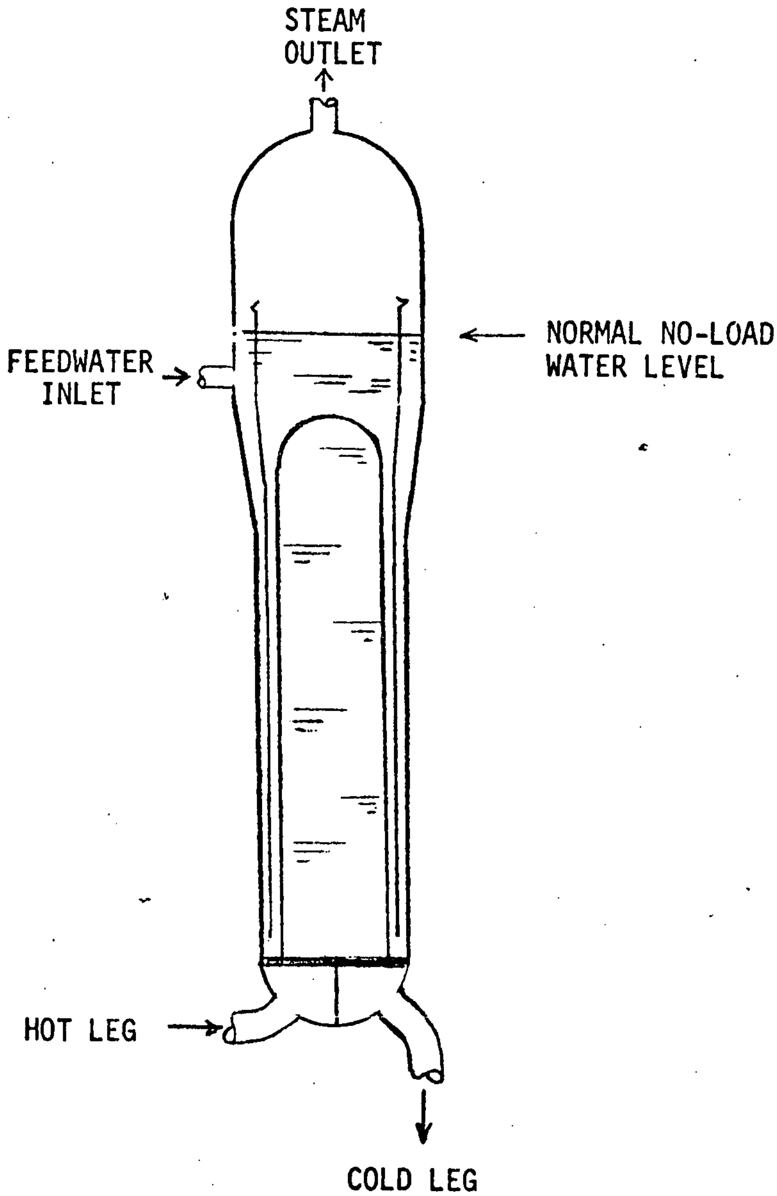


FIGURE 2.4.3

SG SECONDARY NO-LOAD WATER LEVEL



SECTION 3
TYPICAL RESULTS

3.1 MASS INPUT MITIGATED BY RELIEF VALVE

Based on the probability of occurrence and past experience, the most likely mass input case is considered to be the charging/letdown flow mismatch case in which the letdown is terminated within 2 seconds, presumably by a valve closure. Selecting an initial reactor coolant system pressure of 50 psig, the pressure response to the letdown isolation will be as described by Figure 3.1.1 for a small plant with a reactor coolant volume of 6000 cu.ft. As would be expected, the pressure increases more rapidly for the case of the larger mass input from the centrifugal pump (about 16 lb/sec) than for the input from the positive displacement pump (about 6 lb/sec). For these particular examples, the reference relief valve was given a signal to open when the pressure rose above 615 psia, but since the reference valve operator has a time delay of 0.6 seconds, the pressure continued to rise until the valve started to open. Very soon after the valve started to open, the pressure was found to stop increasing and to begin to decrease as the capacity of the valve exceeded the relatively constant mass input rate. The valve continued to move open until the reactor coolant pressure had decreased 20 psi below the valve setpoint of 615 psia. At this reset pressure the valve was signalled to close but the pressure continued to decrease as the valve began its closing cycle. Eventually the valve capacity decreased to less than the continuing mass input and the reactor coolant pressure stopped decreasing and again began to increase toward the relief valve setpoint. It is interesting to note that for the relatively low values of mass input in these examples, the relief valve did not stroke to the full open position since the valve capacity far exceeded that required to relieve the mass input. The valve floated on the motive air in the diaphragm chamber during the opening cycle and did not reach the full open position before the air was vented from the operator. However, due to the closing characteristics of the relief valve, the valve did close completely during each cycle.

The reactor coolant pressure will repeat the cycle through the relief valve setpoint pressure and reset pressure as shown on Figure 3.1.1 until the mass input is terminated. The figure clearly shows the pressure transient is quickly mitigated by the reference relief valve for the entire range of charging flow rates and that the peak pressure reached (less than 625 psia) is less than 10 psi above the valve setpoint.

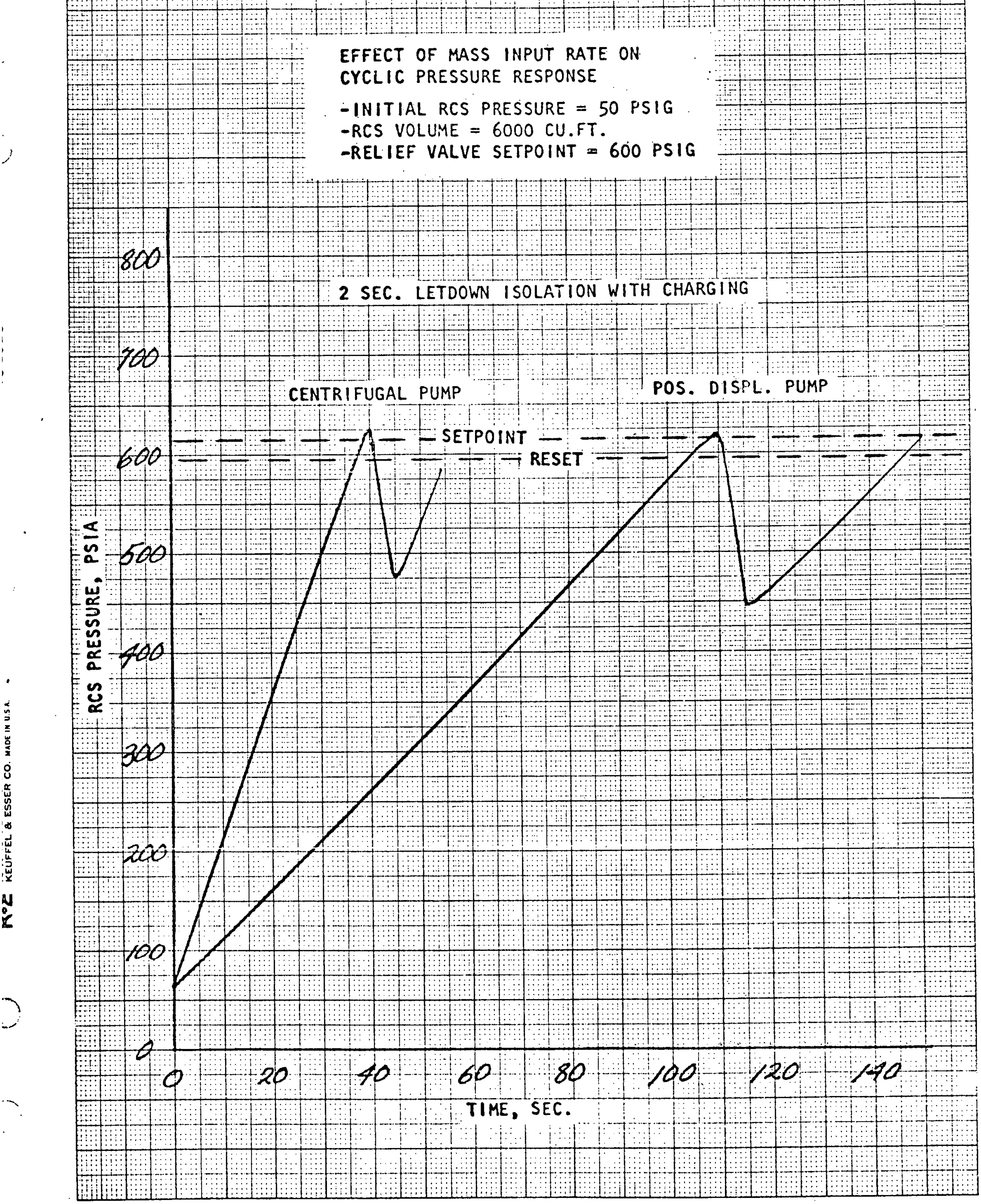
The effect of a much larger mass input flow rate on the pressure response and relief valve performance is demonstrated by Figure 3.1.2 which shows the pressure response for the case of an abnormal operation of the reference safety injection pump. For this example of a very high mass input (113 lb/sec) into a 6000 cu.ft. volume plant, the pressure rose rapidly to the setpoint of the relief valve. Due to the inherent time delay of the valve operator, the pressure continued to rise about 74 psi above the setpoint before the valve started to open. After the valve had started to open, it very quickly provided sufficient capacity to mitigate the pressure transient, but due to the rapid rate of change of system pressure during the early period of the valve stroke, the pressure rose to a peak of 770 psia before it began to decrease. The pressure overshoot above the valve 615 psia setpoint was 155 psi for this particular example of an extreme mass input into a small coolant volume.

For the example SI pump startup case shown on Figure 3.1.2, the relief valve did reach the full open position during its cycle and, therefore, when it received the close signal, there was a short time delay for the motive air to vent from the operator before the valve started to move. This time delay plus the finite time for the valve to stroke resulted in a pressure decrease before the valve capacity became less than the mass input rate. When the capacity of the valve became less than the input flow rate, the reactor coolant pressure again began to increase toward the valve setpoint. The valve will continue to cycle open and closed with an 8-1/2 second cycle time while following the coolant pressure response until the mass input is terminated.

There is a direct relationship between the rate of change of reactor coolant pressure and the rate of mass input into a given system volume as indicated by Figure 3.1.2 and Figure 3.1.3, and, conversely, there is also an inverse relationship between the rate of pressure change and the size of the volume into which a given mass rate is injected. This relationship of the system volume is shown for the particular case of the reference SI pump mass input into two different system volumes of 6000 and 13,000 cu.ft. on Figure 3.1.4.

The pressure overshoot above the 615 psia setpoint for the reference SI pump mass input case was shown to be about 155 psi on Figure 3.1.2, which gave a peak pressure of 770 psia. To reduce the peak pressure, the relief valve setpoint can be set at a lower value so that the valve begins to relieve at a lower pressure. However, the capacity of the valve is less and the mass input from the SI pump is greater at the lower pressure so the valve is not as effective in mitigating the pressure transient. These two effects of reduced capacity and higher mass input result in the pressure overshoot being increased from 155 to 192 psi as the setpoint is reduced from 600 to 400 psig for a net gain of 163 psi in the peak pressure reached. This effect is shown on Figure 3.1.5.

FIGURE 3.1.1


EFFECT OF MASS INPUT RATE ON
CYCLIC PRESSURE RESPONSE
-INITIAL RCS PRESSURE = 50 PSIG
-RCS VOLUME = 6000 CU.FT.
-RELIEF VALVE SETPOINT = 600 PSIG
2 SEC. LETDOWN ISOLATION WITH CHARGING
CENTRIFUGAL PUMP
POS. DISPL. PUMP
SETPOINT
RESET
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
TIME, SEC.
K&E KEUFFEL & ESSER CO. MADE IN U.S.A.

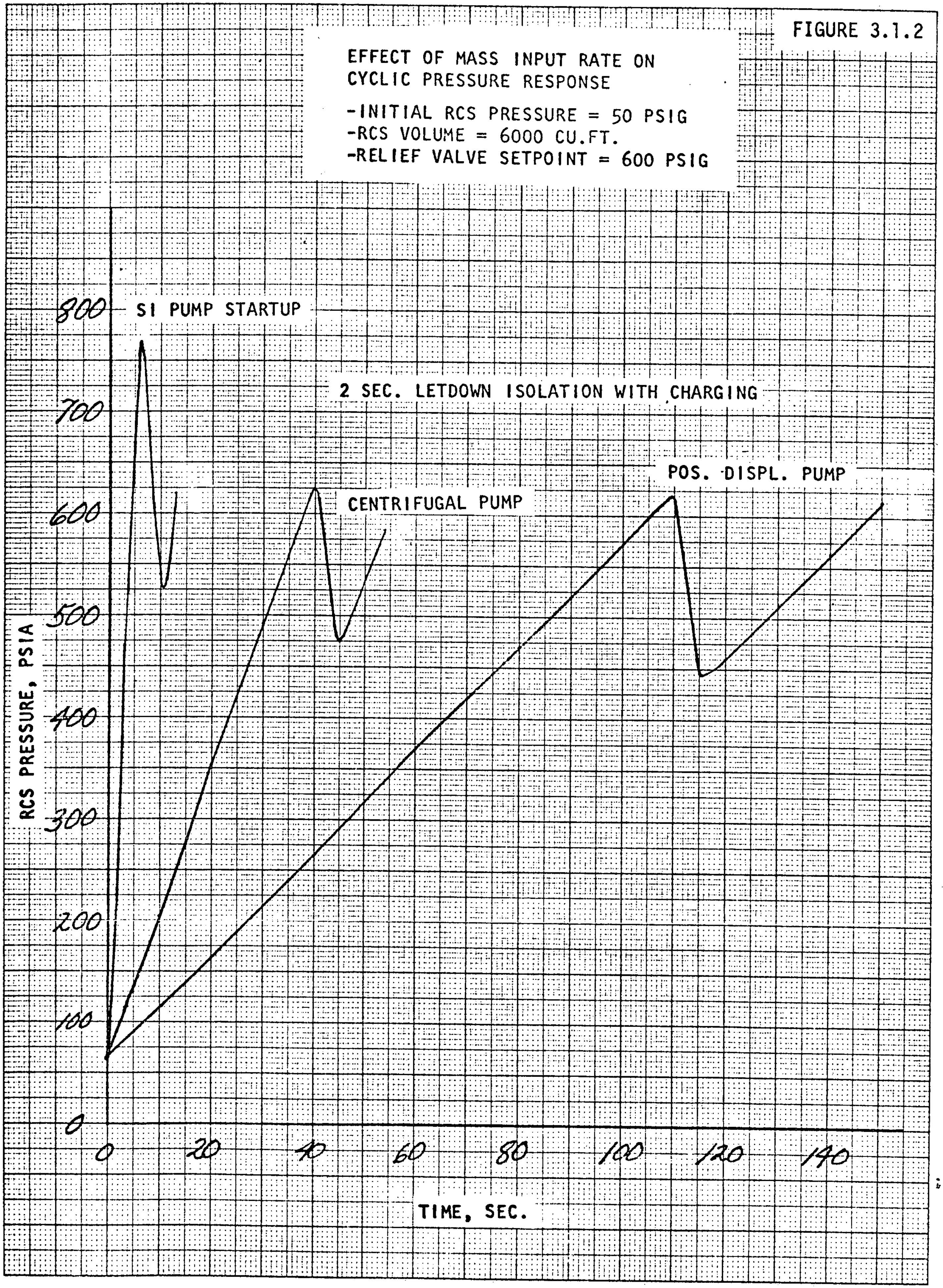


FIGURE 3.1.2
EFFECT OF MASS INPUT RATE ON
CYCLIC PRESSURE RESPONSE
-INITIAL RCS PRESSURE = 50 PSIG
-RCS VOLUME = 6000 CU.FT.
-RELIEF VALVE SETPOINT = 600 PSIG
SI PUMP STARTUP
2 SEC. LETDOWN ISOLATION WITH CHARGING
POS. DISPL. PUMP
CENTRIFUGAL PUMP
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
TIME, SEC.
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.
461510

FIGURE 3.1.3

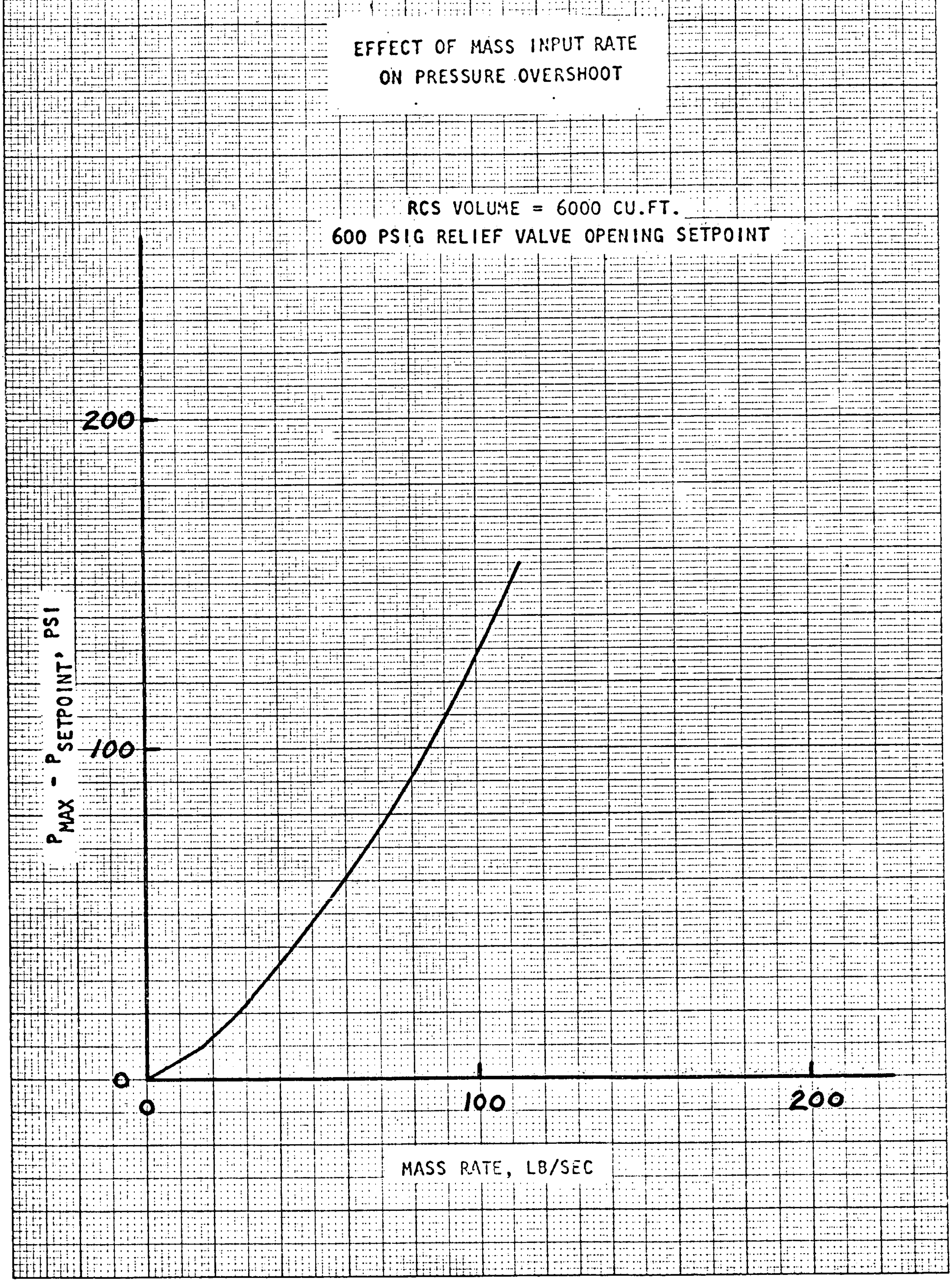

EFFECT OF MASS INPUT RATE
ON PRESSURE OVERSHOOT
RCS VOLUME = 6000 CU.FT.
600 PSIG RELIEF VALVE OPENING SETPOINT
$P_{MAX} - P_{SETPOINT}$, PSI
200
100
0
0
100
200
MASS RATE, LB/SEC

FIGURE 3.1.4

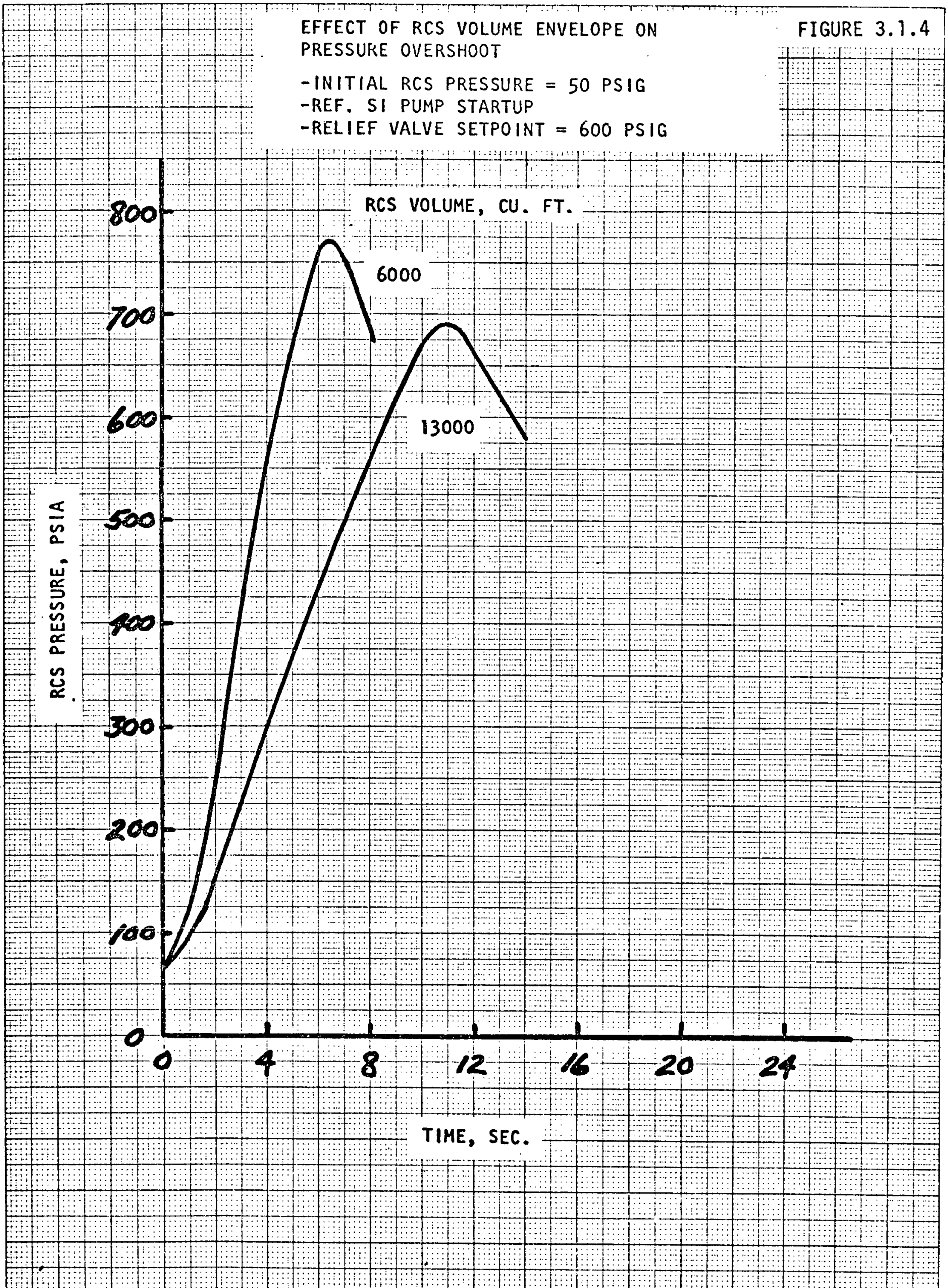
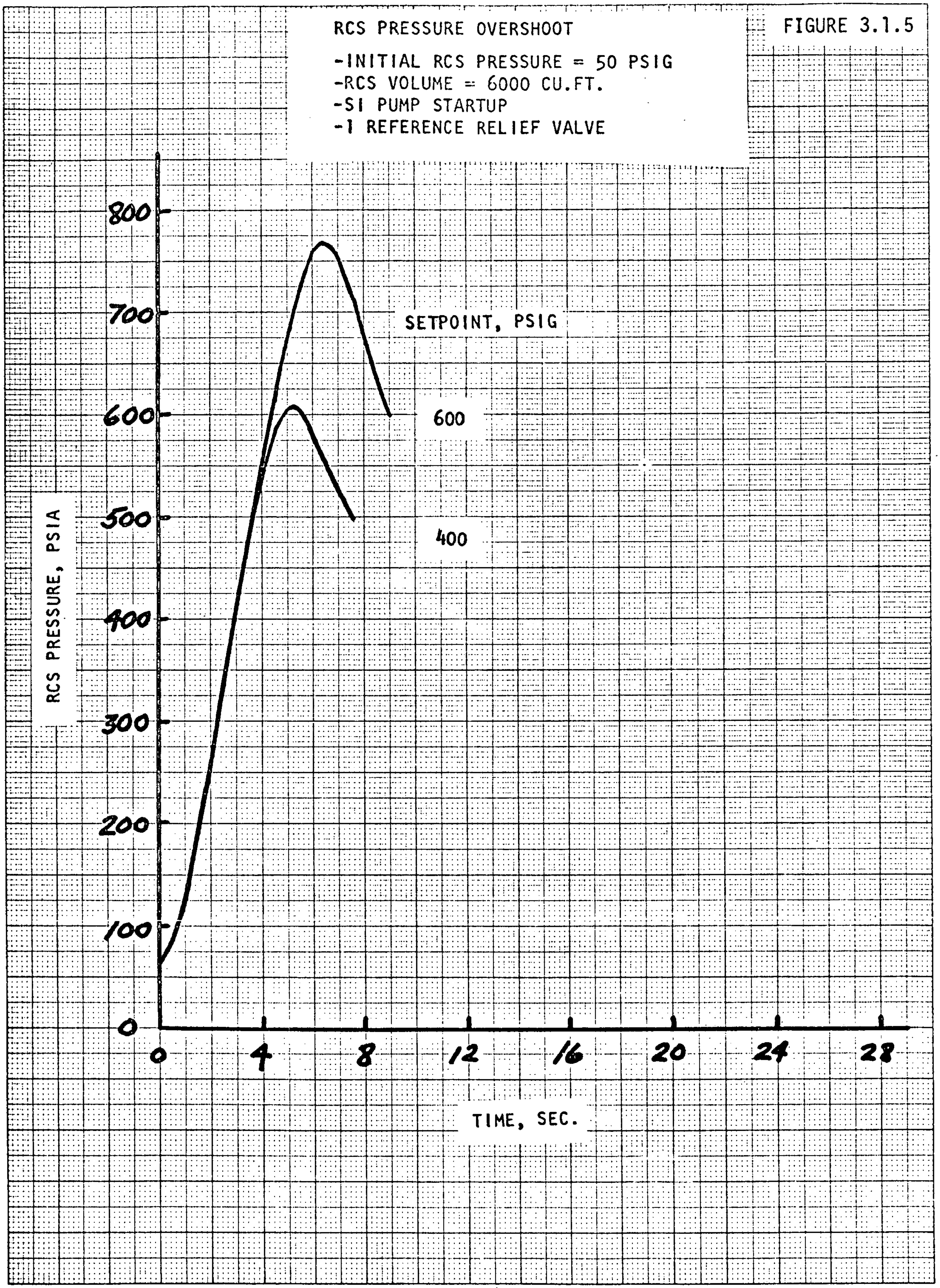

EFFECT OF RCS VOLUME ENVELOPE ON
PRESSURE OVERSHOOT
-INITIAL RCS PRESSURE = 50 PSIG
-REF. SI PUMP STARTUP
-RELIEF VALVE SETPOINT = 600 PSIG
RCS VOLUME, CU. FT.
6000
13000
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
TIME, SEC.

FIGURE 3.1.5


RCS PRESSURE OVERSHOOT
-INITIAL RCS PRESSURE = 50 PSIG
-RCS VOLUME = 6000 CU.FT.
-SI PUMP STARTUP
-1 REFERENCE RELIEF VALVE
SETPOINT, PSIG
600
400
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
28
TIME, SEC.

3.2 HEAT INPUT MITIGATED BY RELIEF VALVE

As shown in Section 2.4, the heat input cases which have the potential for severe pressure transients are those in which the steam generators exhibit a higher temperature than the remainder of the reactor coolant system. The magnitude of the difference in temperature is dependent on the means by which the temperature asymmetry was achieved, but a typical difference is considered to be about 50°F because higher differentials are more difficult to achieve and are more easily recognized by the operator.

The transient pressure response for a typical heat input case in which the initial reactor coolant temperature was 180°F and the temperature differential to the steam generators was 50°F (secondary temperature 230°F; steam pressure 21 psia) is shown on Figure 3.2.1. For this transient in a 6000 cu.ft. plant (2 loop), one of the two reactor coolant pumps was started to circulate the reactor coolant through the warmer steam generators. As the coolant flow began, the warm water (230°F) in the tubes of the steam generator in the active loop was forced out and into the reactor coolant pump where it was pumped into and mixed with the 180°F reactor coolant. In the inactive loop(s), the warmer water from the tubes of the steam generator was forced out in a reverse direction due to the backflow in the inactive loop, and also mixed with the cooler reactor coolant. This initial mixing of the warm water with the larger volume of cooler water caused an initial shrinkage effect and tended to decrease the initial coolant pressure.

Simultaneously, the cooler reactor coolant which entered the steam generator began to be heated as it moved through the tube bundle. As heat was added to the coolant due to heat transfer from the secondary water in the steam generator, the coolant attempted to expand and caused a resultant pressure increase. The net effect of the expansion due to the heat transferred to the coolant and the shrinkage effect due to the mixing of the warm water into the cooler coolant was a relatively constant coolant pressure in the initial few seconds of the transient as seen on Figure 3.2.1. Then, as the flow rate increased and the heat transfer mechanism became predominant, the coolant pressure increased rapidly.

The reactor coolant pressure continued to increase until the pressure reached 500 psig, the setpoint of the relief valve. The relief valve was given a signal to open when the pressure reached 515 psia (at 9.2 seconds) but due to the inherent time delay of 0.6 seconds, the pressure continued to increase until about 9.8 seconds into the transient, at which time the relief valve began to open and the pressure began to be mitigated. Very soon afterwards, the valve had opened sufficiently to provide a capacity in excess of the expansion rate of the coolant and the coolant pressure decreased rapidly after reaching an overshoot of 100 psi above the setpoint.

For comparison, a transient pressure response for the particular case in which the temperature differential was only 20°F is also shown on Figure 3.2.1. With the lesser temperature difference, the transient is much slower and the resultant setpoint overshoot is only 15 psi, versus the overshoot of 100 psi for the 50°F ΔT case.

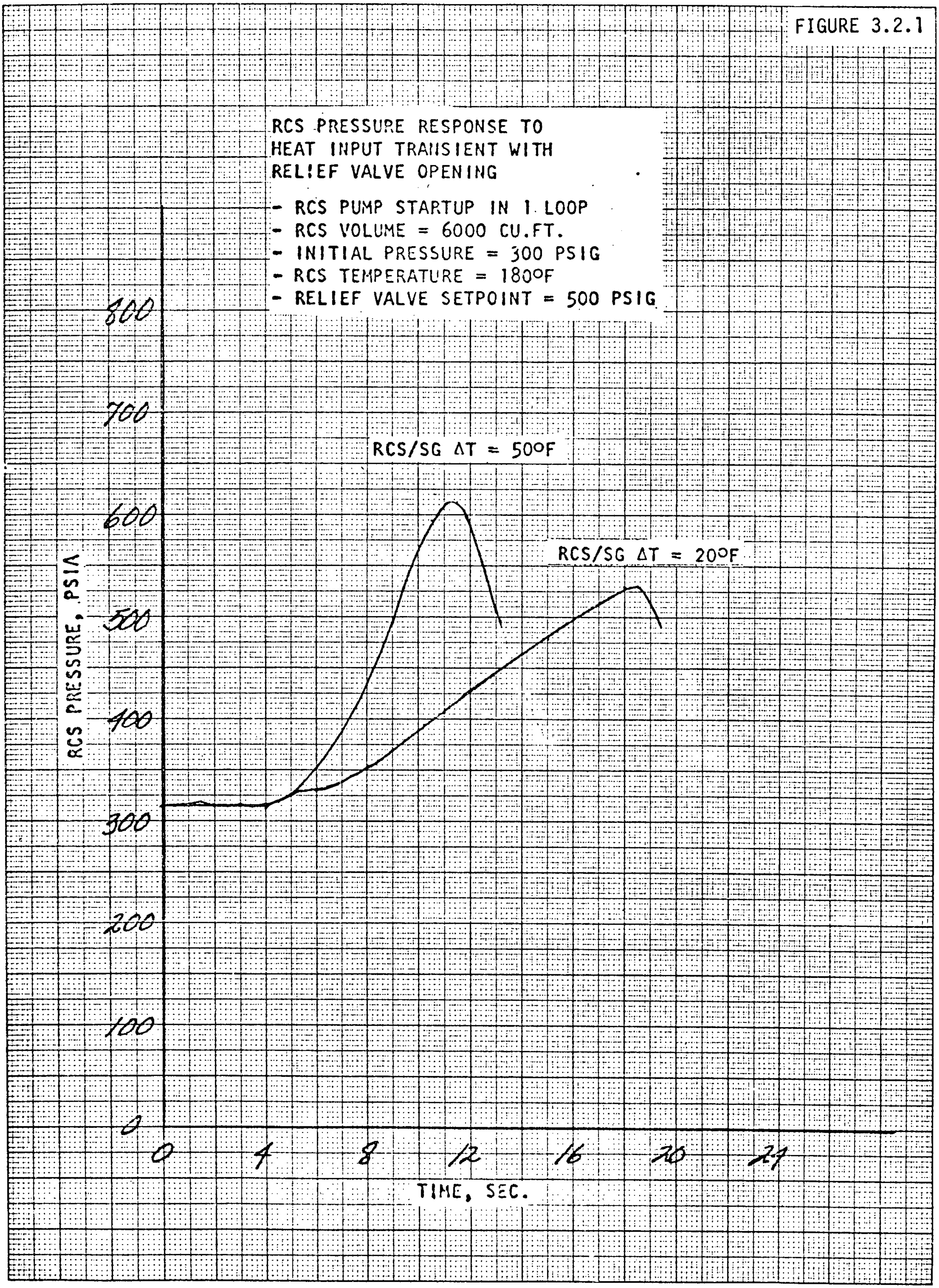
Figure 3.2.2 is presented to show the relationship between the setpoint overshoot and the temperature difference between the steam generators and the reactor coolant for three initial RCS temperatures; 100°F, 140°F and 180°F. For a given initial reactor coolant temperature (e.g., 180°F) the overshoot is seen to increase with increasing ΔT, where the ΔT as high as 100°F has been plotted to show the effect. It can also be seen from Figure 3.2.2 that at low values of ΔT, e.g., less than 10°F, no setpoint overshoot would be expected because the pressure would only rise from the initial value of 300 psig to some pressure less than 500 psig and the relief valve would not be actuated.

As already evidenced in Figure 3.2.2, the initial temperature of the reactor coolant also has a significant effect on the magnitude of the resultant pressure transient for the heat input cases. Figure 3.2.3 indicates the effect of the initial temperature on the setpoint overshoot for a 50°F differential temperature. By way of illustration, Figure 3.2.3 gives a pressure overshoot of 113 psi at a temperature of 200°F, whereas the overshoot is only 30 psi for an initial temperature of 100°F.

The heat input transients due to temperature asymmetry in the reactor coolant system are unique in that they are self limiting; i.e., when the temperatures are brought to equilibrium by the reactor coolant flow, the transient is ended. The use of a relief valve to mitigate the pressure transient will result in a valve cycling effect when the valve capacity is greater than the expansion rate of the coolant as it is heated, but the valve will only be required to cycle a few times until the temperatures in the system are brought to equilibrium and coolant expansion ceases. The first cycle will result in the largest setpoint overshoot. Subsequent valve cycles will result in diminishing overshoots as the coolant expansion rate diminishes until eventually the valve will close and remain closed.

Figure 3.2.4 describes the first complete cycle for the reference relief valve as it mitigates a heat input transient with an initial severe temperature difference of 100°F. For this particular case, the valve is signalled to open at a pressure of 615 psia and the resultant setpoint overshoot is 145 psi. Then, as the pressure is caused to decrease by the valve action, the valve is signalled to close at 595 psia (20 psi below setpoint) and the valve closes over a period of 5 seconds. The figure indicates the valve will close completely and the pressure will again begin to rise toward the setpoint. The open/close cycles will be repeated but subsequent cycles are expected to become of longer duration and of lesser magnitude, as the temperatures in the system approach equilibrium, until the valve will no longer be required to lift.

FIGURE 3.2.1


RCS PRESSURE RESPONSE TO
HEAT INPUT TRANSIENT WITH
RELIEF VALVE OPENING
- RCS PUMP STARTUP IN 1 LOOP
- RCS VOLUME = 6000 CU.FT.
- INITIAL PRESSURE = 300 PSIG
- RCS TEMPERATURE = 180°F
- RELIEF VALVE SETPOINT = 500 PSIG
RCS/SG ΔT = 50°F
RCS/SG ΔT = 20°F
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
TIME, SEC.

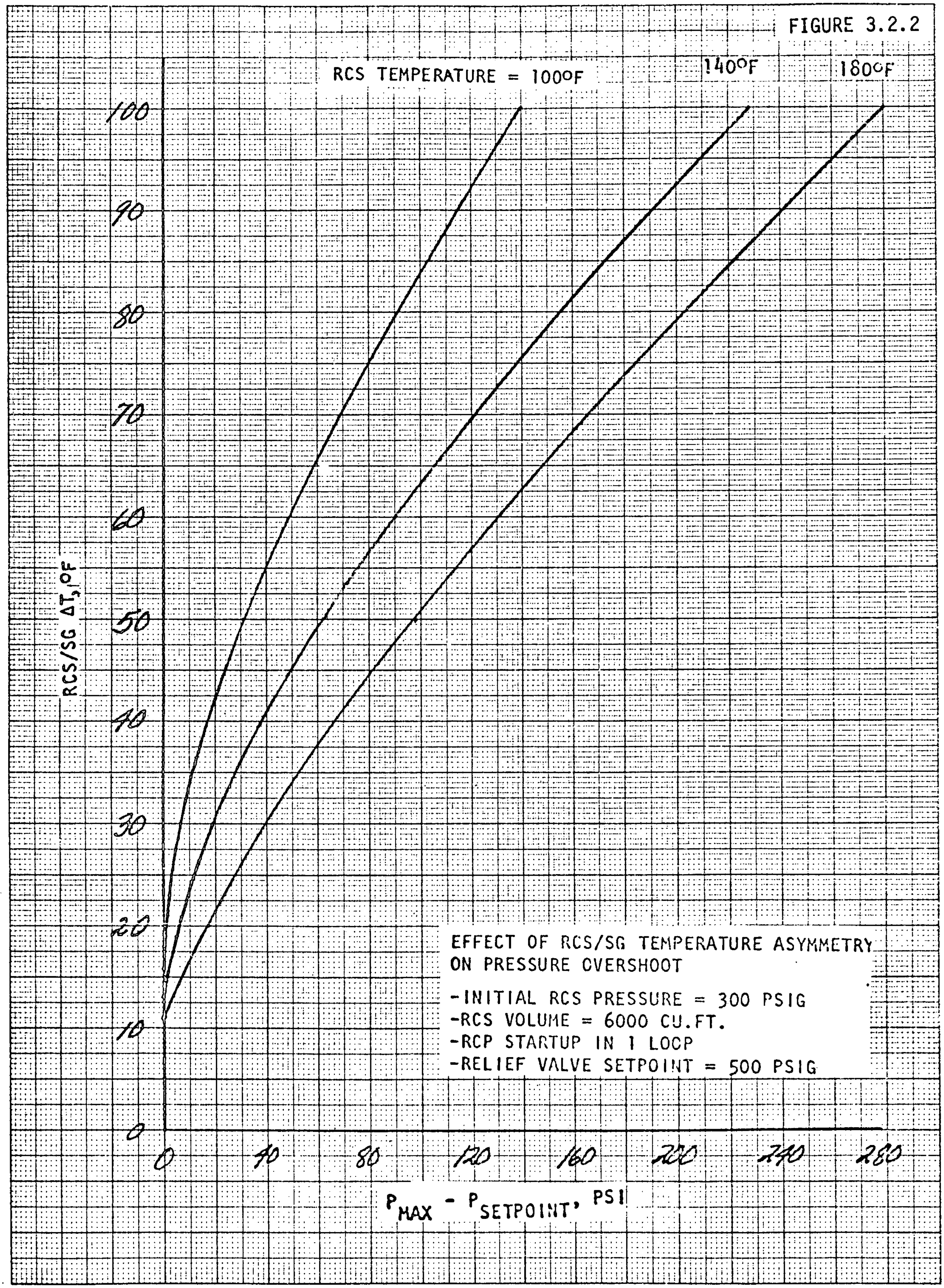


FIGURE 3.2.2
RCS TEMPERATURE = 100°F
140°F
180°F
RCS/SG ΔT, °F
0
10
20
30
40
50
60
70
80
90
100
0
40
80
120
160
200
240
280
P MAX - P SETPOINT, PSI
EFFECT OF RCS/SG TEMPERATURE ASYMMETRY ON PRESSURE OVERSHOOT
-INITIAL RCS PRESSURE = 300 PSIG
-RCS VOLUME = 6000 CU.FT.
-RCP STARTUP IN 1 LOOP
-RELIEF VALVE SETPOINT = 500 PSIG
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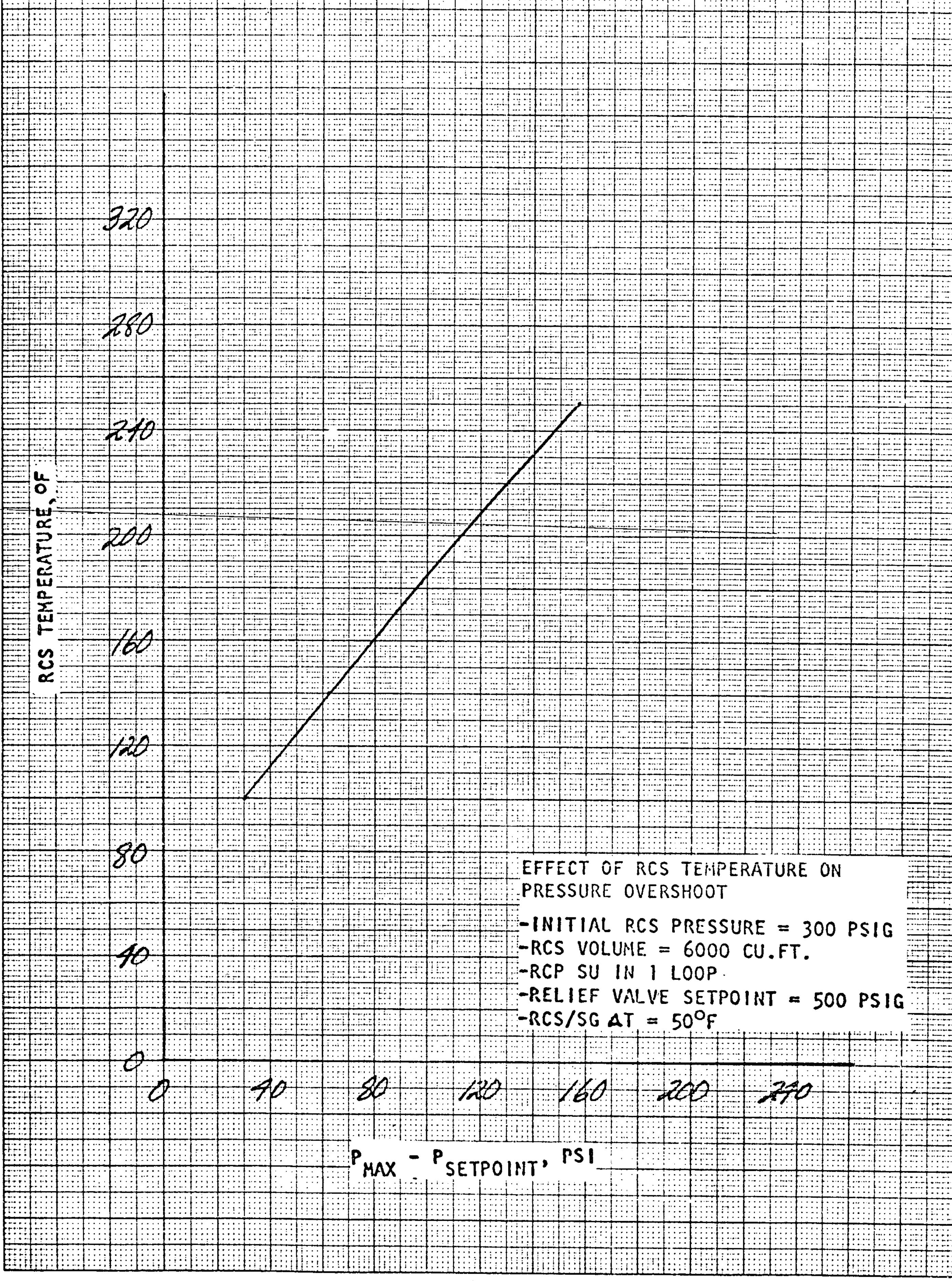
FIGURE 3.2.3


RCS TEMPERATURE, OF
320
280
240
200
160
120
80
40
0
0
40
80
120
160
200
240
PMAX - PSETPOINT, PSI
EFFECT OF RCS TEMPERATURE ON PRESSURE OVERSHOOT
-INITIAL RCS PRESSURE = 300 PSIG
-RCS VOLUME = 6000 CU.FT.
-RCP SU IN 1 LOOP
-RELIEF VALVE SETPOINT = 500 PSIG
-RCS/SG ΔT = 50°F

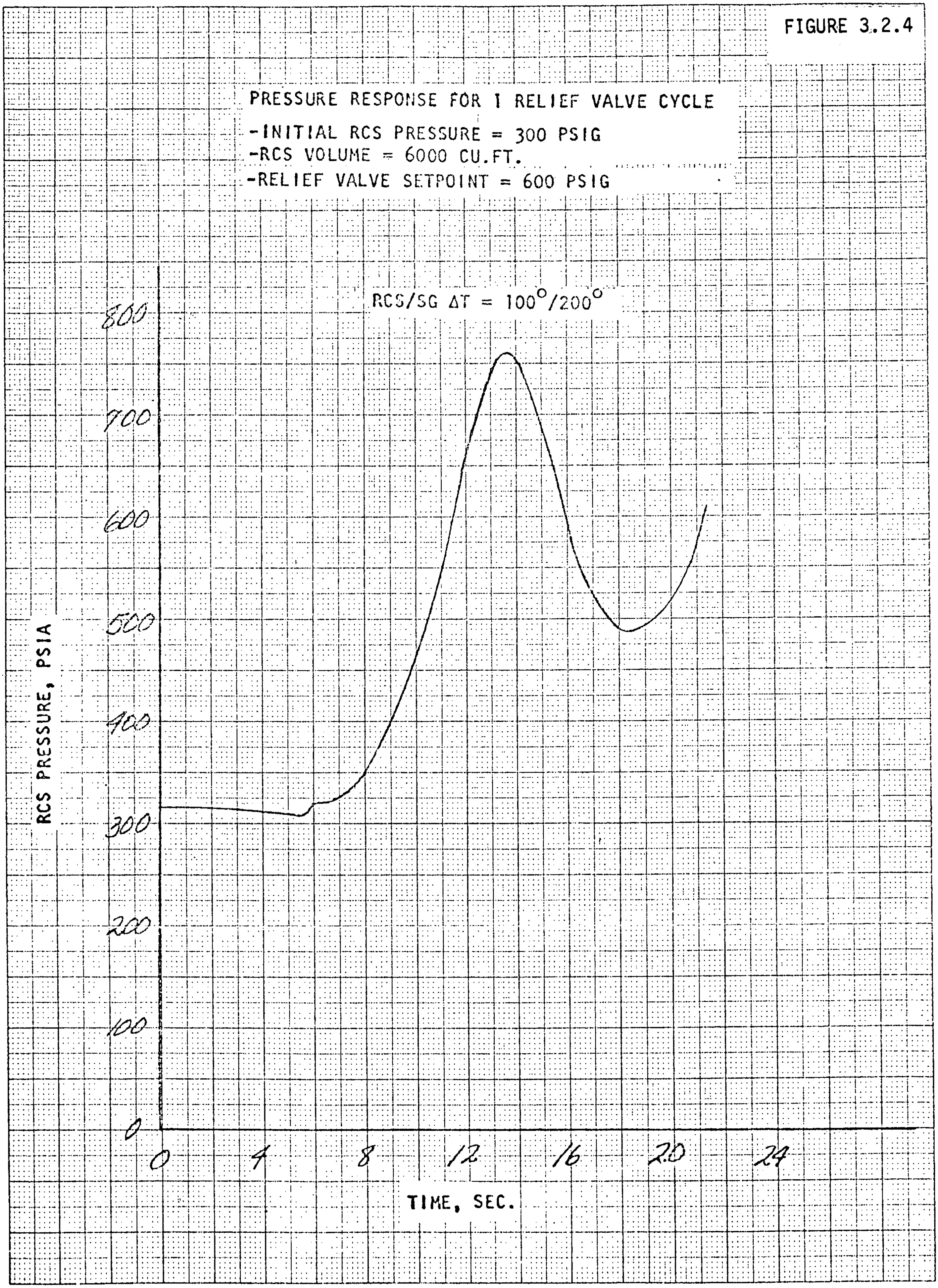

PRESSURE RESPONSE FOR 1 RELIEF VALVE CYCLE
-INITIAL RCS PRESSURE = 300 PSIG
-RCS VOLUME = 6000 CU.FT.
-RELIEF VALVE SETPOINT = 600 PSIG
RCS/SG ΔT = 100°/200°
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
TIME, SEC.

FIGURE 3.2.4

SECTION 4
INSTRUCTIONAL GUIDE FOR
SETPOINT/OVERSHOOT DETERMINATION

4.1 INTRODUCTION

Determination of relief valve setpoint for a specific plant requires knowledge of the expected overshoot which could occur under all possible mass input and heat input additions for that plant.

Many mass input and heat input possibilities were considered in LOFTRAN analyses which were performed to generate values of setpoint overshoot. The analyses were performed for operating plant parameters selected to bracket or bound those of the plants in the W Owners Group on RCS Overpressurization. The bounding envelope of mass input and heat input generic results are not generally applicable to any specific plant. To determine a specific relief valve setpoint, a means of interpolating the setpoint overshoot from the generic envelope has been made available and algorithms have been developed to facilitate such interpolation.

The heat input algorithm involves the use of a procedure to interpolate the setpoint overshoot for plants exhibiting a reactor coolant (RCS) volume and steam generator design different from those defined by the generic setpoint overshoot envelope. This procedure is presented in Section 4.2.2, together with an example of its application for a specific RCS volume and steam generator design.

The mass input algorithm involves the use of a procedure for the determination of a relief valve setpoint, which includes interpolation of setpoint overshoot for plants with RCS volume, relief valve setpoint, relief valve opening time and mass input rate different from, but included within, the envelope of generic setpoint overshoot results. Interpolation is expedited through the use of an equation, developed for this purpose. This equation is based on the adjustment of reference (generic envelope) setpoint overshoot results by linear application factors, with one factor determined for each of the input parameters; RCS volume, relief valve setpoint, relief valve opening time, and mass input rate for the specific plant under consideration. The equation and application factor development is presented in Section 4.2.1.

4.2 ALGORITHMS USED FOR SETPOINT/OVERSHOOT DETERMINATION

4.2.1 Setpoint Determination for Mass Input Transient

Determination of a relief valve setpoint which will not result in a peak pressure in excess of the Appendix G limit, for the case of mass input as applied to a specific operating plant, is accomplished with a procedure based on the following simplified interpolating equation:

$$\Delta P\ (V,\ S,\ Z,\ x) = \Delta P_{REF}\ (x) * F_V * F_S * F_Z \qquad (1)$$

The procedure for determining the relief valve setpoint is described below. To illustrate the application of the procedure, a set of sample input parameters will be considered, and the results of the sequential application of each step of the procedure to these parameters will be noted.

PARAMETERS FOR MASS INPUT EXAMPLE

Relief Valve Setpoint	=	500 psig
Relief Valve Opening Time	=	2.0 seconds
Mass Input Rate	=	60 lb/sec
RCS Volume	=	10,000 cu.ft.

Applying the mass input procedure:

Step	Procedure	Example Application
1	Select relief valve setpoint operating range	Setpoint = 500 psig
2	For limiting mass input rate, obtain ΔP_{REF} from Figure 4.2.1	ΔP_{REF} = 82 psi for mass input rate (x) = 60 lb/sec
3	For total RCS volume, obtain F_V factor from Figure 4.2.2	F_V = 0.71 for total RCS volume (V) = 10,000 cu.ft.
4	For the relief valve opening time (total, including delay), obtain F_Z factor from Figure 4.2.3	F_Z = 0.733 for relief valve opening time Z = 2.0 seconds
5	For the relief valve setpoint selected, obtain F_S factor from Figure 4.2.4	F_S = 1.14 for relief valve setpoint = 500 psig
6	Calculate the product of factors ΔP_{REF}, F_V, F_S, and F_Z determined in Steps 2 through 5 (application of Equation 1). This is the setpoint overshoot, ΔP.	ΔP (10,000 cu.ft., 500 psig, 2 seconds, 60 lb/sec) = 49 psi†

† Conservative - LOFTRAN analysis for these conditions gives an overshoot equal to 25 psi.

FIGURE 4.2.1

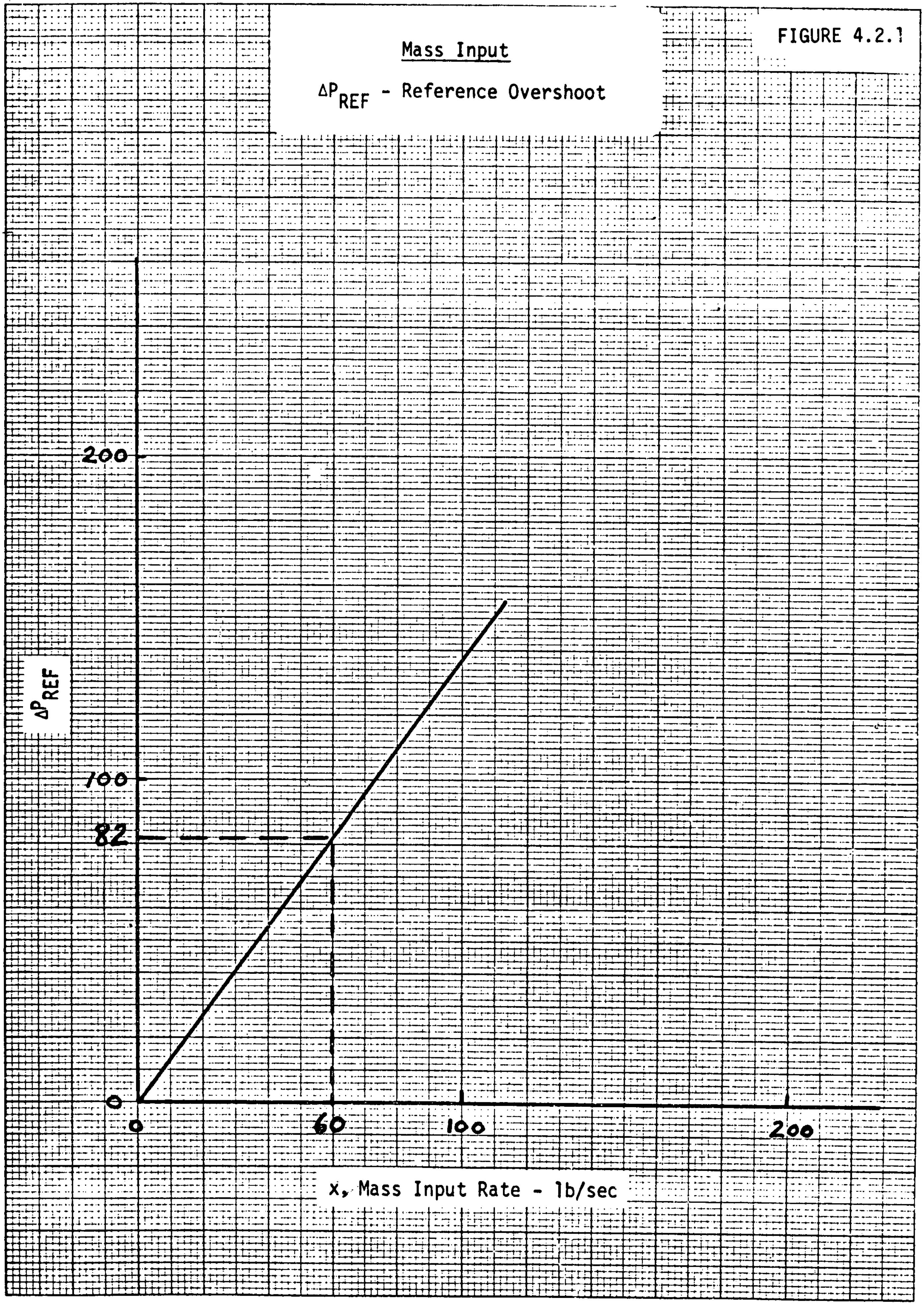

Mass Input
ΔP REF - Reference Overshoot
ΔP REF
200
100
82
0
0
60
100
200
x, Mass Input Rate - lb/sec

FIGURE 4.2.2

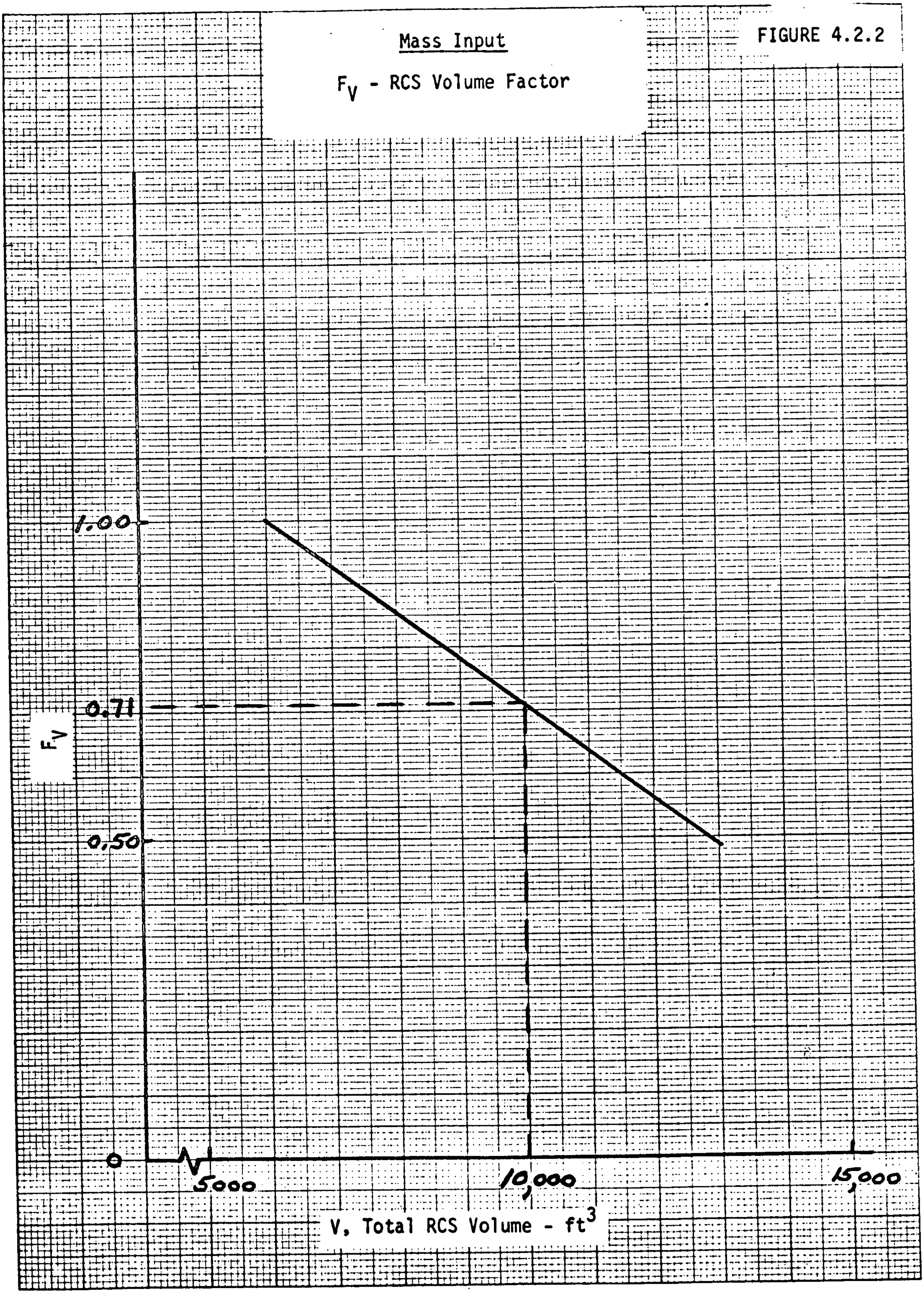

Mass Input
F_V - RCS Volume Factor
1.00
0.71
0.50
F_V
0
5000
10,000
15,000
V, Total RCS Volume - ft^3

FIGURE 4.2.3

Mass Input

F_Z - Relief Valve Opening Time Factor

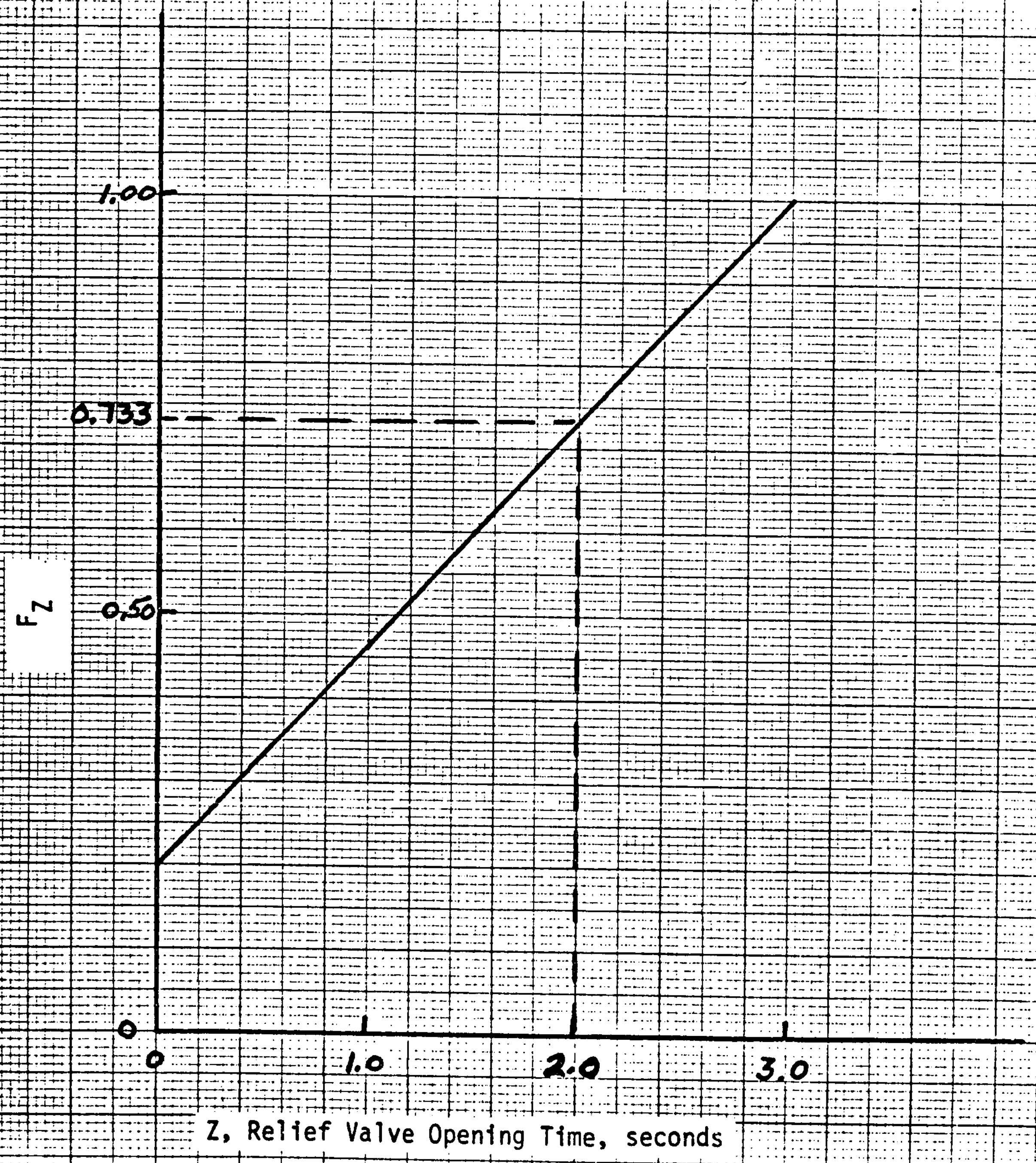
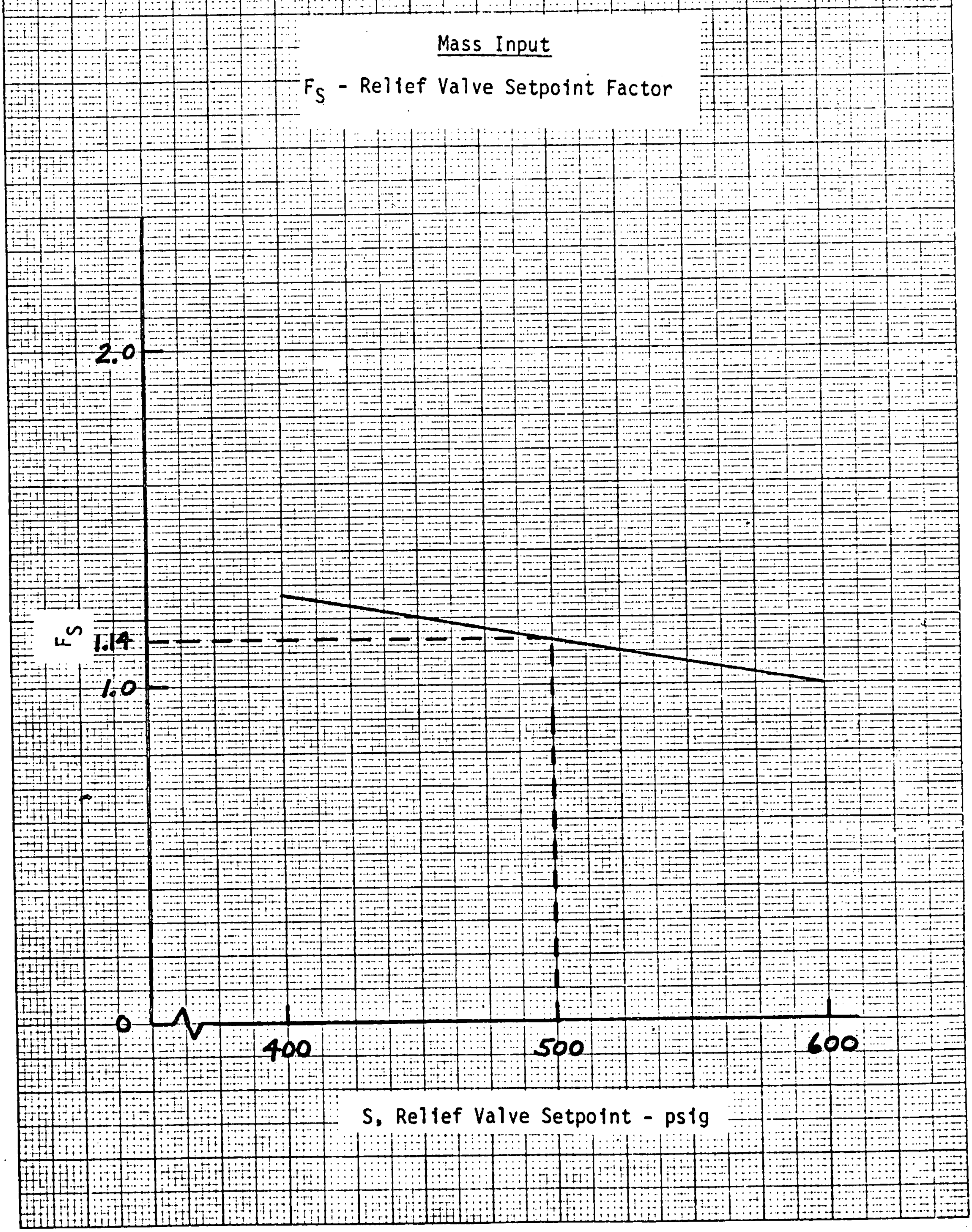
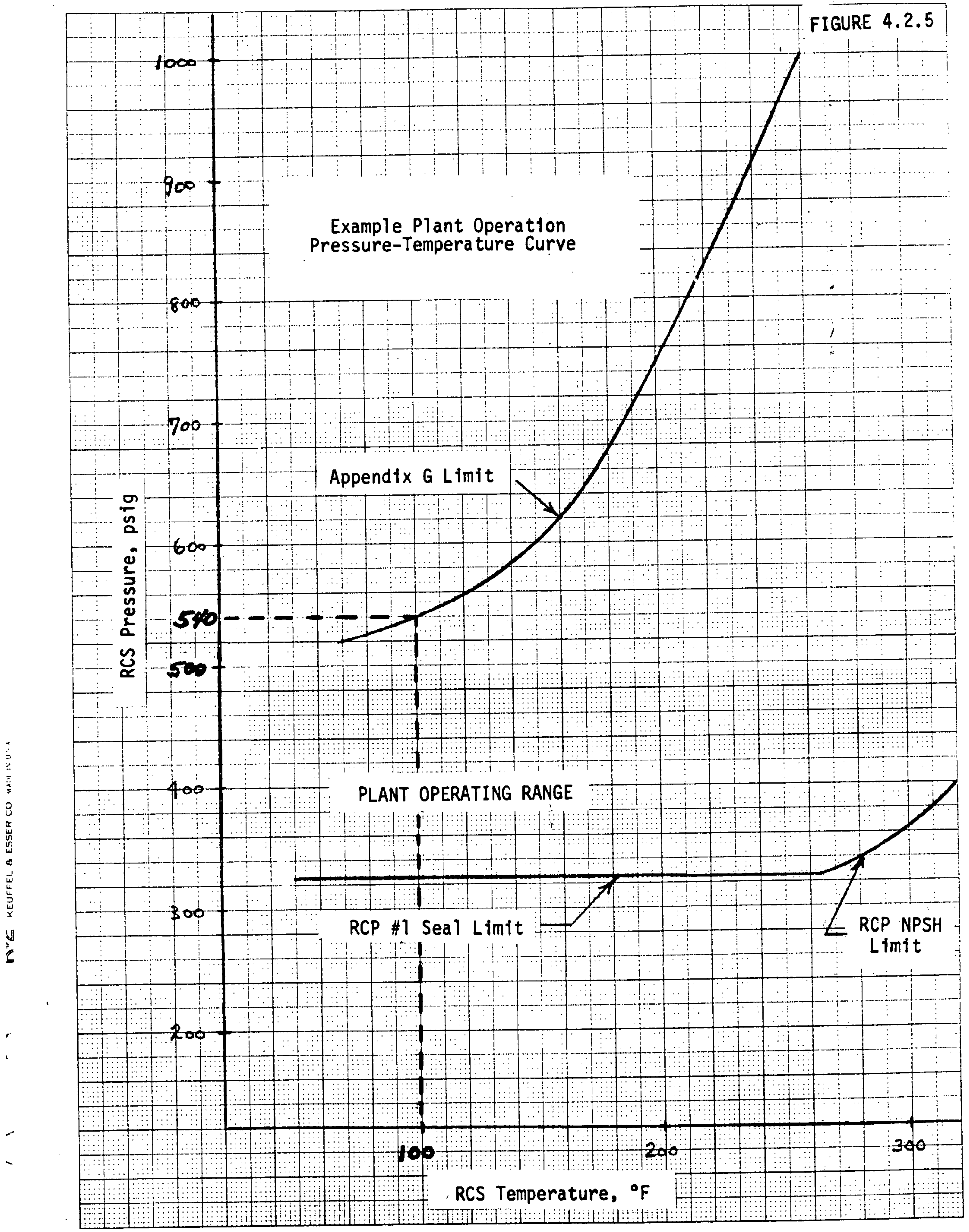


FIGURE 4.2.4


Mass Input
F_S - Relief Valve Setpoint Factor
F_S
2.0
1.14
1.0
0
400
500
600
S, Relief Valve Setpoint - psig

Step	Procedure	Example Application
7	Add ΔP (Step 6) to the relief valve setpoint (Step 1) to obtain maximum transient pressure, P_{MAX}. If P_{MAX} < Appendix G limitation, selected relief valve setpoint is acceptable. If P_{MAX} > Appendix G limitation, go to Step 8.	P_{MAX} = 515 psia (relief valve setpoint) plus 49 psi, or 564 psia. From Figure 4.2.5 at RCS temperature = 100°F, Appendix G pressure limit = 540 psig + 15, or 555 psia. Thus, P_{MAX} > Appendix G limitation.
8	If P_{MAX} > Appendix G limitation, selected relief valve setpoint is too high. Reduce setpoint and repeat Steps 5 through 7 until an acceptable setpoint is determined.	Reducing setpoint by 10 psi (564 psia - 555 psia) to 490 psig and repeating Steps 2 through 6 results in ΔP = 49.4 psi and P_{MAX} = 505 psia + 49.4 = 554.4 psia. Since 554.5 psia < Appendix G limit, 490 psig is an acceptable setpoint.

FIGURE 4.2.5



Example Plant Operation
Pressure-Temperature Curve
RCS Pressure, psig
1000
900
800
700
600
540
500
400
300
200
Appendix G Limit
PLANT OPERATING RANGE
RCP #1 Seal Limit
RCP NPSH
Limit
100
200
300
RCS Temperature, °F
KEUFFEL & ESSER CO. MADE IN U.S.A.

4.2.2 Setpoint Overshoot Determination for Heat Input Transient

Correlations of RCS setpoint pressure overshoot variation with RCS volume, steam generator overall UA and initial RCS temperature are presented in Figures 4.2.6, 4.2.7 and 4.2.8 for the following conditions:

Initial RCS Pressure	=	300 psig
RCS/SG ΔT	=	50°F
Relief Valve Setpoint	=	500 psig
SG Heat Transfer Area	=	58,000 ft^2

$6{,}000\ ft^3 \leq$ RCS Volume $\leq 13{,}000\ ft^3$

FIGURE 4.2.6

EFFECT OF RCS VOLUME ON PRESSURE OVERSHOOT

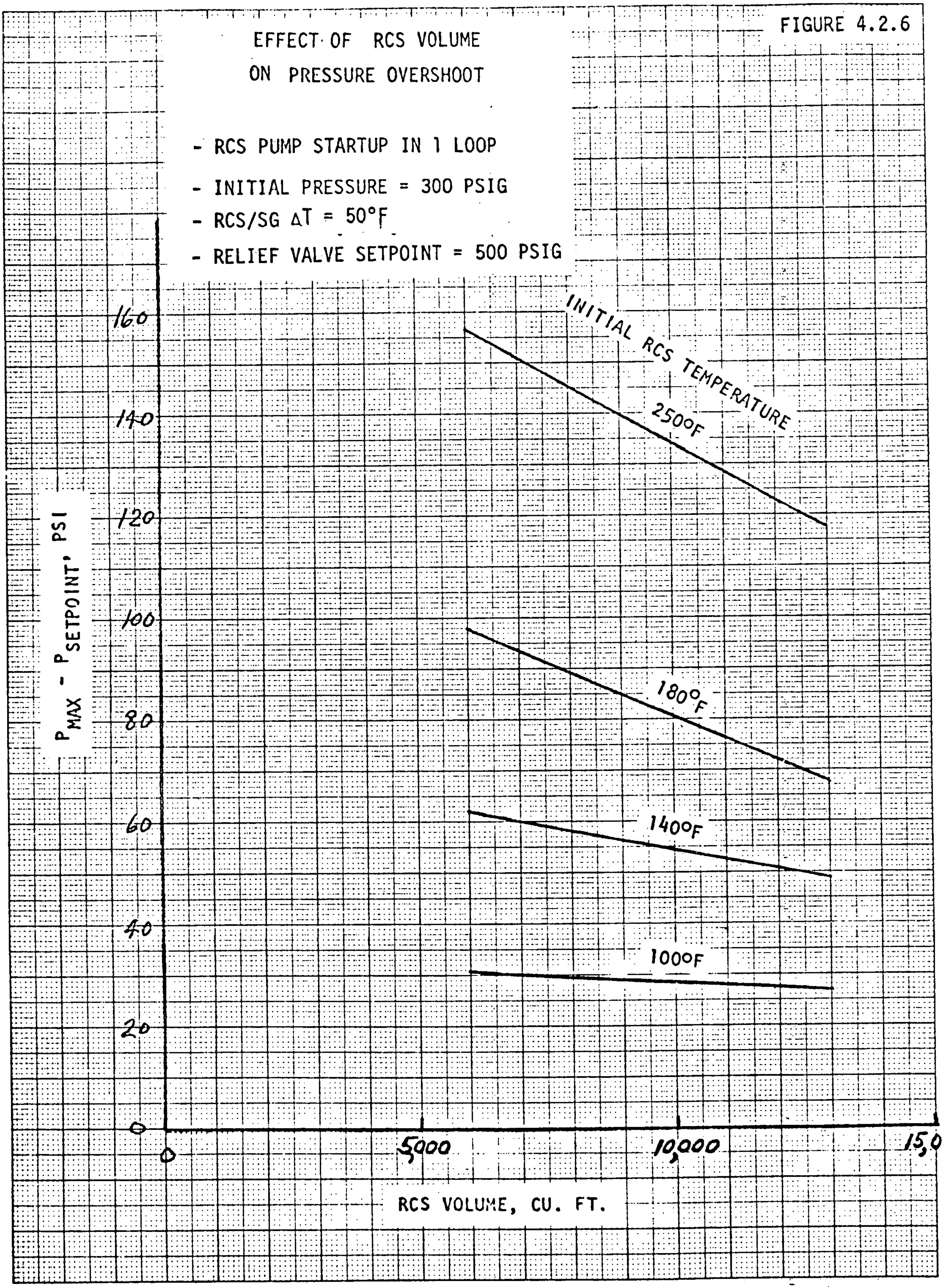
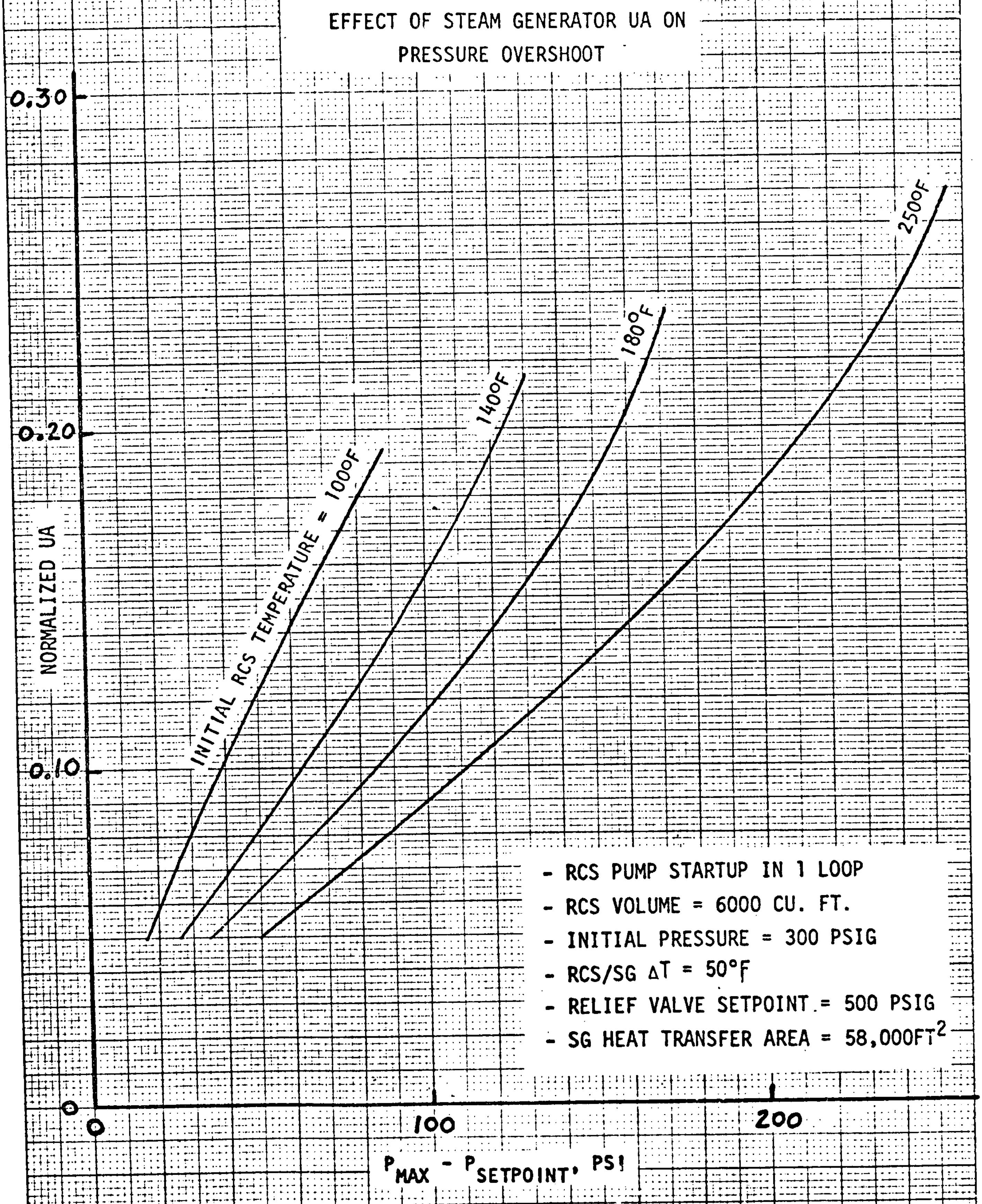


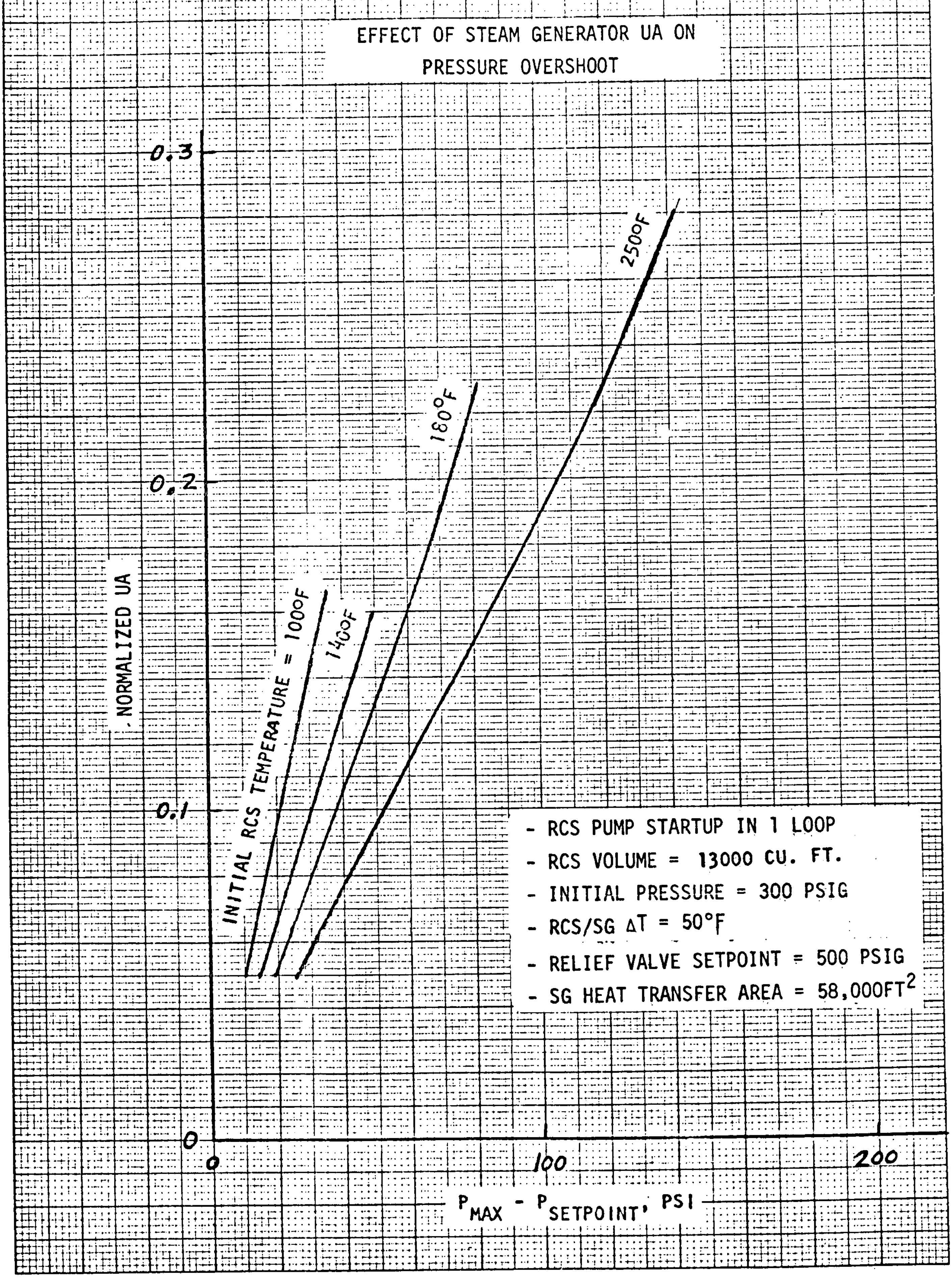
FIGURE 4.2.7



46 1320

K&E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 4.2.8


EFFECT OF STEAM GENERATOR UA ON
PRESSURE OVERSHOOT
0.3
0.2
0.1
0
NORMALIZED UA
0
100
200
$P_{MAX} - P_{SETPOINT}$, PSI
INITIAL RCS TEMPERATURE = 100°F
140°F
180°F
250°F
- RCS PUMP STARTUP IN 1 LOOP
- RCS VOLUME = 13000 CU. FT.
- INITIAL PRESSURE = 300 PSIG
- RCS/SG ΔT = 50°F
- RELIEF VALVE SETPOINT = 500 PSIG
- SG HEAT TRANSFER AREA = 58,000FT²

To determine the setpoint overshoot for a smaller steam generator heat transfer area and for an intermediate RCS volume, the following interpolation procedure is used. This procedure utilizes Figures 4.2.6, 4.2.7 and 4.2.8 directly without the introduction of linearization factors and associated conservatisms as for the mass input case.

The use of the procedure is described for the following example heat input parameters and the results of the sequential application of each step in the procedure to these parameters will be noted.

PARAMETERS FOR HEAT INPUT EXAMPLE

SG Heat Transfer Area	=	29,000 ft^2
RCS Volume	=	10,000 cu.ft.
Initial RCS Temperature	=	180°F
RCS/SG ΔT	=	50°F
Relief Valve Setpoint	=	500 psig

Applying the heat input procedure:

Step	Procedure	Example Application
1	For both the 6000 ft^3 and 13,000 ft^3 RCS volumes, obtain reference setpoint overshoots ΔP_{6K} and ΔP_{13K} from Figure 4.2.9 for the initial RCS temperature, T_{RCS}.	For T_{RCS} = 180°F, $\Delta P†_{6K}$ = 98 psi and $\Delta P†_{13K}$ = 68 psi for RCS volumes of 6_K and 13_K, respectively.
2	Using both Figures 4.2.10 and 4.2.11, determine the reference normalized UA (UA_{6K} and UA_{13K}) for both RCS volumes using ΔP_{6K} and ΔP_{13K} determined in Step 1 and for the isotherm, T_{RCS}.	For T_{RCS} = 180°F and ΔP = 98 psi, UA_{6K} = 0.115 (Figure 4.2.10). For T_{RCS} = 180°F and ΔP_{13K} = 68 psi, UA_{13K} = 0.184 (Figure 4.2.11).
3	Determine what fraction, f, of 58,000 ft^2 constitutes the actual steam generator heat transfer area.	29,000 ft^2/58,000 ft^2 = 0.5
4	Multiply both UA_{6K} and UA_{13K} (from Step 2) by f (from Step 3) to obtain new normalized UA'_{6K} and UA'_{13K} values.	UA'_{6K} = 0.115 * 0.5 = 0.0575 and UA'_{13K} = 0.184 * 0.5 = 0.092

† Setpoint Overshoot, $\Delta P = P_{MAX} - P_{SETPOINT}$

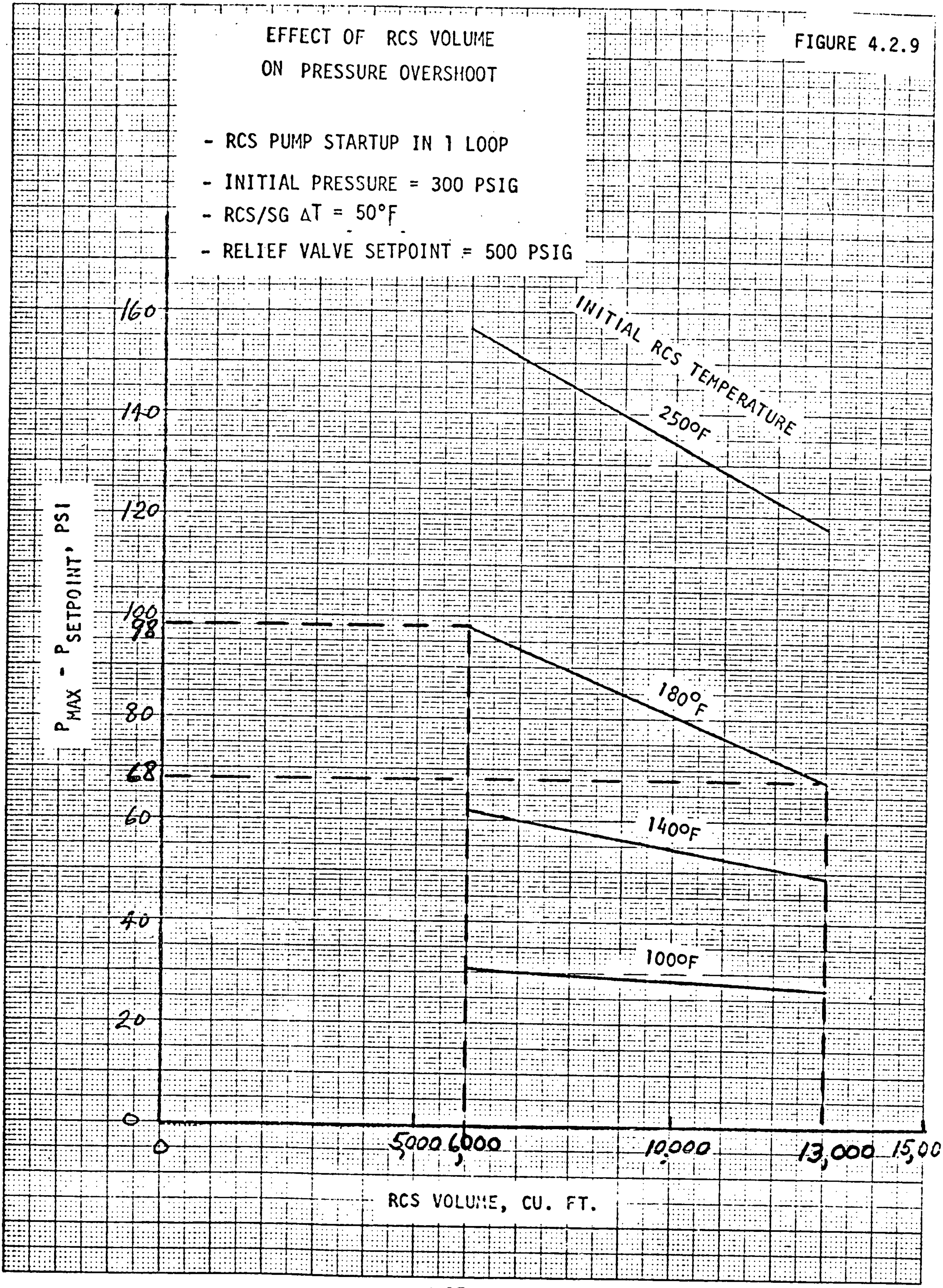

EFFECT OF RCS VOLUME
ON PRESSURE OVERSHOOT
- RCS PUMP STARTUP IN 1 LOOP
- INITIAL PRESSURE = 300 PSIG
- RCS/SG ΔT = 50°F
- RELIEF VALVE SETPOINT = 500 PSIG
FIGURE 4.2.9
INITIAL RCS TEMPERATURE
250°F
180°F
140°F
100°F
P_MAX - P_SETPOINT, PSI
160
140
120
100
98
80
68
60
40
20
0
0
5000
6000
10,000
13,000
15,000
RCS VOLUME, CU. FT.

FIGURE 4.2.10

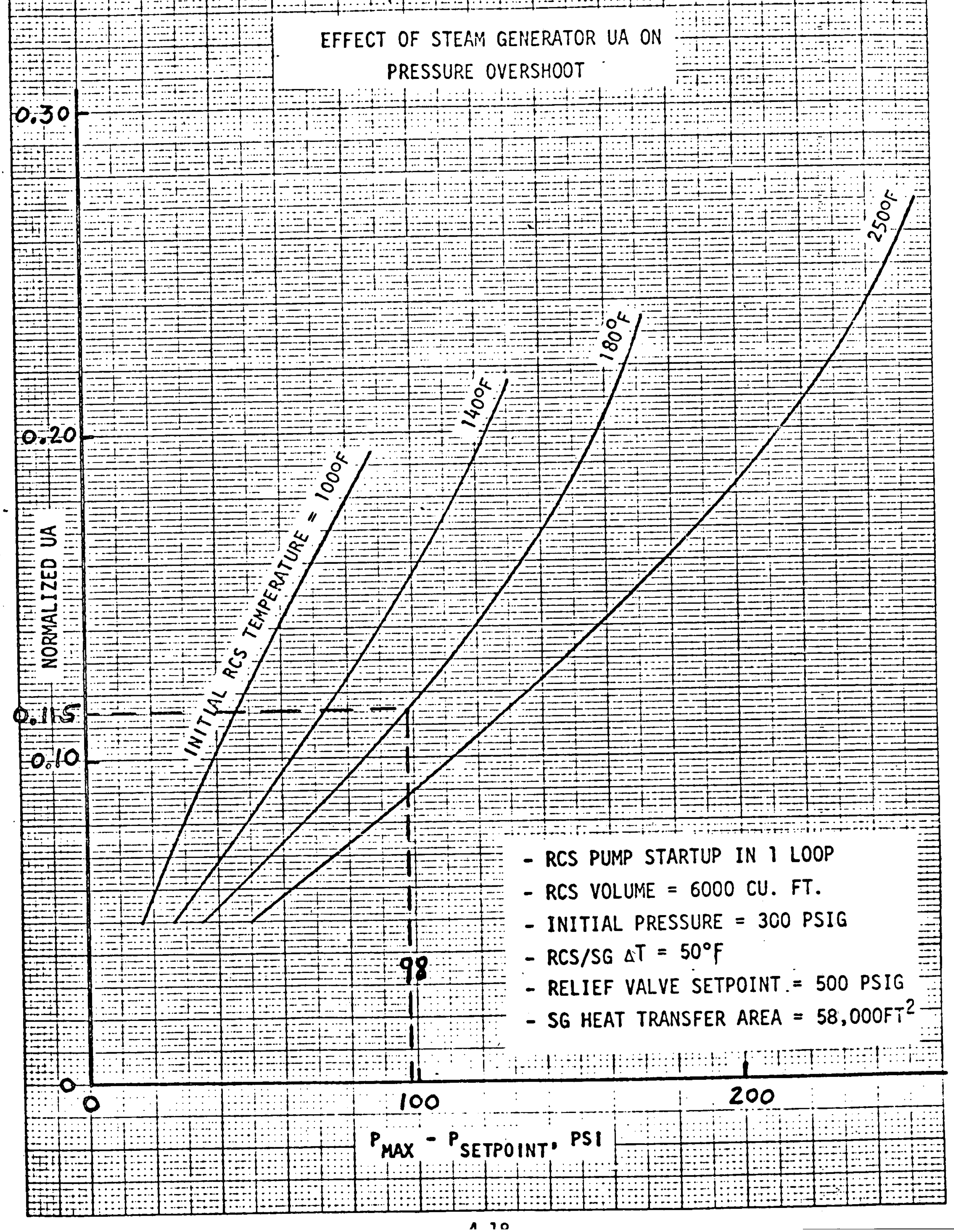
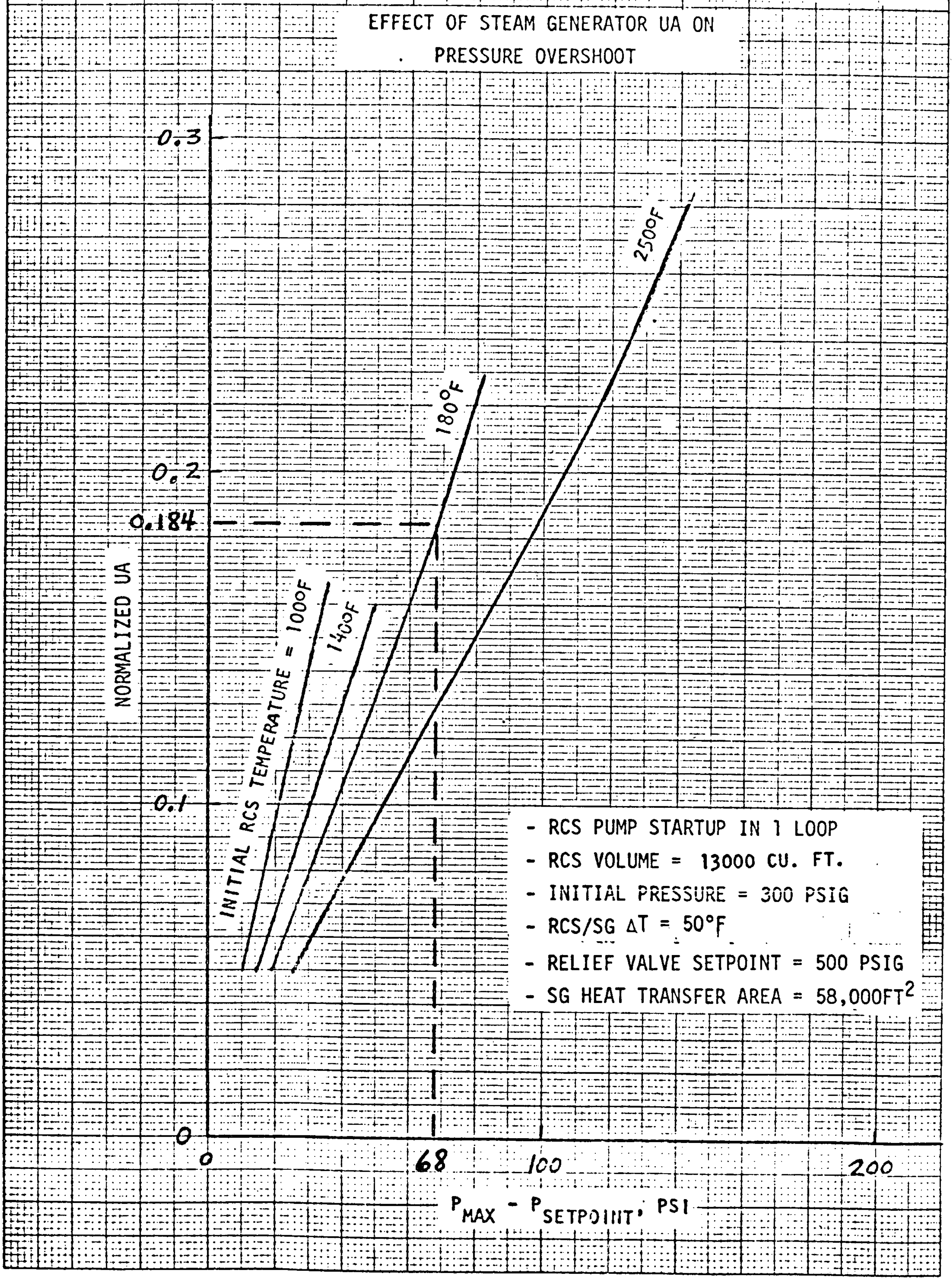

EFFECT OF STEAM GENERATOR UA ON PRESSURE OVERSHOOT
0.30
0.20
0.115
0.10
0
NORMALIZED UA
INITIAL RCS TEMPERATURE = 100°F
140°F
180°F
250°F
98
0
100
200
$P_{MAX} - P_{SETPOINT}$, PSI
- RCS PUMP STARTUP IN 1 LOOP
- RCS VOLUME = 6000 CU. FT.
- INITIAL PRESSURE = 300 PSIG
- RCS/SG ΔT = 50°F
- RELIEF VALVE SETPOINT = 500 PSIG
- SG HEAT TRANSFER AREA = 58,000FT²

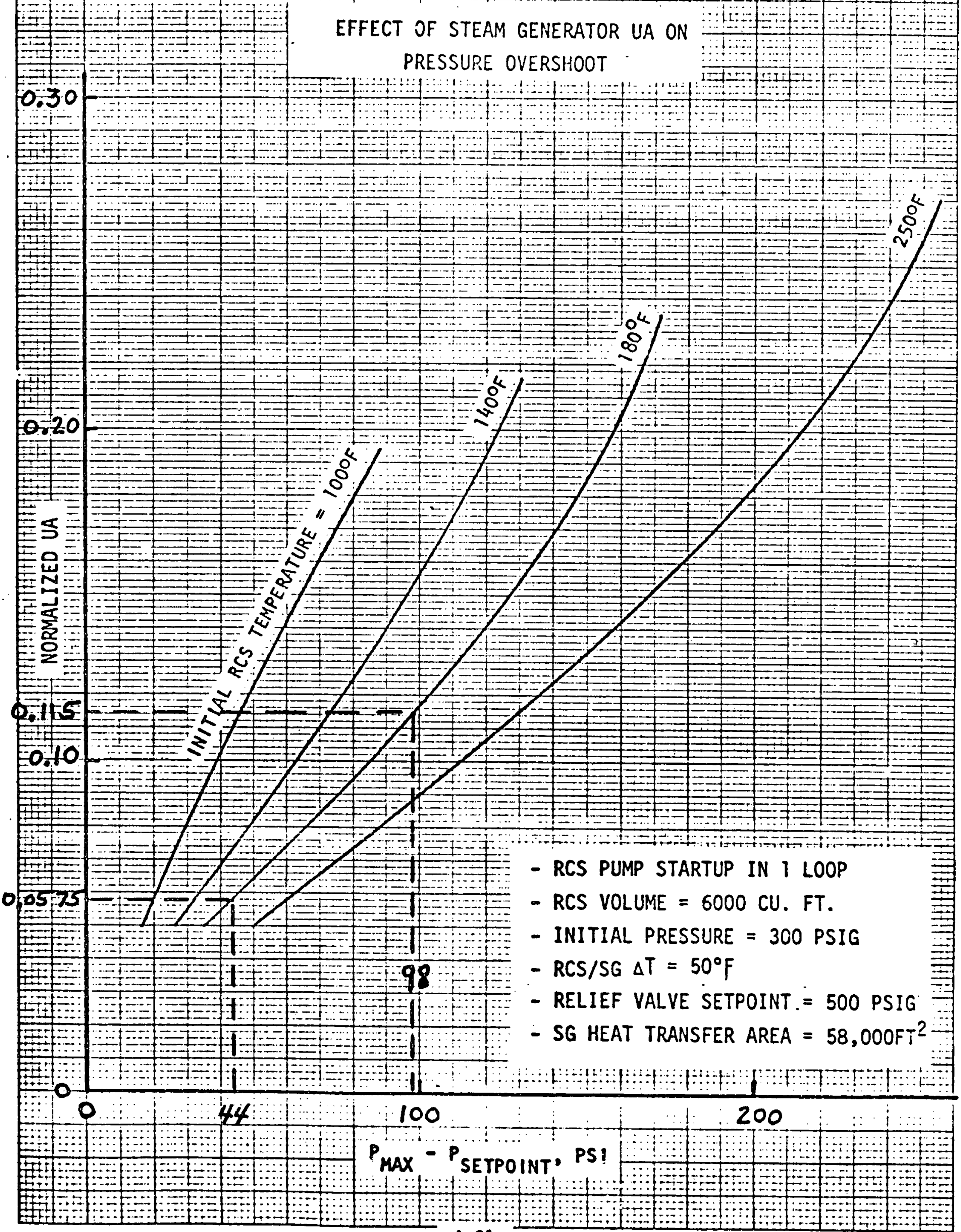
FIGURE 4.2.11


EFFECT OF STEAM GENERATOR UA ON
PRESSURE OVERSHOOT
0.3
0.2
0.184
0.1
0
NORMALIZED UA
0
68
100
200
$P_{MAX} - P_{SETPOINT}$, PSI
INITIAL RCS TEMPERATURE = 100°F
140°F
180°F
250°F
- RCS PUMP STARTUP IN 1 LOOP
- RCS VOLUME = 13000 CU. FT.
- INITIAL PRESSURE = 300 PSIG
- RCS/SG ΔT = 50°F
- RELIEF VALVE SETPOINT = 500 PSIG
- SG HEAT TRANSFER AREA = 58,000FT^2

Step	Procedure	Example Application
5	For the same isotherm, T_{RCS}, and for UA'_{6K} and UA'_{13K}, obtain new setpoint overshoots $\Delta P'_{6K}$ and $\Delta P'_{13K}$ for the 6000 ft^3 and 13,000 ft^3 volumes.	From Figure 4.2.12, for T_{RCS} = 180°F and UA'_{6K} = 0.0575, $\Delta P'_{6K}$ = <u>44 psi</u>. From Figure 4.2.13, for T_{RCS} = 180°F and UA'_{13K} = 0.092, $\Delta P'_{13K}$ = <u>35 psi</u>
6	For the actual volume, V_{RCS}, linearly interpolate the setpoint overshoot, $\Delta P'_{VRCS}$, for the new steam generator UA from the relationship:	For V_{RCS} = 10,000 cu.ft., $\Delta P'_{6K}$ = 44 psi and $\Delta P'_{13K}$ = 35 psi,
	$\Delta P'_{VRCS} =$	$\Delta P'_{10K} =$
	$\Delta P'_{6K} - \frac{V_{RCS} - 6000}{7000} (\Delta P'_{6K} - \Delta P'_{13K})$	$44 - \frac{10,000 - 6000}{7000} (44 - 35)$
		= <u>39 psi</u>

This P'_{VRCS} is the overshoot corresponding to the actual steam generator heat transfer area and RCS volume.

FIGURE 4.2.12


EFFECT OF STEAM GENERATOR UA ON PRESSURE OVERSHOOT
NORMALIZED UA
0.30
0.20
0.15
0.10
0.0575
0
INITIAL RCS TEMPERATURE = 100°F
140°F
180°F
250°F
- RCS PUMP STARTUP IN 1 LOOP
- RCS VOLUME = 6000 CU. FT.
- INITIAL PRESSURE = 300 PSIG
- RCS/SG ΔT = 50°F
- RELIEF VALVE SETPOINT = 500 PSIG
- SG HEAT TRANSFER AREA = 58,000FT²
98
0
44
100
200
P MAX - P SETPOINT, PSI

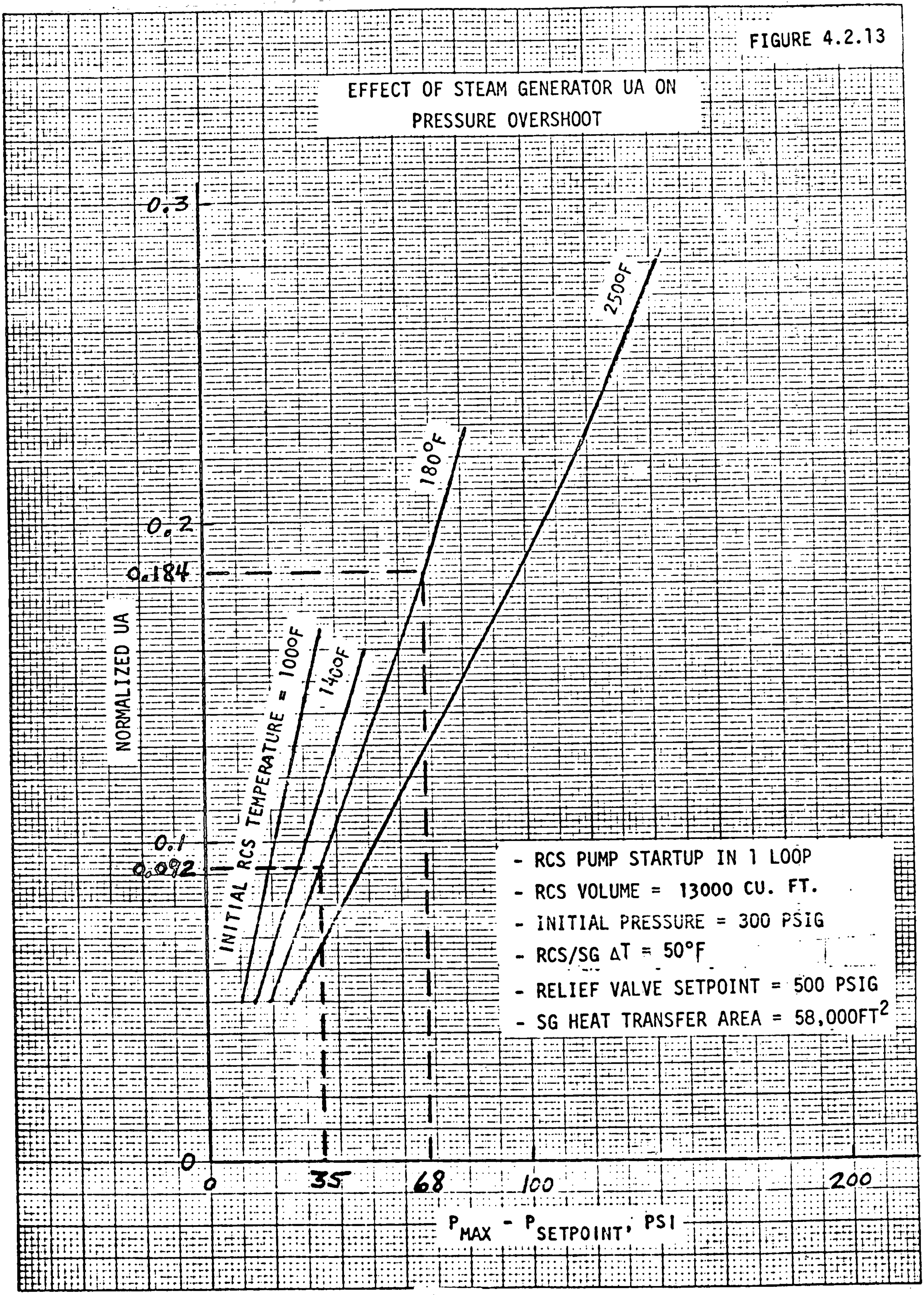


FIGURE 4.2.13

EFFECT OF STEAM GENERATOR UA ON PRESSURE OVERSHOOT

4.3 DEVELOPMENT OF INTERPOLATING MASS INPUT EQUATION

The following, simplified equation is utilized for determining mass input setpoint overshoot for a specific set of plant input parameters from the generic data.

$$\Delta P\ (V, S, Z, x) = \Delta P_{REF}\ (x) * F_V * F_S * F_Z \qquad (1)$$

where:

$\Delta P\ (V, S, Z, x)$	=	setpoint overshoot, psi
V	=	total RCS volume, cu.ft.
S	=	relief valve setpoint, psig
Z	=	relief valve opening time, seconds
x	=	mass input rate, lb/seconds
$\Delta P_{REF}\ (x)$	=	reference overshoot at mass input rate x, psi
F_V	=	RCS volume factor
F_S	=	relief valve setpoint factor
F_Z	=	relief valve opening time factor

Equation (1) involves obtaining a product of a reference overshoot ΔP_{REF}, and three application factors which account for variation in the ΔP_{REF} from reference values of RCS volume, relief valve setpoint and relief valve opening time. Linearizations involved in the development of Equation (1) will necessarily introduce some degree of conservatism in the pressure overshoot and in the determination of relief valve setpoint.

4.3.1 Analytical Basis

Development of Equation (1), and, more specifically, the development of the three application factors is based on an elementary, linear, algebraic equation involving one dependent and one independent variable, or

$$f(x) = ax + b \tag{2}$$

If this linear function is defined to pass through the origin of the coordinate system, and if f(x) takes on the constant value c for a specific, reference value of $x = x_r$, then

$$f(x_r) = c$$
$$b = 0$$
$$a = c/x_r$$

and Equation (2) becomes

$$f(x) = \left(\frac{c}{x_r}\right) x \tag{3}$$

Now consider two linear functions of x, $f_1(x)$ and $f_2(x)$, both passing through the origin of the coordinate system, with

$$f_1(x_r) = c_1 \tag{4}$$

$$f_2(x_r) = c_2 \tag{5}$$

These functions may be written as

$$f_1(x) = (\frac{c_1}{x_r})\ x \qquad (6)$$

and

$$f_2(x) = (\frac{c_2}{x_r})\ x \qquad (7)$$

Both functions f_1 and f_2 are graphically depicted in Figure 4.3.1. In solving Equations (6) and (7) simultaneously, the equation for one linear equation may be obtained in terms of the second equation by multiplying the second equation by the ratio of $c(x_r)$ values for the two functions, or

$$f_2(x) = f_1(x) * \frac{c_2}{c_1} \qquad (8)$$

This analytic technique for the determination of one linear function from a known second linear function through the use of a multiplication factor is extended to the development of interpolative factors for the generic mass input study.

4.3.2 Development of Application Factors

1. F_V - RCS Volume Factor

Consider the setpoint overshoot-mass input rate correlation shown in Figure 4.3.2 for V_{RCS} = 6000 (6K) ft^3 and relief valve setpoint = 600 psig. If this curve is linearized from the point (ΔP, mass rate) = (155 psi, 113 lb/sec) through the origin (0 psi, 0 lb/sec), the resultant linear function as shown in Figure 4.3.3 exhibits the same characteristics as the linear analytic function $f_1(x)$ described earlier, namely

FIGURE 4.3.1

MASS INPUT

Analytical Basis for Mass Input Equation

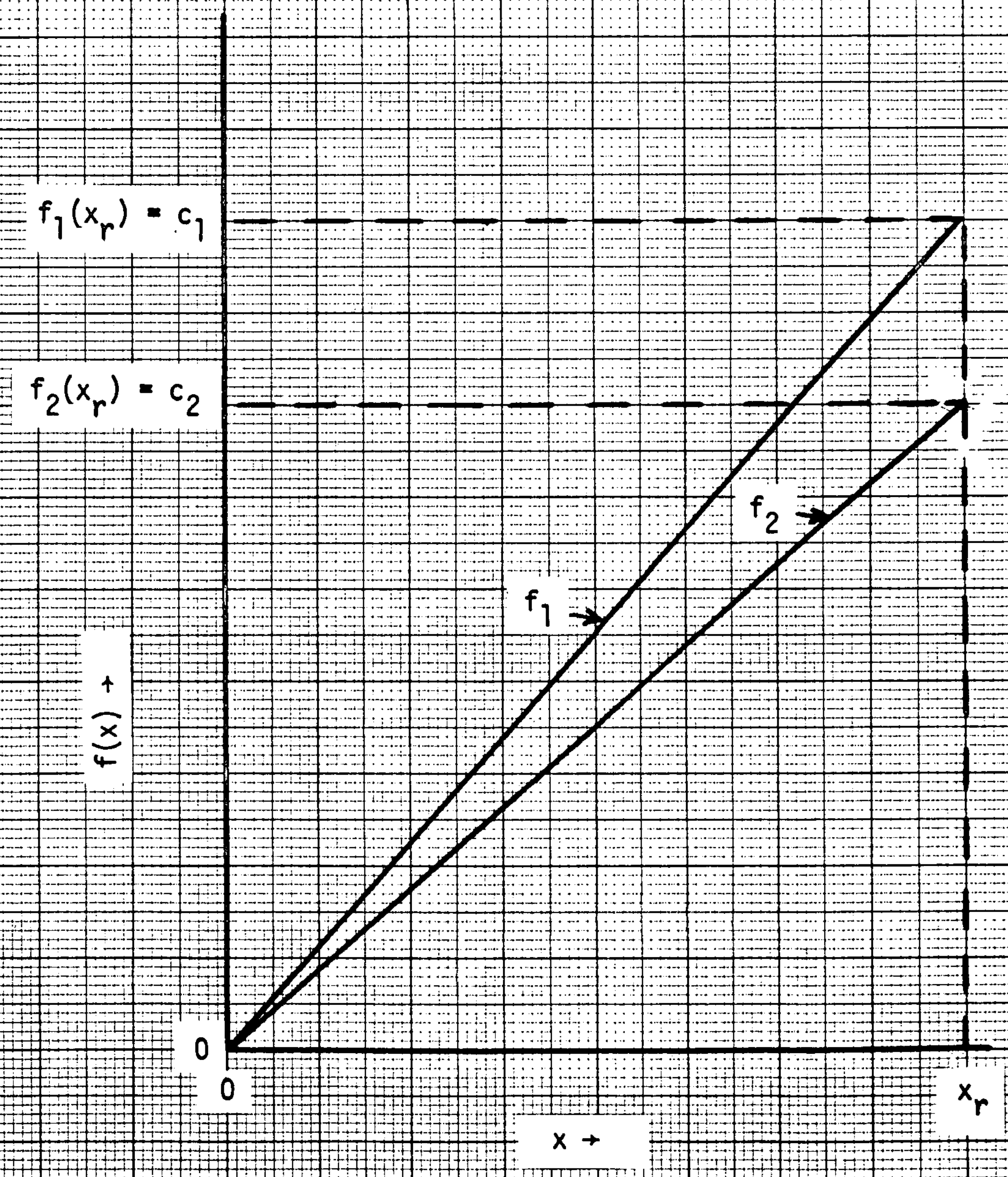
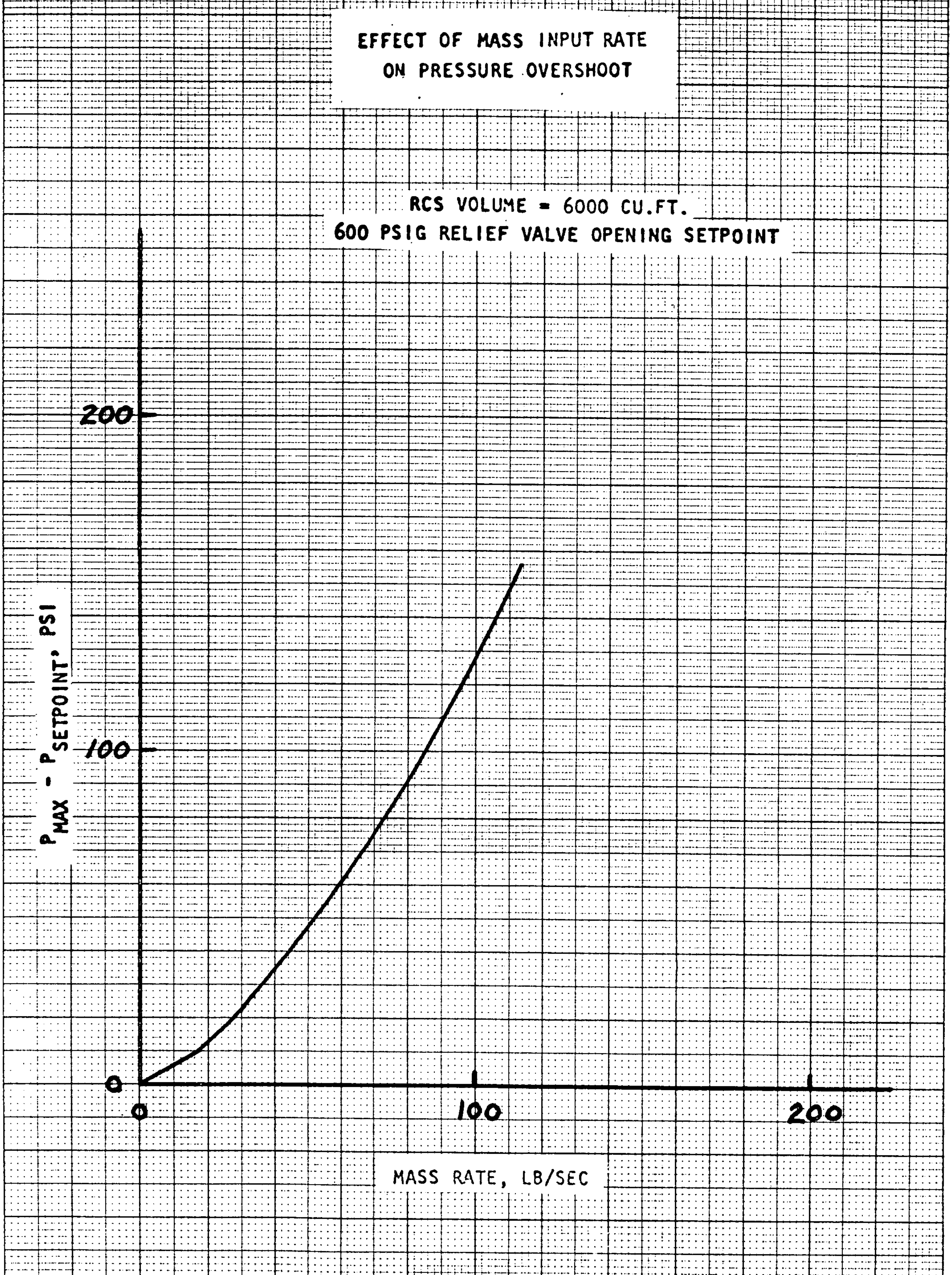


FIGURE 4.3.2



46 1320

K•E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

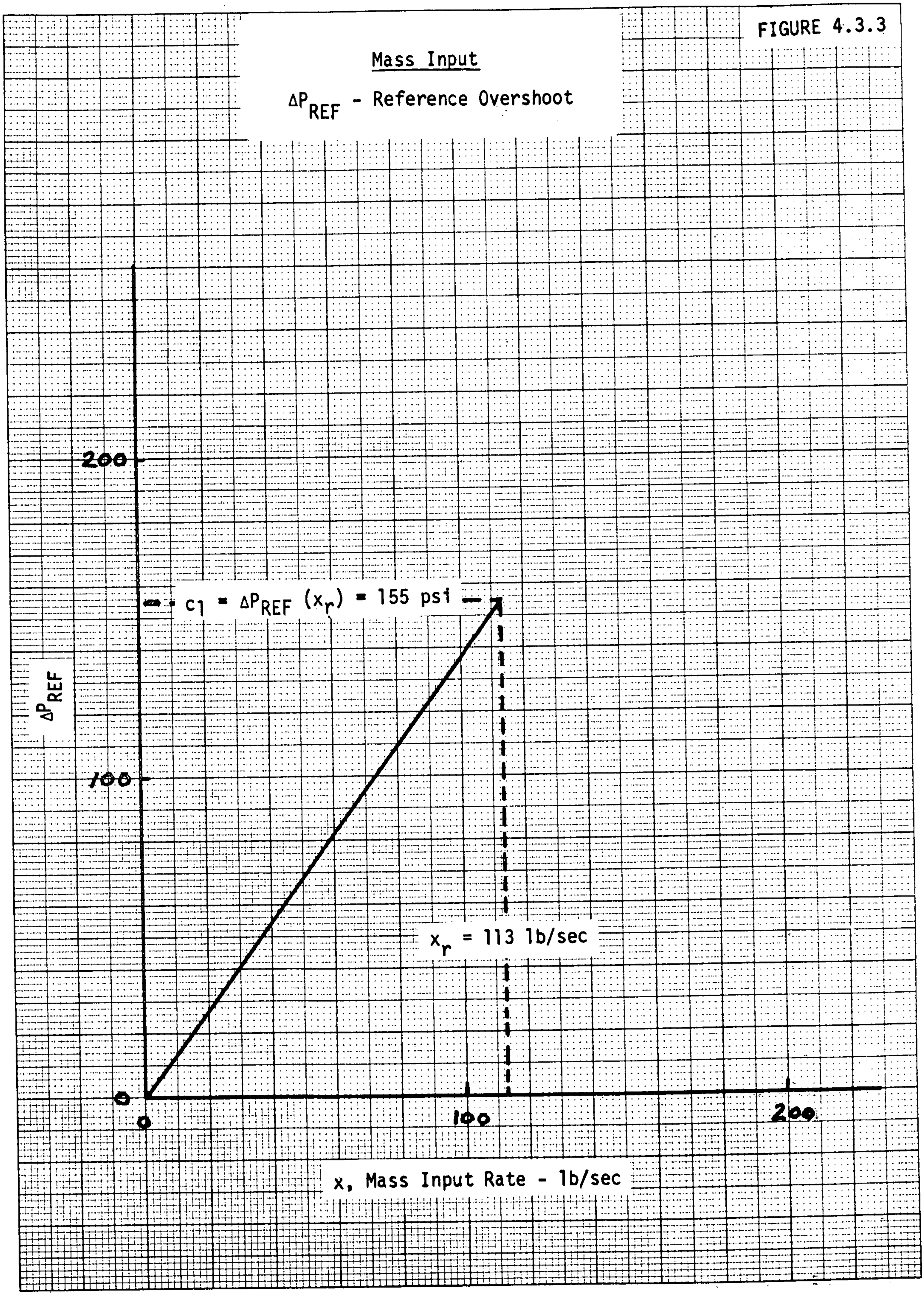


FIGURE 4.3.3
Mass Input
ΔP_REF - Reference Overshoot
200
100
0
c1 = ΔP_REF (x_r) = 155 psi
ΔP_REF
x_r = 113 lb/sec
0
100
200
x, Mass Input Rate - lb/sec

$$f_1(x) = \Delta P_{6K/600}(x) = (\frac{c_1}{x_r})\ x \qquad (9)$$

where:

$\Delta P_{6K/600}(x)$ = linearized reference setpoint overshoot, psi

x = mass input rate, lb/sec

x_r = reference mass input rate, lb/sec

c_1 = $\Delta P_{6K/600}(x_r)$, psi

For the reference conditions of 6000 ft^3 RCS volume and 600 psig relief valve setpoint, Equation (9) may be written

$$\Delta P_{6K/600}(x) = (\frac{155\ psi}{113\ lb/sec})\ x = \Delta P_{REF}\ (x) \qquad (10)$$

Further, assume that the setpoint overshoot for the same 600 psig setpoint but for a 13,000 ft^3 RCS volume, or $\Delta P_{13K/600}$, may also be represented by a second linear function (Figure 4.3.4), namely,

$$f_2(x) = \Delta P_{13K/600}(x) = (\frac{c_2}{x_r})\ x \qquad (11)$$

where:

$\Delta P_{13K/600}$ = linearized setpoint overshoot for the second linear function, psi

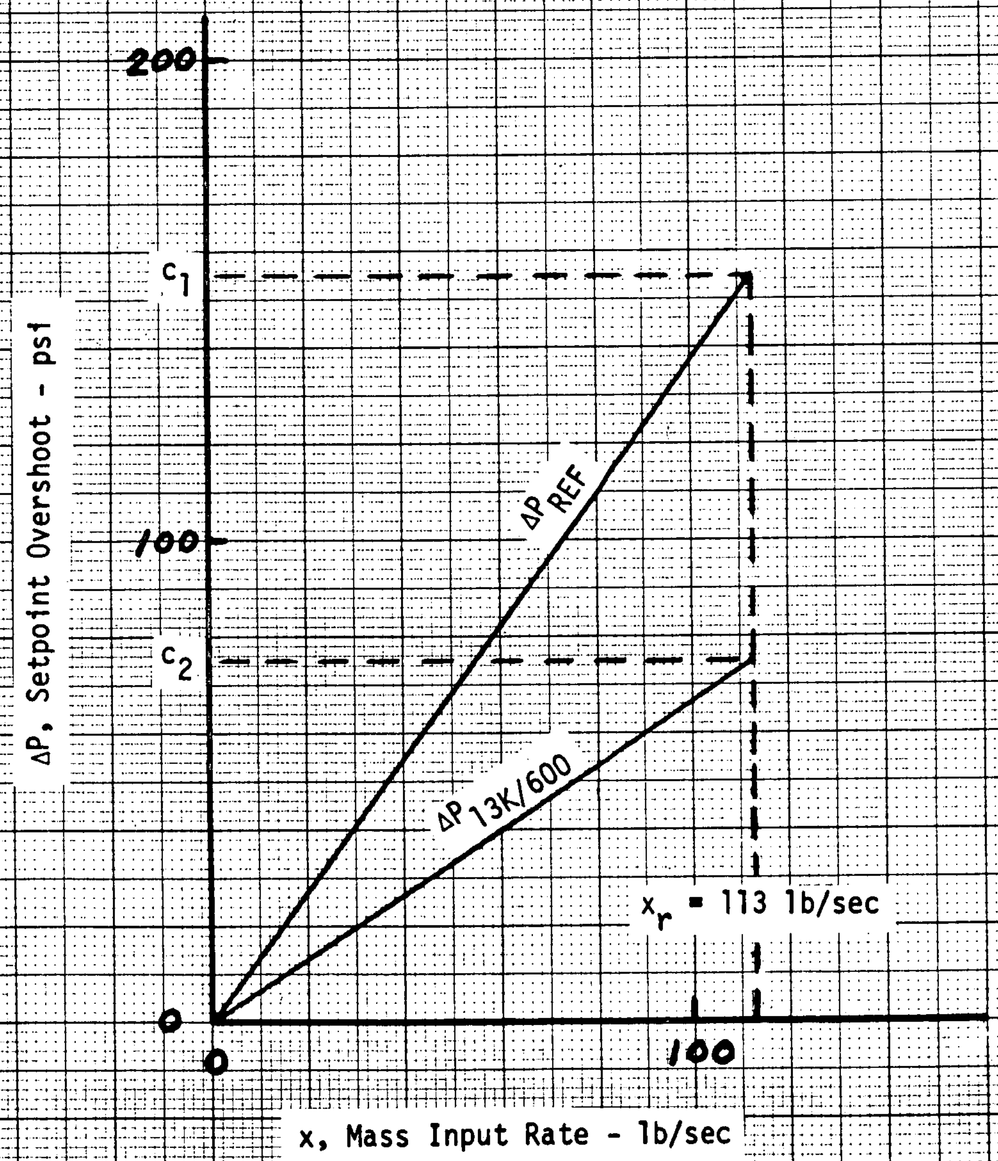
c_2 = $\Delta P_{13K/600}\ (x_r)$, psi

For V = 13,000 ft^3 (and S = 600 psig), Equation (11) may be written:

$$\Delta P_{13K/600}\ (x) = (\frac{75\ psi}{113\ lb/sec})\ x \qquad (12)$$

FIGURE 4.3.4

MASS INPUT
Linearized Setpoint Overshoot
RCS Volume Variation



where:

$c_2 \;=\; \Delta P_{13K/600}$ (113 lb/sec) = 75 psi

From Equation (8), Equations (10) and (12) may be combined to give the setpoint overshoot for a 13,000 ft^3 RCS volume in terms of an overshoot determined for the reference 6000 ft^3 volume, and a ratio of overshoots (c_2/c_1) determined at the reference mass input rate, or x_r = 113 lb/sec. This relationship, for which setpoint remains unchanged at 600 psig, may be written

$$\begin{aligned} \Delta P_{13K/600}(x) &= \Delta P_{6K/600}(x) * \frac{c_2}{c_1} \\ &= \Delta P_{REF}(x) * \frac{75}{155} \\ &= 0.484\ \Delta P_{REF}(x) \qquad (13) \end{aligned}$$

For RCS volumes intermediate to 6000 ft^3 and 13,000 ft^3, values of c_2 will vary between

$$75 \text{ psi} \leq c_2 \leq 155 \text{ psi}$$

and the c_2/c_1 ratio will vary between

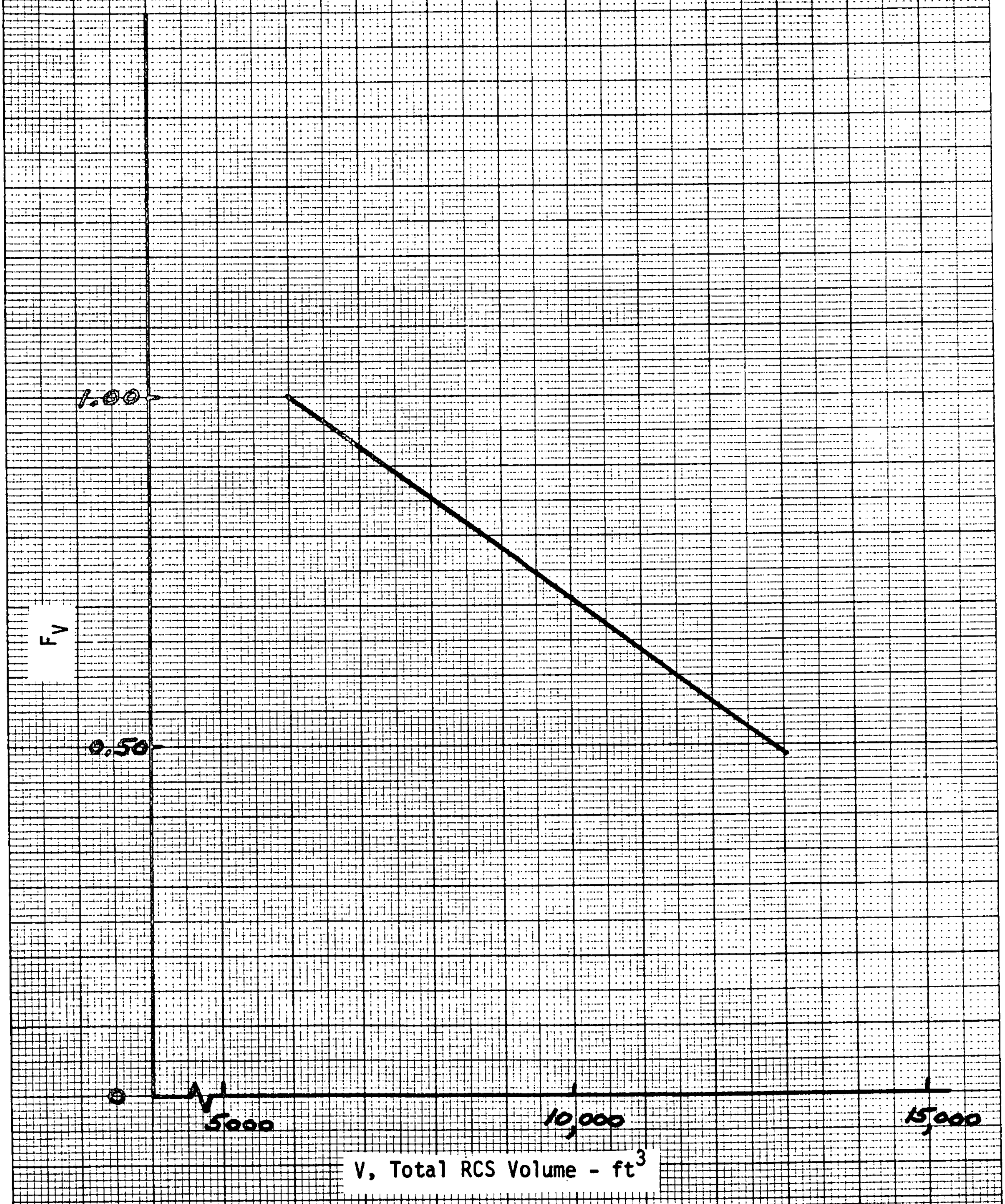
$$0.484 \leq c_2/c_1 \leq 1.00$$

If the c_2/c_1 ratio is set equal to F_V, the RCS volume application factor, its variation with RCS volume would be as shown in Figure 4.3.5, and the setpoint overshoot at 600 psig relief valve setpoint for any 6000 ft^3 $\leq V \leq$ 13,000 ft^3 would be obtained from the relationship

FIGURE 4.3.5

Mass Input

F_V - RCS Volume Factor



$$\Delta P_{V/600}(x) = \Delta P_{REF}(x) * F_V \quad (14)$$

where:

$\Delta P_{V/600}(x)$ = setpoint overshoot at mass input rate x for RCS volume V and S = 600 psig, psi

$\Delta P_{REF}(x)$ = reference setpoint overshoot at x (6K/600)

F_V = RCS volume factor

2. F_S - Relief Valve Setpoint Factor

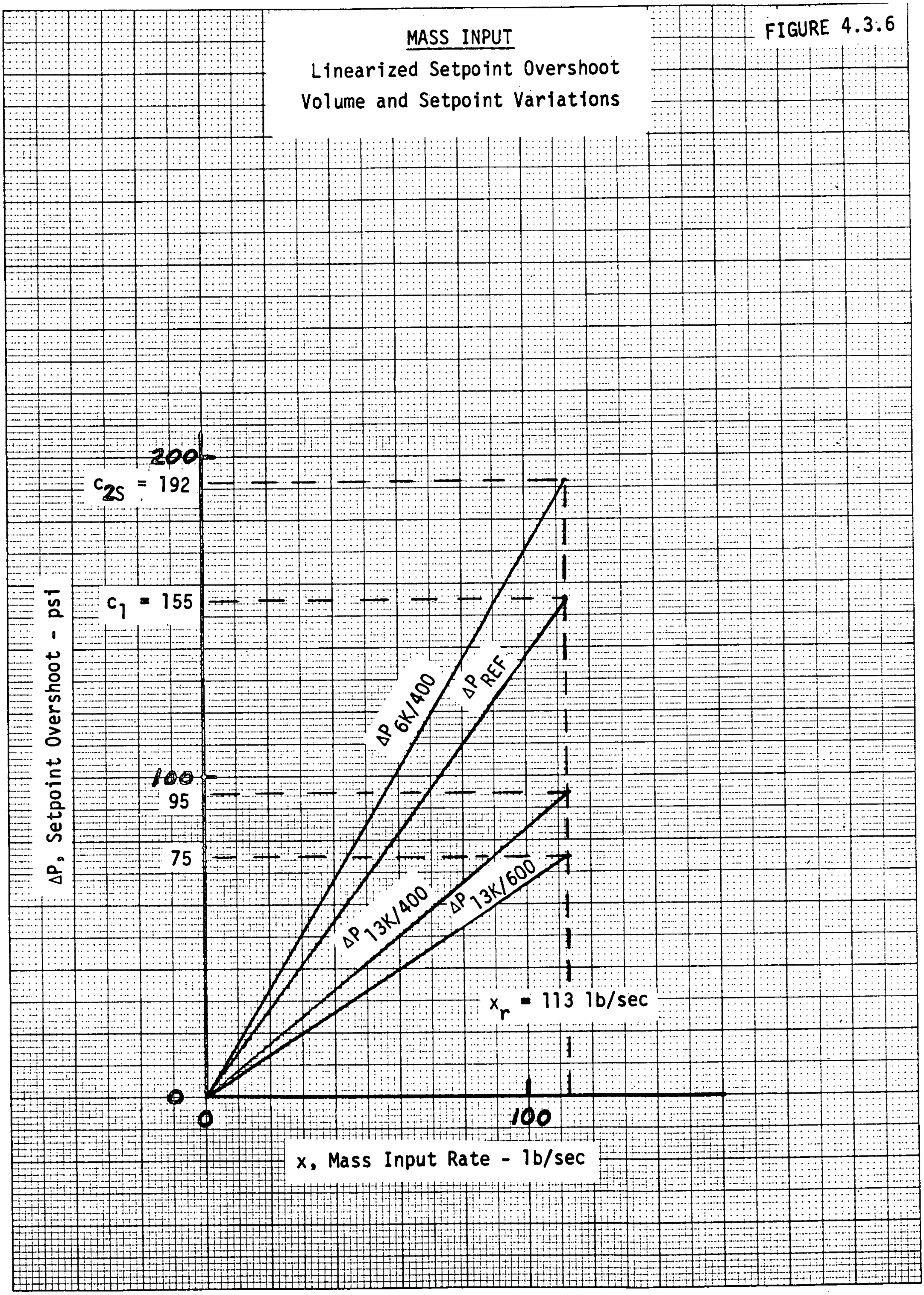
Just as the $\Delta P_{6K/600}(x)$ and $\Delta P_{13K/600}(x)$ functions were linearized in Figure 4.3.4 for a change in RCS volume from 6K ft^3 to 13K ft^3, linear correlations for setpoint variations from 600 psig to 400 psig can be drawn as shown in Figure 4.3.6. Further, just as Equation (8) was utilized to relate one linear function to another for RCS volume variation from 6K ft^3 to 13K ft^3, it may also be applied to the situation where setpoint is varied. In this case, to obtain the setpoint overshoot ΔP at 400 psig for a 6000 ft^3 plant knowing ΔP at 600 psig, Equation (8) is utilized to obtain

$$\Delta P_{6K/400}(x) = \Delta P_{REF}(x) * \frac{c_{2S}}{c_1}$$

$$= \Delta P_{6K/600}(x) * (\frac{192}{155})$$

$$= 1.25\ \Delta P_{6K/600}(x) \quad (15)$$

FIGURE 4.3.6



MASS INPUT
Linearized Setpoint Overshoot
Volume and Setpoint Variations
200
100
0
0
100
c2S = 192
c1 = 155
95
75
ΔP 6K/400
ΔP REF
ΔP 13K/400
ΔP 13K/600
xr = 113 lb/sec
ΔP, Setpoint Overshoot - psi
x, Mass Input Rate - lb/sec

For a RCS volume of 13K ft^3, this relationship (for a setpoint change from 600 psig to 400 psig) would be

$$\Delta P_{13K/400}(x) = \Delta P_{13K/600}(x) * (\frac{95}{75})$$

$$= 1.27 \ \Delta P_{13K/600}(x) \qquad (16)$$

To ensure a conservative determination of setpoint overshoot for a setpoint variation at any RCS volume, the maximum coefficient (1.27) in Equations (15) and (16) is utilized in the development of the application factor for the generalized correlation for setpoint variation. In this correlation, for any relief valve setpoint between 400 psig and 600 psig, the setpoint overshoot for RCS volume V from Equation (15) is given by

$$\Delta P_{V/S}(x) = \Delta P_{V/600}(x) * F_S \qquad (17)$$

where:

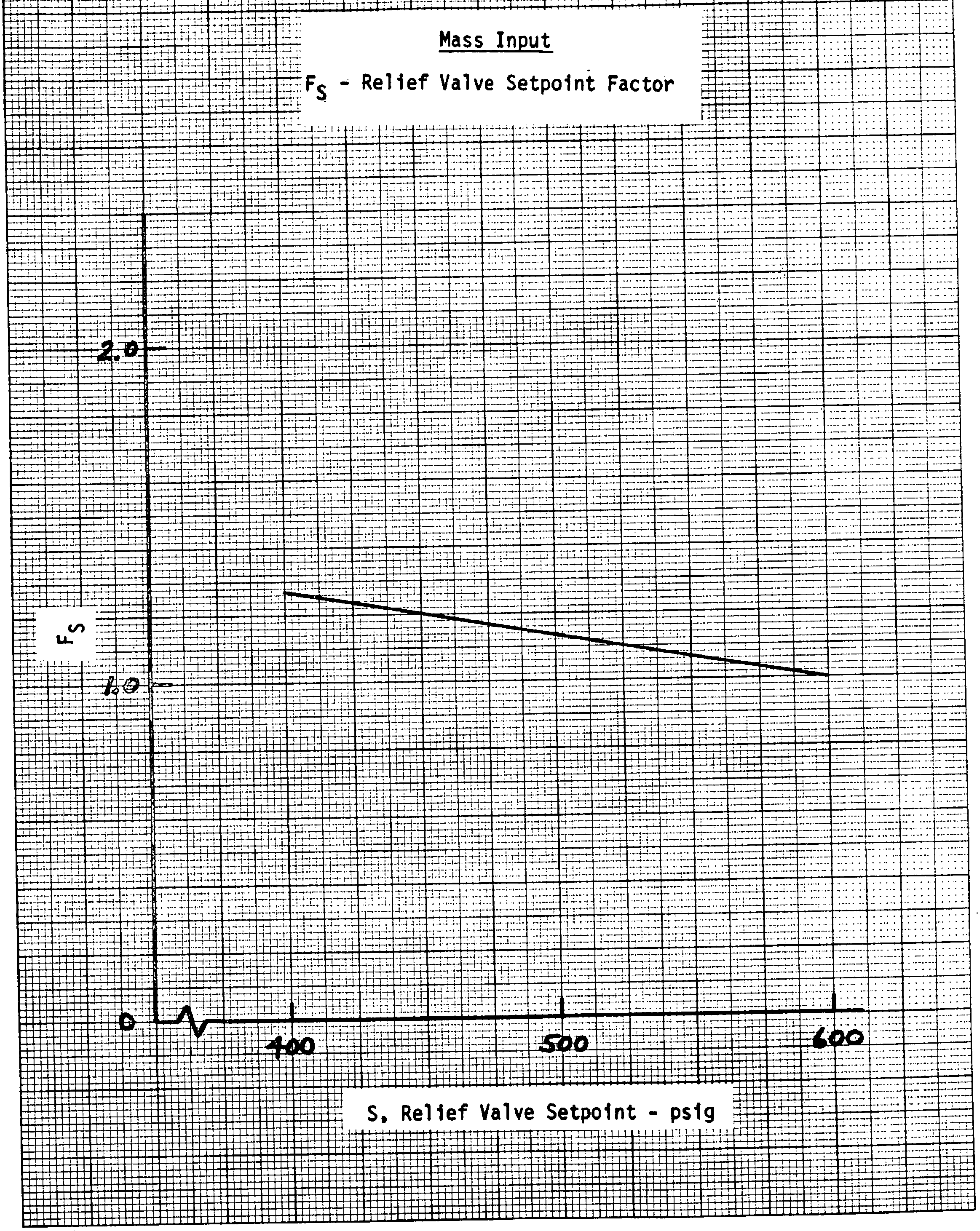
F_S = relief valve setpoint factor as defined in Figure 4.3.7

S = relief valve setpoint 400 psig $\leq$ S $\leq$ 600 psig

Incorporating the volume variation effect from Equation (14), Equation (17) becomes

$$\Delta P_{V/S}(x) = \Delta P_{V/600}(x) * F_S$$

$$= \Delta P_{REF}(x) * F_V * F_S \qquad (18)$$


Mass Input
F_S - Relief Valve Setpoint Factor
2.0
F_S
1.0
0
400
500
600
S, Relief Valve Setpoint - psig

To this point in the development, the effects of relief valve setpoint and RCS volume variations on setpoint overshoot have been accounted for in Equation (18). The effect of relief valve opening time remains to be considered.

3. F_Z - Relief Valve Opening Time Factor

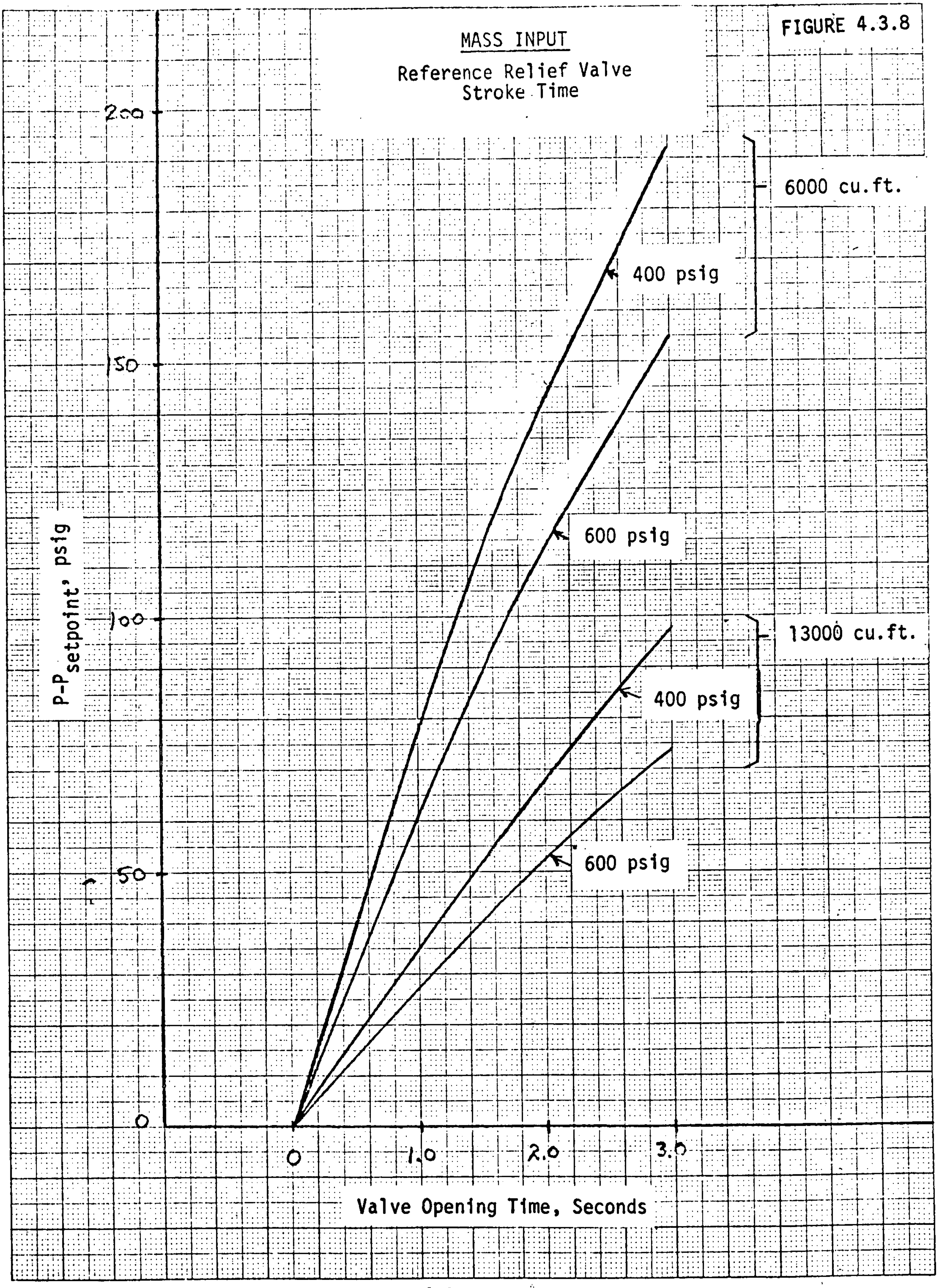
Figure 4.3.8 describes the variation in setpoint overshoot ΔP with relief valve opening time, which includes a time delay (for air accumulation prior to valve stem motion) equal to 20% of the total opening time. Correlations are presented for 400 psig and 600 psig relief valve setpoints at RCS volumes equal to 6000 ft^3 and 13,000 ft^3.

To facilitate the determination of setpoint overshoot with variation in valve opening time, each correlation in Figure 4.3.8 was linearized by drawing a line, tangent to each curve at the reference condition (relief valve opening time = 3 seconds), and intersecting the abscissa at a point to the lift of the origin.

Figure 4.3.9 illustrates this procedure for the reference case (600 psig setpoint, 6000 ft^3 RCS volume). If the new origin defined by the linear approximation is designated as 0', and the displacement of the origin as $\Delta Z'$, then the coordinate system for the linear functions will have a new abscissa, Z, defined in terms of the original abscissa Z' (where: 0 seconds $\leq Z' \leq$ 3 seconds) and the displacement $\Delta Z'$, or

$$Z = Z' + \Delta Z' \quad (19)$$

FIGURE 4.3.8


MASS INPUT
Reference Relief Valve Stroke Time
6000 cu.ft.
400 psig
600 psig
13000 cu.ft.
400 psig
600 psig
200
150
100
50
0
P-P setpoint, psig
0
1.0
2.0
3.0
Valve Opening Time, Seconds

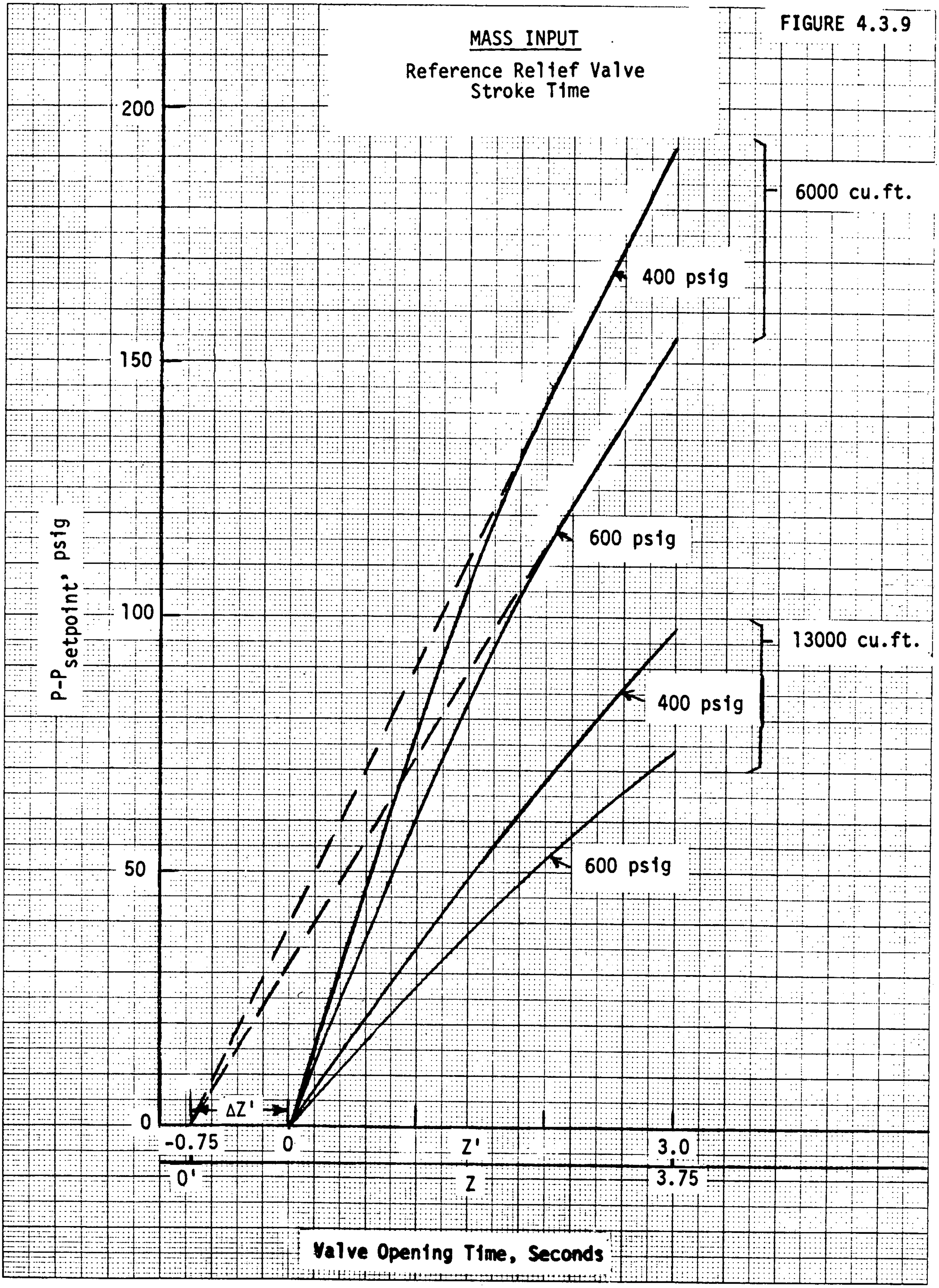

MASS INPUT
Reference Relief Valve
Stroke Time
200
150
100
50
0
P-P$_{setpoint}$, psig
6000 cu.ft.
400 psig
600 psig
13000 cu.ft.
400 psig
600 psig
ΔZ'
-0.75
0
Z'
3.0
0'
Z
3.75
Valve Opening Time, Seconds

FIGURE 4.3.9

For any relief valve opening time, Z', therefore, the setpoint overshoot ΔP may be obtained from the linear relationship

$$\Delta P_{V/S}(x, Z') = \left(\frac{Z' + \Delta Z'}{3 + \Delta Z'}\right) * \Delta P_{V/S}(x) \qquad (20)$$

$$= F_Z * \Delta P_{V/S}(x) \qquad (21)$$

The F_Z factor was optimized from a linearization of all the correlations in Figure 4.3.9. It was determined that both setpoint parametrics for 6000 ft^3 RCS volume produced the largest abscissa displacement ($\Delta Z'$ = 0.75 seconds). This displacement maximizes the F_Z factor to ensure a conservative setpoint overshoot. A plot of the F_Z factor with valve opening time, Z', is shown in Figure 4.3.10. It should be noted that conservatism in overshoot determination increases as the relief valve opening time is reduced from the 3 second reference value.

By way of illustration of the use of the F_Z factor, consider a relief valve opening time of 2.0 seconds. The reference setpoint overshoot ΔP_{REF} (= $\Delta P_{6K/600}$) would be determined as follows. From Figure 4.3.10, for Z' = 2.0 seconds,

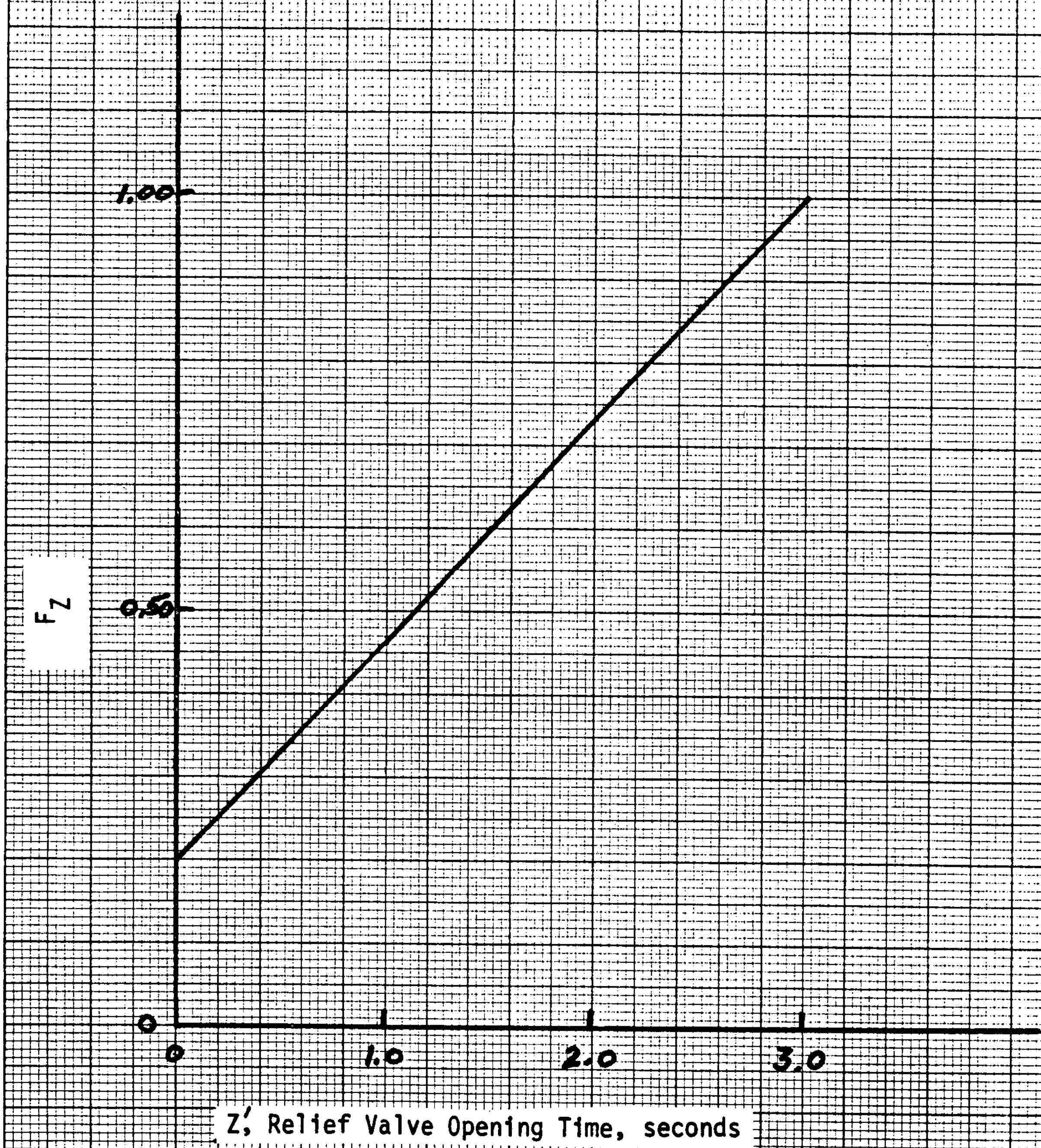
$$F_Z = 0.73$$

from Equation (21),

FIGURE 4.3.10

Mass Input

F_Z - Relief Valve Opening Time Factor



$$\Delta P_{6K/600}\ (x,\ Z' = 2.0) = 0.73 * \Delta P_{REF}\ (x) \quad (22)$$

$$= 0.73 * 155 \text{ psi}$$

$$= 113 \text{ psi}$$

This compares almost exactly with the setpoint overshoot given in Figure 4.3.8. For smaller valve opening times, use of Equation (21) will give progressively more conservative values of overshoot.

Incorporating the effect of relief valve opening time as given by Equation (21) into the expression (Equation 18) which reflects the effect of relief valve setpoint and RCS volume interpolation, the following expression is derived:

$$\Delta P_{V/S}\ (x,\ Z') = \Delta P_{V/S}\ (x) * F_Z$$

$$= \Delta P_{REF}\ (x) * F_V * F_S * F_Z \quad (23)$$

or

$$\Delta P\ (V,\ S,\ Z,\ x) = \Delta P_{REF}\ (x) * F_V * F_S * F_Z$$

which is the simplified interpolating equation (Equation 1) used in the algorithm for setpoint determination for the mass input transient.

SECTION 5
CONSERVATISMS IN STUDY

The analyses presented in this report were conducted such that certain parameters provided a degree of conservatism in the peak pressure reached during a transient. By selecting more realistic values of the parameters, the peak pressure would be reduced. This section describes the use of five particular items, each of which resulted in a conservatively high calculated value of the peak transient pressure.

5.1 RELIEF VALVE STROKE TIME

The reference relief valve selected for use in this study was considered to have a total opening time of 3.0 seconds from the instant the signal to open is received until the valve reaches the full open position. Many of the pressurizer power operated relief valves have been found by experience to act in less than 3 seconds.

To evaluate the effect of a decrease in the stroke time, a calculation was made for the particular case of mass input from the reference SI pump into a small 6000 cu.ft. volume system, for two values of valve stroke time. The first time was the reference stroke time of 2.4 seconds (that is, no delay time to fill the air system) in which the overshoot above the setpoint was found to be 80 psi. When the stroke time was reduced from 2.4 to 1.5 seconds, the overshoot was reduced to about 62 psi. Extrapolating the data to a value of zero overshoot, corresponding to a valve that opens instantaneously, the relationship shown on Figure 5.1 is obtained. This figure indicates the sensitivity of the setpoint overshoot to the time to stroke the valve and the advantage provided by the faster valves.

The effect of the stroke time on pressure overshoot for two valves is also shown on Figure 5.1.

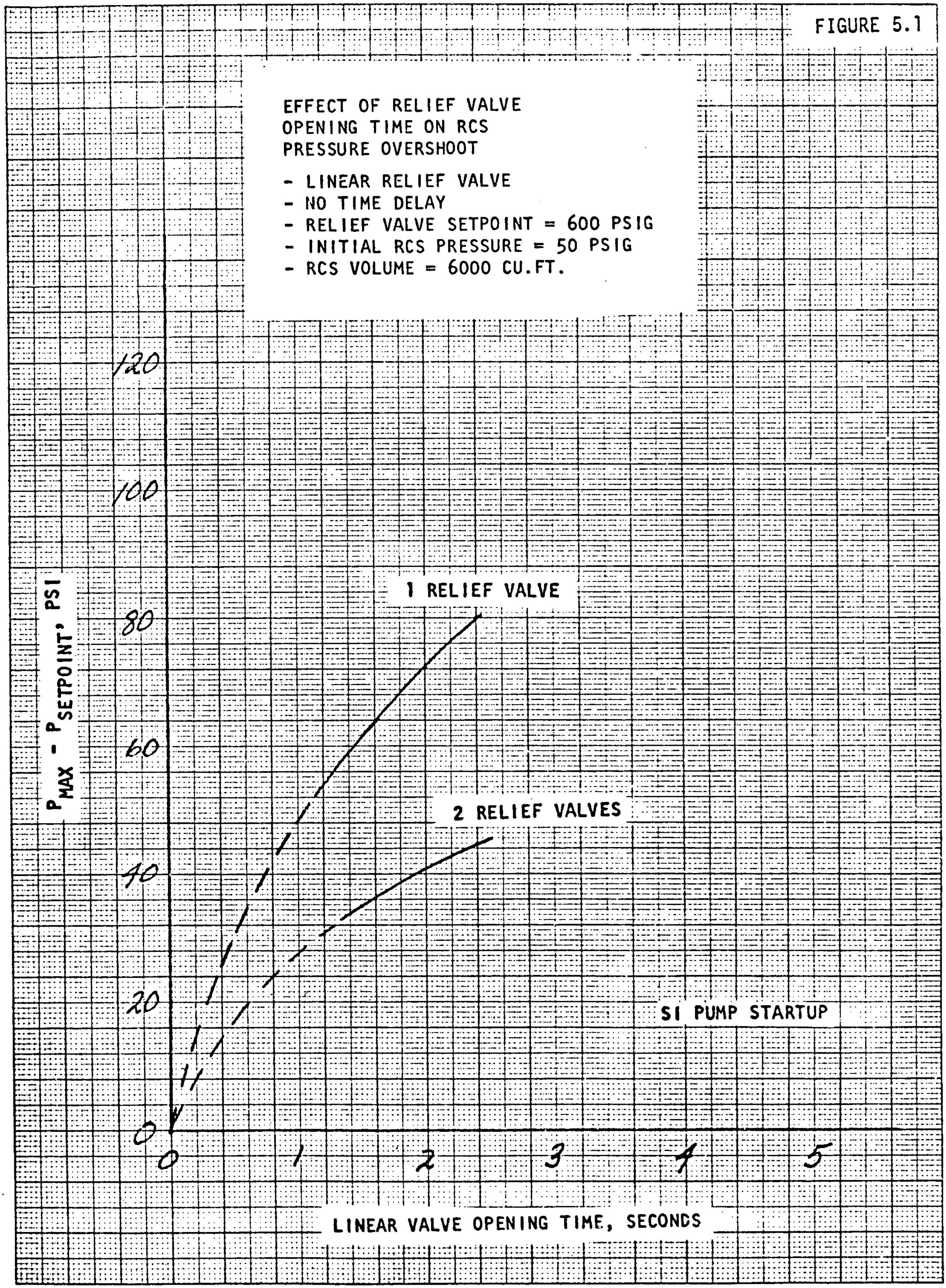


FIGURE 5.1
EFFECT OF RELIEF VALVE
OPENING TIME ON RCS
PRESSURE OVERSHOOT
- LINEAR RELIEF VALVE
- NO TIME DELAY
- RELIEF VALVE SETPOINT = 600 PSIG
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 6000 CU.FT.
120
100
80
60
40
20
0
P_{MAX} - $P_{SETPOINT}$, PSI
1 RELIEF VALVE
2 RELIEF VALVES
SI PUMP STARTUP
0
1
2
3
4
5
LINEAR VALVE OPENING TIME, SECONDS

5.2 EFFECT OF METAL EXPANSION

The coolant pressure transients for all cases presented in this study were computed assuming that the coolant was enclosed by a rigid, non-yielding boundary and that the pressure change was a direct result of the inability of the coolant to expand into a larger volume. In reality, the pressure boundary is elastic, and for each increase in coolant pressure, there is a finite increase in system volume which will tend to mitigate the coolant pressure response.

To evaluate the significance of the pressure boundary elasticity effect, an estimate was made of the unit change in system volume for a particular change in internal system pressure. Only the simple geometric shapes of cylinders and hemispheres were utilized in the delta volume calculation and the other portions of the pressure boundary; reactor vessel upper head and nozzle course, pump casing, steam generator inlet and outlet plenums and miscellaneous connecting piping were assumed to be inelastic.

Table 5.2 summarizes the results of the calculation to determine the change in volume, for a coolant pressure change of 1000 psi, of each major portion of the reactor coolant system. The first two columns indicate the total coolant volume enclosed in the elastic section under consideration and the second two columns indicate the change in volume (cu.ft.) of each of the sections under a 1000 psi internal pressure. The last two columns are listed to show which sections contribute the greatest percentage of the total volume change.

Table 5.2 indicates that for a volume typical of a 2 loop plant, the total volume will increase about 3 cu.ft. for a 1000 psi pressure change. To evaluate the effect of this increased volume, the mass input case with the reference SI pump was recomputed by considering that a portion of the mass input supplied by the pump is used to fill and pressurize the additional volume made available by the metal expansion. For the particular case evaluated, i.e., the reference SI pump and 6000 cu.ft. volume plant, it was determined that only about 83% of the pump flow was effective in increasing the coolant pressure and the remaining flow would be used to fill and pressurize the expansion volume.

Figure 5.2 describes the reduction in the peak pressure reached in the cycle when the pressure boundary expansion is taken into consideration. The figure shows the pressure overshoot above the setpoint calculated for the inelastic case is at least 35% higher than the realistic pressure overshoot for the actual elastic system. A similar significant degree of conservatism is inherent in all analyses presented in this study.

The pressure boundary would also change dimensions if the temperature of the metal were changed during the transients. For the mass input cases, the system was assumed to be isothermal at 100°F so for these cases there would be no dimensional change. However, in the heat input cases the reactor coolant did increase in temperature due to the heat transferred from the steam generators but at such a rapid rate that the massive metal parts of the reactor coolant system could not be changed in temperature during the short term transients considered. Therefore, the temperature effect on metal expansion was not included in this study.

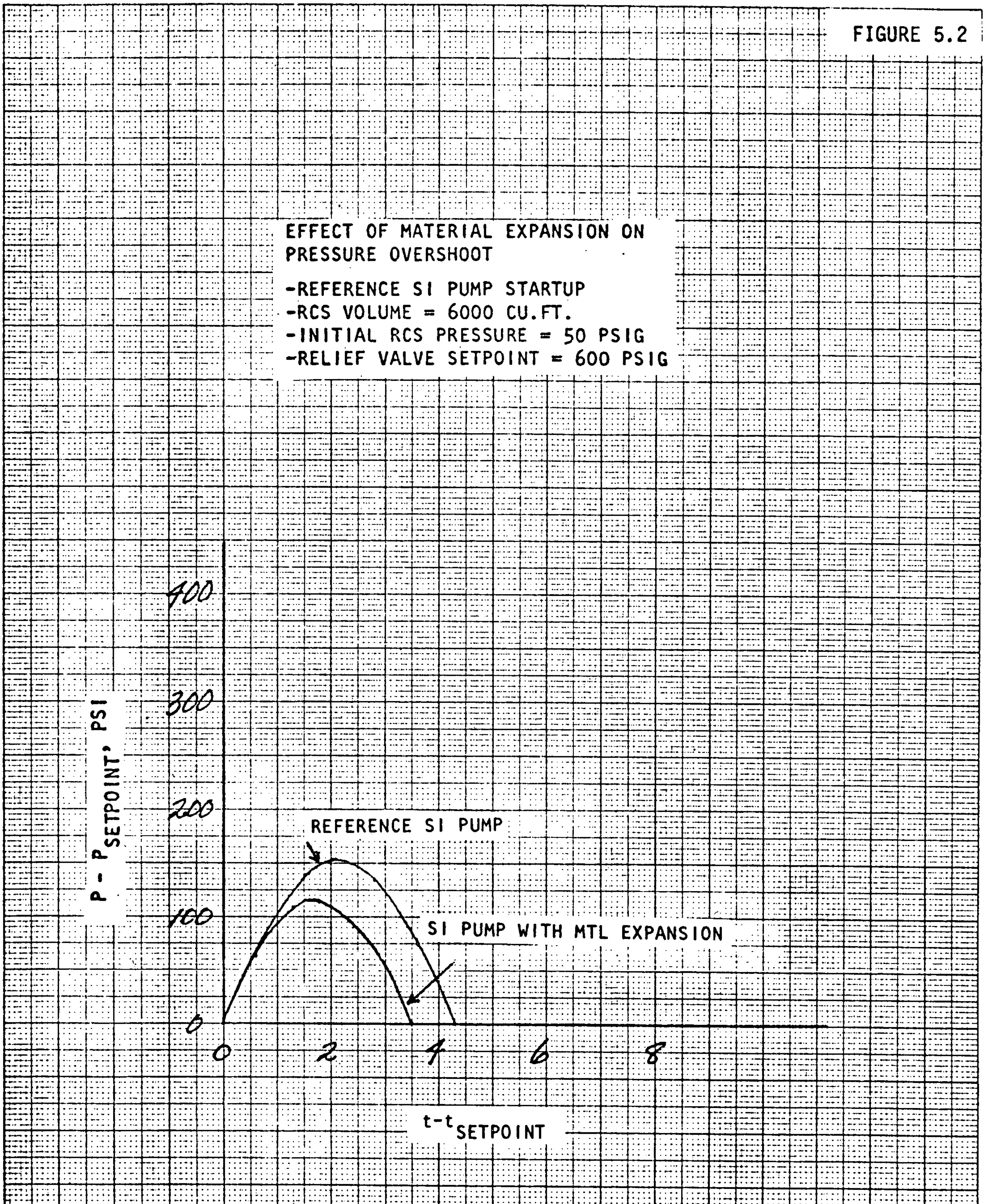
TABLE 5.2

RCS VOLUME

SUMMARY

	Total, ft^3		ΔV/1000 psi		%	
	4 Loop	2 Loop	4 Loop	2 Loop	4 Loop	2 Loop
REACTOR VESSEL (lower shell and head)	3775	2089	2.37	1.32	42.0	43.9
PRESSURIZER	1800	1000	1.34	0.73	23.8	24.2
STEAM GENERATOR (tubes only)	3065	1532	1.44	0.72	25.6	23.9
PIPING (equivalent 29" ID)	1225	612	0.48	0.24	8.5	8.0
		Σ	5.63	3.01		

FIGURE 5.2



461510

K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A.

5.3 EFFECT OF REACTOR COOLANT AND INJECTION WATER TEMPERATURES - MASS INPUT CASES

All of the mass input transients evaluated considered the reactor coolant to be isothermal at a temperature of 100°F (except the pressurizer, see Section 6.1) during the period of injection. At this low temperature, the bulk modulus of the water is at its maximum value (least compressible), which results in the greatest unit pressure change for any given unit volume change and hence the most severe transient. If the injection water temperature is equal to the coolant temperature and the uniform temperature of the coolant is about 210°F at the time of the mass injection, the bulk modulus would be about 8% lower and consequently the unit pressure change for a given volume addition would be 8% less. At higher coolant temperatures the compressibility increases markedly, and, hence, the mass input transients become less severe as the temperature is increased.

A second effect of a higher initial coolant temperature which also was not included in the mass input cases is a shrinkage effect, which occurs when cold injection water mixes with the warmer reactor coolant. The effect of mixing a volume of cold water with a volume of hot water is a net shrinkage of the total fluid volume, and if the mixture is compressed in a fixed volume, the result will be a reduction in the compression pressure. No credit was taken in any of the mass input analyses for this shrinkage effect.

5.4 EFFECT OF STEAM GENERATOR MASS AND OVERALL HEAT TRANSFER COEFFICIENT - HEAT INPUT CASES

Two parameters which directly influence the transfer of heat from the hotter steam generator secondary to the colder reactor coolant are the heat source provided by the water mass contained in the steam generator secondary side, and the rate of heat transfer across the steam generator tubes as determined by the overall heat transfer coefficient.

The quantity of heat available for heat transfer to the reactor coolant is dependent on the mass of water in the steam generator secondary and its temperature. In the LOFTRAN program, the entire steam generator secondary water mass is considered to be active in the heat transfer process. Since it is unlikely that free convection circulation will occur between the steam generator secondary mass in the tube bundle and the warmer mass above it or with the water in the downcomer region, the use of the steam generator secondary tube bundle mass alone would constitute a reasonable representation of the heat source in LOFTRAN. In all of the heat input analyses, however, the entire steam generator secondary water mass of 215,000 lb. was input for the heat input study. This large mass provided a degree of conservatism in the setpoint overshoot data obtained.

The free convective secondary side heat transfer coefficient, h_{sec}, can be shown to control the primary to secondary heat transfer. Depending on the magnitude of the reactor coolant flow rate (which determines the primary side heat transfer coefficient, h_{pri}) at any time following the pump startup, the heat transfer resistance due to h_{sec} can constitute up to 90 percent of the total resistance. For this reason, the overall heat transfer coefficient, U, used in the heat input LOFTRAN model was assumed to be equal to h_{sec}. This assumption also provides conservatism in the heat input analyses since it ignores the added resistance to heat transfer of the primary side film and the tube wall.

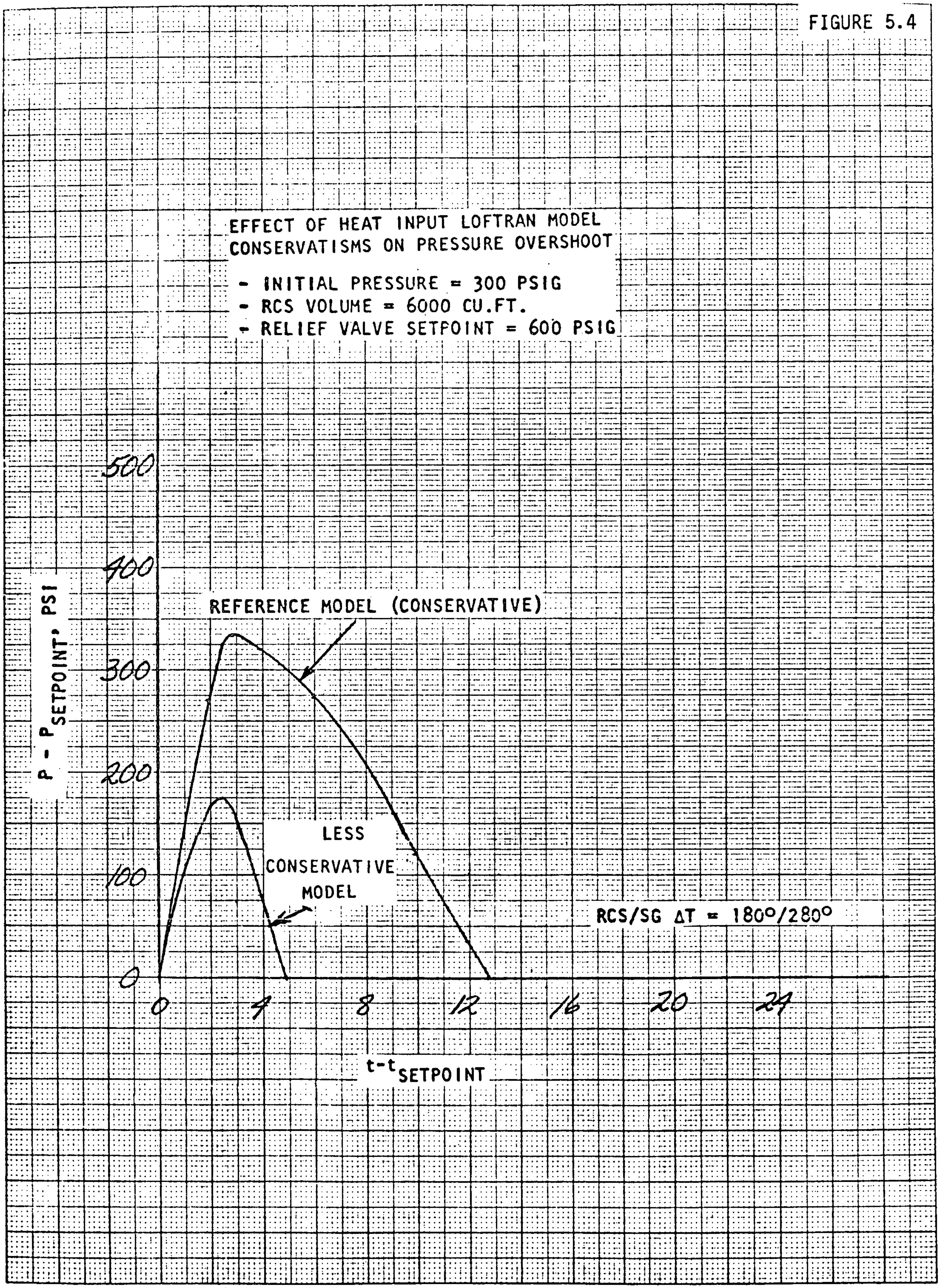
An assessment was made of the effect of the steam generator mass and overall heat transfer coefficient conservatisms on the calculated setpoint overshoot. The conservative and more realistic (less-conservative) LOFTRAN heat input models used for the assessment utilized the following assumptions in their input development.

Parameter	LOFTRAN Model	
	Conservative	Realistic
Steam Generator Secondary Water Mass, lb	Entire mass corresponding to no-load steam generator water level	Mass corresponding to tube bundle coverage only
U, Overall Heat Transfer Coefficient, BTU/hr ft^2 °F	Equal to h_{sec} only	Includes h_{pri}, h_{sec} and tube wall conductivity

Results obtained with these two models are shown in Figure 5.4 in the form of setpoint overshoot versus time after the relief valve starts to open. These results demonstrate that removal of the secondary water mass and heat transfer conservatisms used in the heat input analysis could result in a reduction in setpoint overshoot of as much as 48% (335 psi to 175 psi) for the particular case of a pump startup in one loop of a two loop, 6000 ft^3 plant with a RCS/SG temperature difference equal to 100°F and initial RCS temperature equal to 180°F.

It should be noted that this dramatic reduction in overshoot is based partly on consideration of a heat transfer model for which only a very low flow of reactor coolant through the steam generator tubes was assumed, resulting in a significant h_{pri} contribution. The magnitude of coolant flow, which will be in effect to influence h_{pri} and heat transfer at any time following pump startup, is a function of the pump startup transient. If a flow startup transient is very slow, the assumption of low flow during the pressure transient would be valid and the setpoint overshoot response shown for the less conservative model in Figure 5.4 would be realistic.

FIGURE 5.4



EFFECT OF HEAT INPUT LOFTRAN MODEL
CONSERVATISMS ON PRESSURE OVERSHOOT
- INITIAL PRESSURE = 300 PSIG
- RCS VOLUME = 6000 CU.FT.
- RELIEF VALVE SETPOINT = 600 PSIG
REFERENCE MODEL (CONSERVATIVE)
LESS
CONSERVATIVE
MODEL
RCS/SG ΔT = 180°/280°
P - P SETPOINT, PSI
500
400
300
200
100
0
0
4
8
12
16
20
24
t-t SETPOINT

5.5 EFFECT OF REACTOR COOLANT PUMP STARTUP TIME - HEAT INPUT CASES

The rate of heat transferred from the steam generator to the reactor coolant, and consequently, the rate of coolant pressure change and setpoint overshoot obtained for the heat input analyses, is dependent on the quantity of colder reactor coolant exposed to the hotter steam generator secondary heat source at any particular moment. The rate at which the colder coolant displaces the hot coolant in the steam generator tubes is directly related to the rate at which the coolant flow rate increases with pump startup.

For the Westinghouse Model 93A pump startup, the LOFTRAN program calculates that full loop flow occurs in approximately 9 to 10 seconds, based on internal calculations performed using default homologous pump data provided in the program. This rate is faster than the startup rate normally considered as representative of the 93A pump.

All of the pressure transients and corresponding setpoint overshoots obtained with the LOFTRAN program for the heat input studies reflect this flow startup conservatism.

SECTION 6
OTHER CONSIDERATIONS

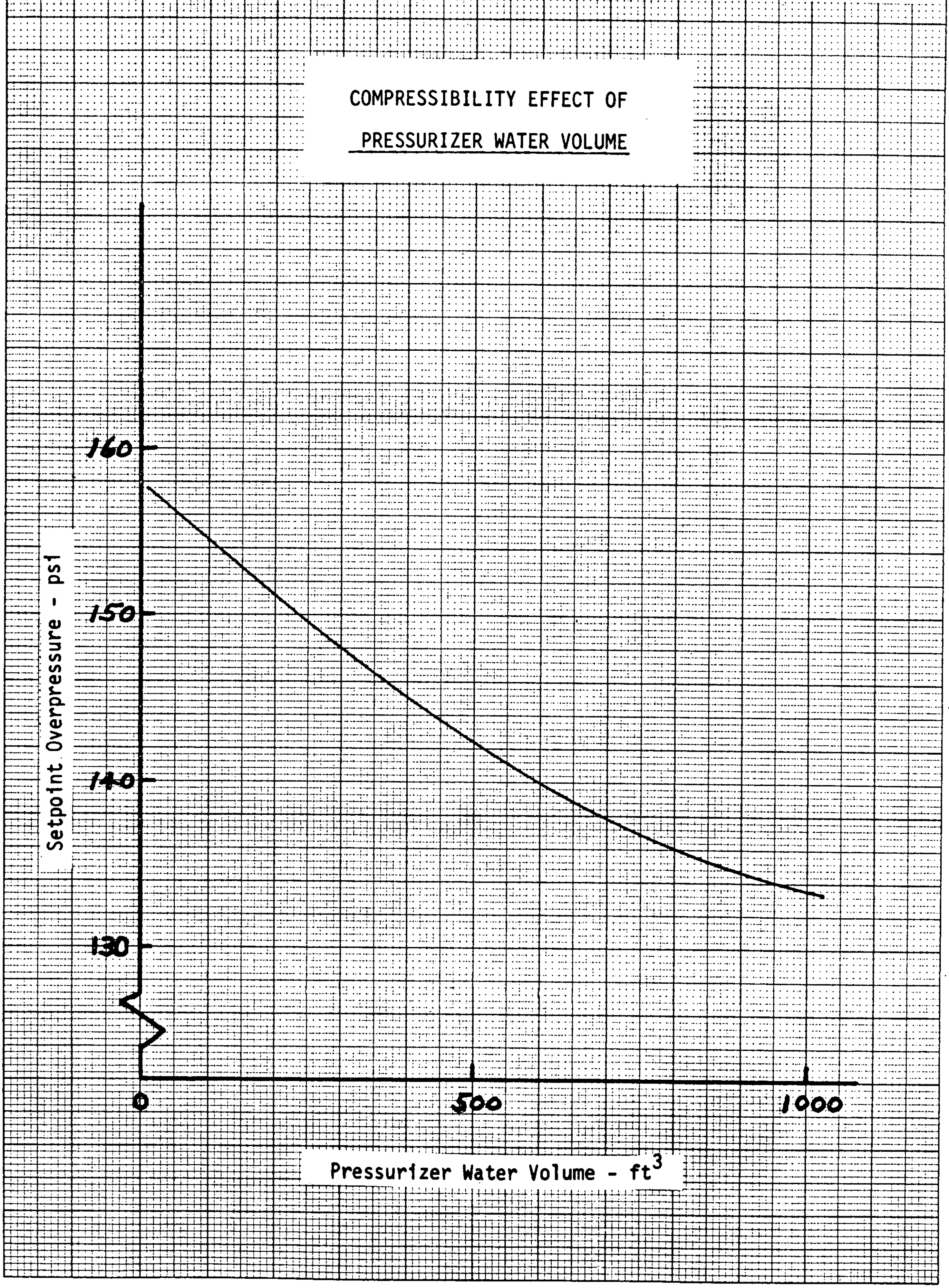
6.1 EFFECT OF PRESSURIZER WATER TEMPERATURE

In a water solid reactor coolant system, the compressibility of the coolant is related to its temperature. For the mass input studies, the analyses were to be performed for an isothermal coolant temperature equal to 100°F. However, for LOFTRAN to maintain a prescribed initial coolant pressure, P_o, the pressurizer must be maintained at the saturation temperature, T_{sat}, corresponding to P_o. In the analyses, T_{sat} for the range of P_o considered (50 psig to 450 psig) varies between approximately 300°F and 460°F, which is several times higher than the isothermal (100°F) temperature required. Thus, the pressurizer water volume at $T_{sat} > 100°F$ introduces into the model additional compressibility, which would reduce the setpoint pressure overshoot for the mass input transient.

The amount of overshoot defect is dependent on the volume of the warmer compressible mass, i.e., pressurizer water volume. Figure 6.1 illustrates this effect. From this figure, a reduction in hot (approximately 300°F) pressurizer water volume from 1021 ft^3 (pressurizer volume plus surge line volume for the 6000 ft^3 volume, 2 loop LOFTRAN model) to 100 ft^3 produces a corresponding increase in setpoint overshoot of 22 psi (133 psi to 155 psi), or about 15 percent. Further reduction in pressurizer volume from 100 ft^3 to 10 ft^3 produces an increase in overshoot of only 3 psi (155 psi to 158 psi), or less than 2 percent.

To avoid problems with internal LOFTRAN computations associated with the use of a very small pressurizer, and since the 100 ft^3 model produces only a negligible compressibility effect, the 100 ft^3 pressurizer water volume was selected for use throughout the mass input and heat input analyses.

FIGURE 6.1


COMPRESSIBILITY EFFECT OF
PRESSURIZER WATER VOLUME
Setpoint Overpressure - psi
160
150
140
130
0
500
1000
Pressurizer Water Volume - ft3

6.2 EFFECT OF BACKPRESSURE ON RELIEF VALVE

The reference relief valve was considered to discharge into the pressurizer relief tank against a small backpressure caused by the nitrogen pressure in the tank. Normally this gas pressure will be less than 5 psig, but for this study the backpressure was considered to be 10 psig, which is above the typical high pressure alarm.

As the relief valve discharges into the relief tank, the nitrogen gas and vapor enclosed in the tank will be compressed as the water level in the tank rises. A continuous discharge into the tank will ultimately increase the gas pressure to 100 psig at which time the safety head (rupture disk) will open and the gas will be released to the containment. Therefore, the maximum static backpressure on the relief valve will be 100 psig.

The expected discharge flow rate from the reference relief valve is relatively small for the size of the discharge lines and relief tank when compared to the design flow rate from the pressurizer safety valves. Therefore, the dynamic backpressure on the reference relief valve is negligible.

To evaluate the effect of the change in static backpressure on the valve, a comparison was made between the setpoint pressure overshoot for the case of an extremely high mass input into a small system volume (limiting mass input case) with both a 10 psig and 100 psig backpressure.

For the first relief valve lift cycle, the peak pressure due to an overshoot of 154 psi above the 600 psig setpoint was found to be 754 psig. Then if the injection into the reactor coolant system continues, the backpressure will increase with each subsequent relief valve lift cycle, reaching a maximum of 100 psig. With the 100 psig backpressure, the flow rate through the valve will be slightly decreased (see Figure 2.2.1) and the consequent pressure overshoot will increase to 159 psi above the setpoint, resulting in a peak pressure of 759 psig. Subsequent relief valve cycles after the relief tank has vented through the rupture disk will result in lower peak pressures.

If the reference case described above is considered to be typical of a 2 loop plant with a relief tank having a nominal volume of 800 cu.ft. and an initial gas volume of 172 cu.ft., the reference SI pump would cause the tank to fill and pressurize in about 1-1/2 minutes. Therefore, it is concluded that, for this example limiting mass input case, the relief valve first will cycle 8 to 10 times with the peak pressure for each subsequent cycle being perhaps 0.5 psi greater than for the previous cycle. Then, after the rupture disk opens, the backpressure will be removed and the subsequent pressure cycles will be similar to the first valve lift cycle.

6.3 CAPACITY OF MULTIPLE RELIEF VALVES

The analyses presented in this study considered the use of a single air-operated relief valve, i.e., the reference relief valve, to limit the pressure transients. In all cases, the single reference valve was capable of mitigating the transient since its capacity when full open was greater than any of the mass input rates.

To evaluate the effect of a change in relief valve capacity, a few cases were studied in which the relieving capacity was doubled by considering two reference relief valves in service. The results are shown in Figure 6.3.1 for two particular cases of mass input. With the expected rates of mass input from the charging/letdown flow mismatch case, the effect of the increased capacity on setpoint overshoot is insignificant; but there is a substantial effect on the rate of pressure decrease while the valves are relieving, which is primarily due to the slow closing time used in the analysis. It can be concluded that the capacity of two valves is much greater than required, and, coupled with the slow closing times, could be undesirable under certain circumstances.

For the case of a large mass input into a small reactor coolant volume, as described by the reference SI pump case shown in Figures 6.3.1 and 6.3.2, the doubled capacity provided by the second relief valve does cause the pressure transient to be mitigated earlier and results in a 23% decrease in the pressure overshoot, i.e., from about 155 to 119 psi. However, since the pressure increase is terminated by one valve, it can be concluded that one reference relief valve has ample capacity to mitigate this severe transient and, hence, the additional capacity, such as provided by a second valve, is not required.

The results of a typical study of the effects of multiple valves for a severe heat input case are shown in Figure 6.3.3. This figure also shows that, as a result of doubling the relief capacity, the pressure transient is mitigated earlier and that the pressure overshoot is reduced, e.g., for the 600 psig setpoint case the overshoot is decreased 21% from 140 to 111 psi. However, as in the case of the severe mass input case, the capacity of one reference relief valve was shown to be sufficient and additional capacity is not required.

FIGURE 6.3.1

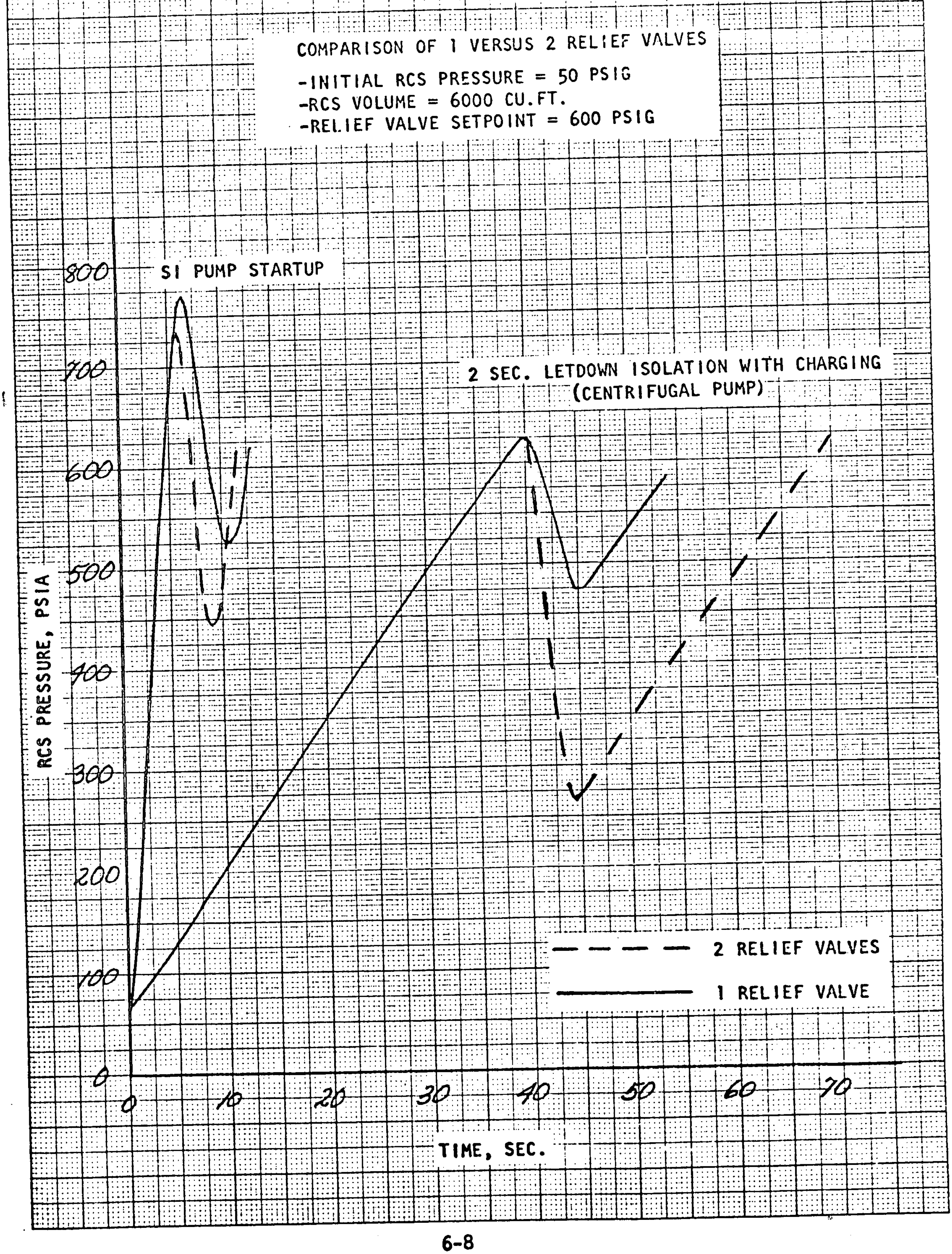
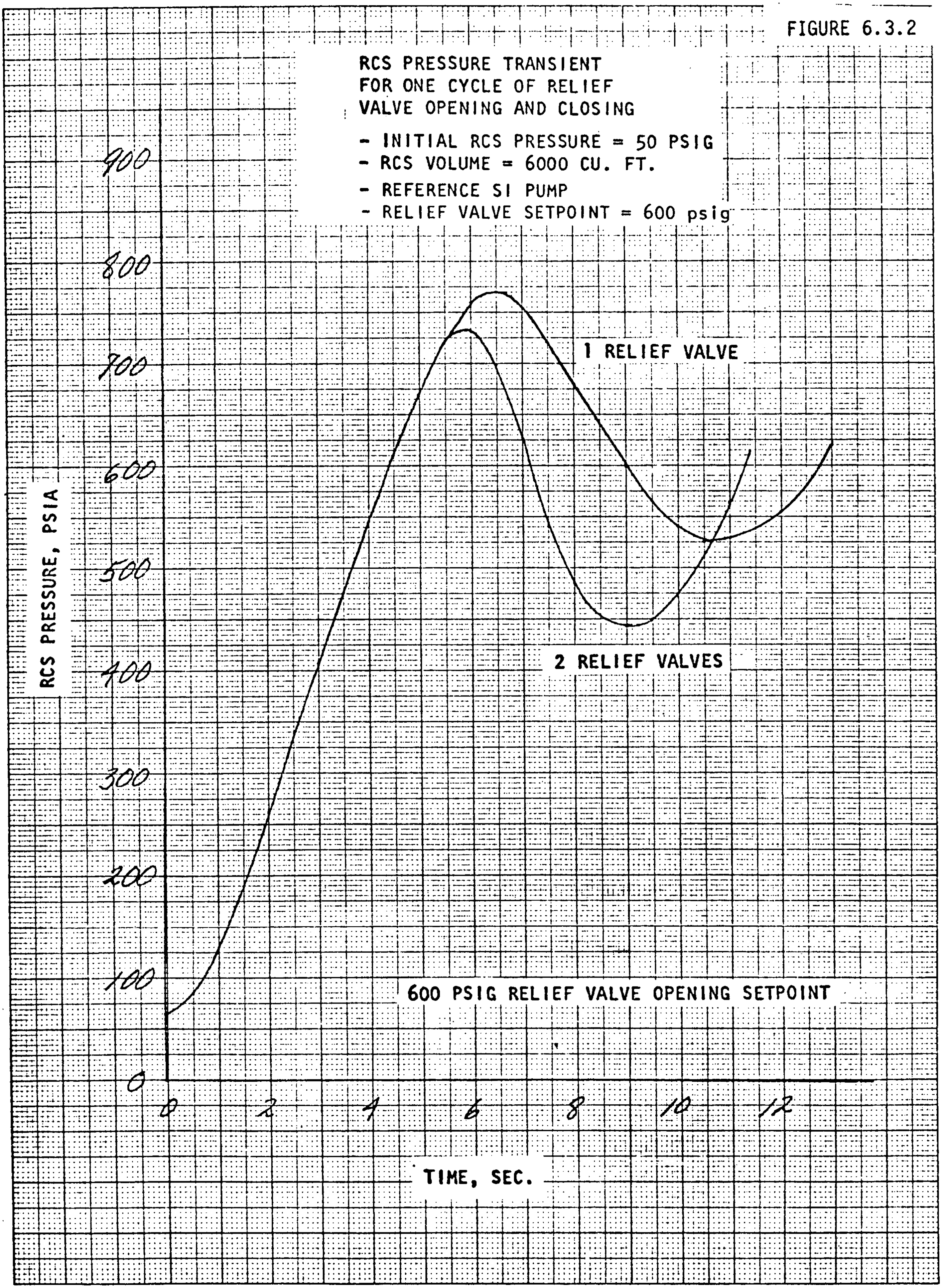

COMPARISON OF 1 VERSUS 2 RELIEF VALVES
-INITIAL RCS PRESSURE = 50 PSIG
-RCS VOLUME = 6000 CU.FT.
-RELIEF VALVE SETPOINT = 600 PSIG
SI PUMP STARTUP
2 SEC. LETDOWN ISOLATION WITH CHARGING
(CENTRIFUGAL PUMP)
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
TIME, SEC.
2 RELIEF VALVES
1 RELIEF VALVE

FIGURE 6.3.2


RCS PRESSURE TRANSIENT
FOR ONE CYCLE OF RELIEF
VALVE OPENING AND CLOSING
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 6000 CU. FT.
- REFERENCE SI PUMP
- RELIEF VALVE SETPOINT = 600 psig
RCS PRESSURE, PSIA
900
800
700
600
500
400
300
200
100
0
1 RELIEF VALVE
2 RELIEF VALVES
600 PSIG RELIEF VALVE OPENING SETPOINT
0
2
4
6
8
10
12
TIME, SEC.

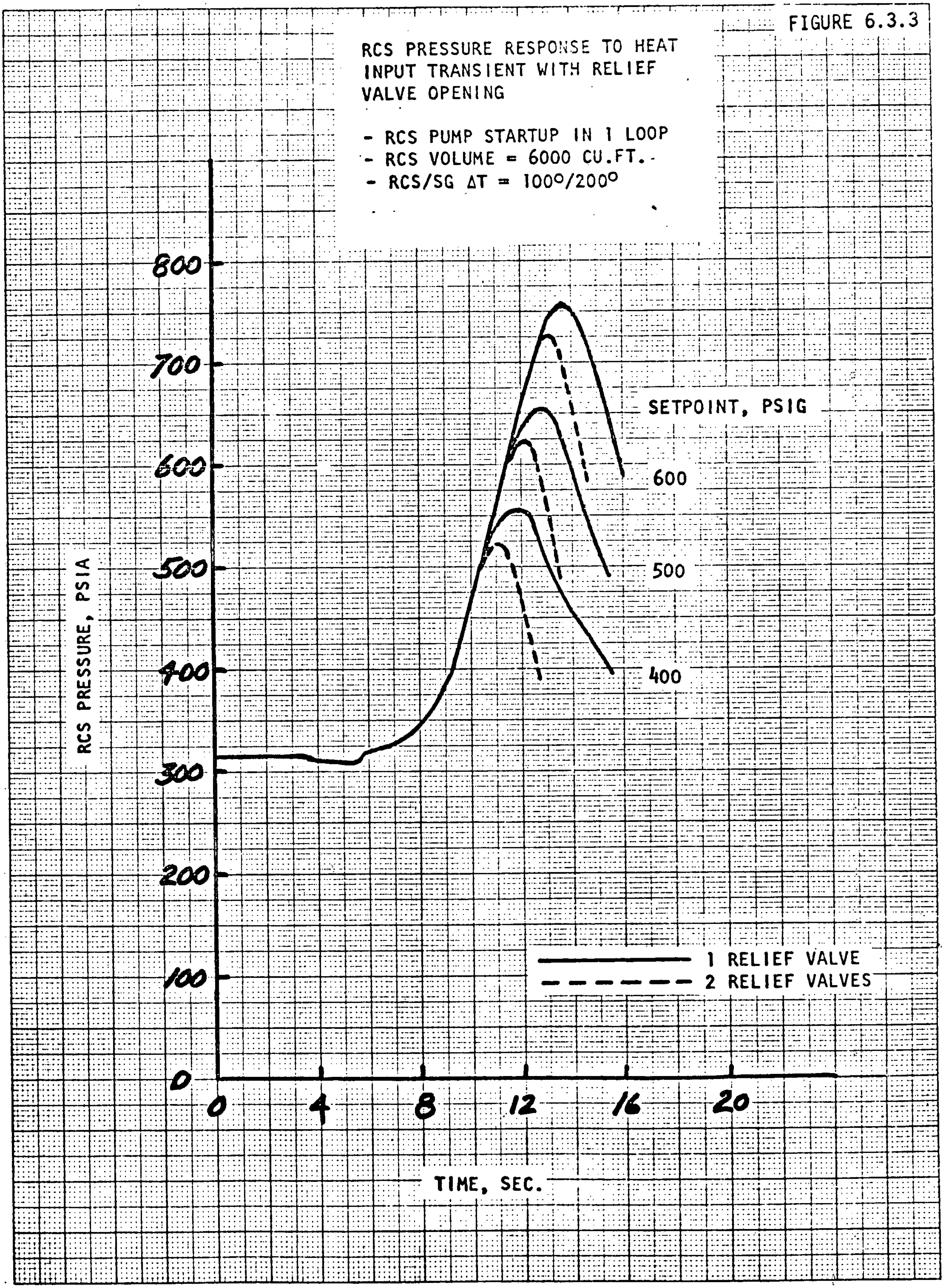


FIGURE 6.3.3
RCS PRESSURE RESPONSE TO HEAT INPUT TRANSIENT WITH RELIEF VALVE OPENING
- RCS PUMP STARTUP IN 1 LOOP
- RCS VOLUME = 6000 CU.FT.
- RCS/SG ΔT = 100°/200°
SETPOINT, PSIG
600
500
400
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
TIME, SEC.
1 RELIEF VALVE
2 RELIEF VALVES

6.4 RELIEF VALVE CYCLING

The reference relief valve has a unique characteristic of operation in that its position is determined by an air pressure under a spring loaded diaphragm in the operator. When air is admitted or vented, the spring will be compressed or relaxed as the diaphragm moves. Air is controlled through a small solenoid valve which is positioned by an electric signal to either admit air into the valve operator or to vent the air from the operator to the atmosphere. If the solenoid is quickly signalled to change position (cycled), the air may not be capable of moving the diaphragm through a full valve stroke, i.e., the valve could theoretically float on a cushion of air.

In some of the analyses of this study it was found that the relief valve had excess capacity such that the relief valve did not reach the full open position before it was signalled to close. For these cases, the valve actually floated on the motive air as it stroked partly open and then returned to the closed position in preparation for another stroke.

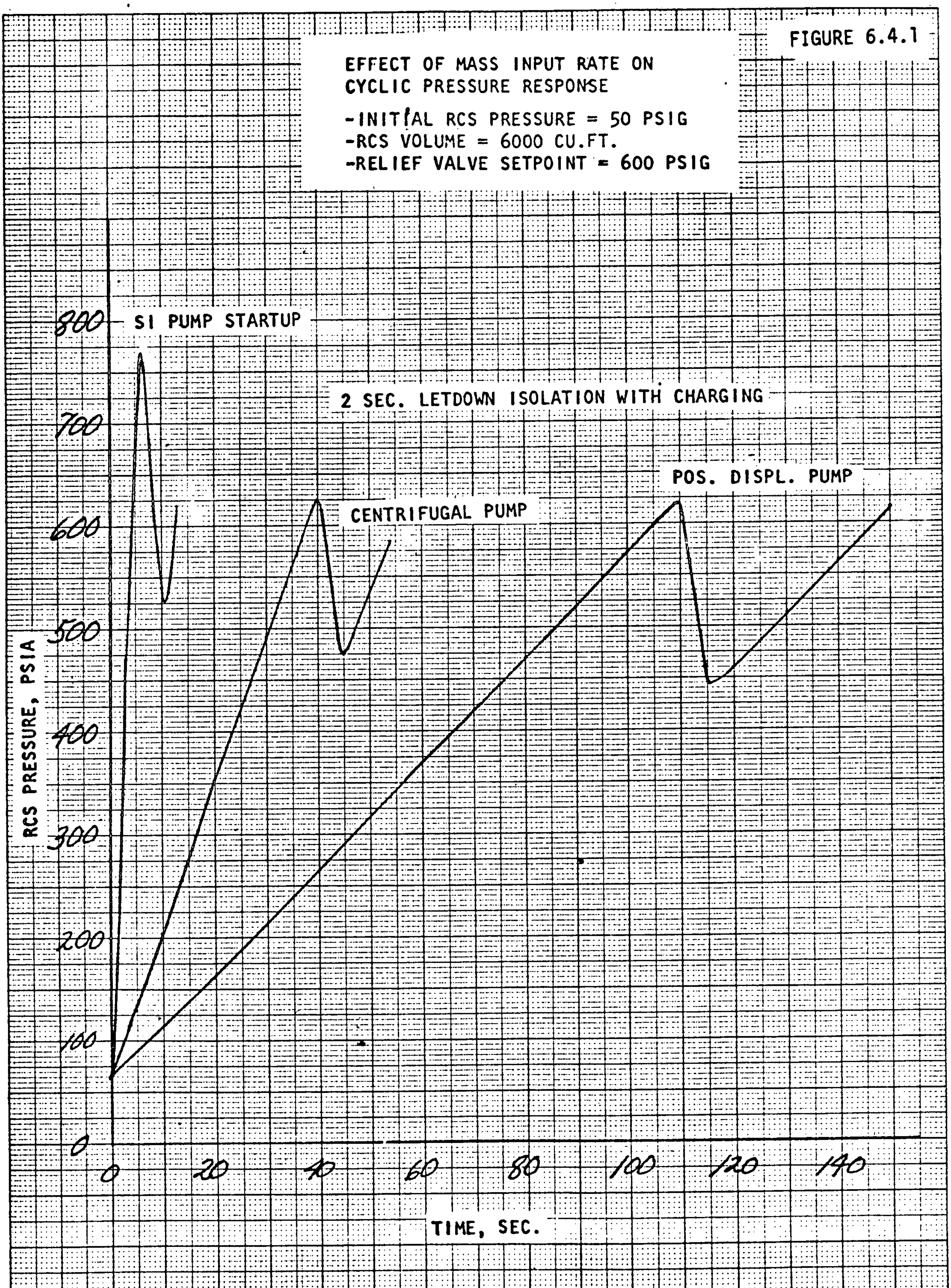
The reference relief valve was considered to have a 3 second opening time, when stroked fully open, and either a 5 or 20 second closing time when stroked from fully open position. With the use of relatively short closing times, the valve will always return to the full closed position and all the air will be vented with each cycle; hence, the opening characteristic for each subsequent cycle will include the conservative time delay of 0.6 seconds before the valve starts to open again.

For the mass input cases, the relief valve was found to cycle open and closed to intermittently discharge the excess mass injected. The greater the rate of mass input the more rapid the valve cycling. As seen from Figure 6.4.1, for a typical case of a charging/letdown flow mismatch in the range of mass input of 40 to 120 gpm, the valve will cycle about every 17 seconds if the injection flow is about 120 gpm and every 42 seconds if the flow is 40 gpm. This valve cycling will continue until the operator intervenes to restore letdown or to stop the mass input. For an extreme case of a high mass input rate, as for example the reference SI pump injection at about 830 gpm, the relief valve would cycle open and closed every 8-1/2 seconds until the operator terminated the input.

The cycle time for the valve can be lengthened by slowing the rates at which the valve opens and closes but this would result in a larger pressure cycle. Figure 6.4.2 shows the effect of a longer closing time on a typical large mass input transient. For this example, the cycle time is almost doubled. However, since there is a minimum coolant pressure required to protect the reactor coolant pump seals from possible damage, it would not be acceptable to allow the pressure to decrease below about 300 psig. This is an economic consideration which must be included in the overall system design. Some plants, however, have closing times equivalent to the opening times (less than 3 seconds) and "undershoot" is not a problem.

Another consideration regarding relief valve cycling is the effect of two valves relieving simultaneously, which is a likely event. When the two valves are signalled to open, the effective capacity is double and neither valve has to lift as far for the pressure transient to be mitigated and the valves signalled to close. Figure 6.4.3 illustrates the characteristics of the pressure response for both the credible charging/letdown flow mismatch case and the extreme mass injection case represented by the reference SI pump injection. As would be expected, the setpoint overshoot is reduced, but due to the high relief capacity during the valve closing period, the coolant pressure decreases markedly for the 2 valve case. For the charging flow case with these particular plant parameters, there would be a concern for the reactor coolant pump seals for relief valves with slow closure times and capacities greater than the reference valve. For those plants with valve closing times equal to opening times, the undershoot would be expected to be similar to the overshoot. Thus, the consideration of the pump seals would not be applicable.

FIGURE 6.4.1


EFFECT OF MASS INPUT RATE ON
CYCLIC PRESSURE RESPONSE
-INITIAL RCS PRESSURE = 50 PSIG
-RCS VOLUME = 6000 CU.FT.
-RELIEF VALVE SETPOINT = 600 PSIG
SI PUMP STARTUP
2 SEC. LETDOWN ISOLATION WITH CHARGING
CENTRIFUGAL PUMP
POS. DISPL. PUMP
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
TIME, SEC.

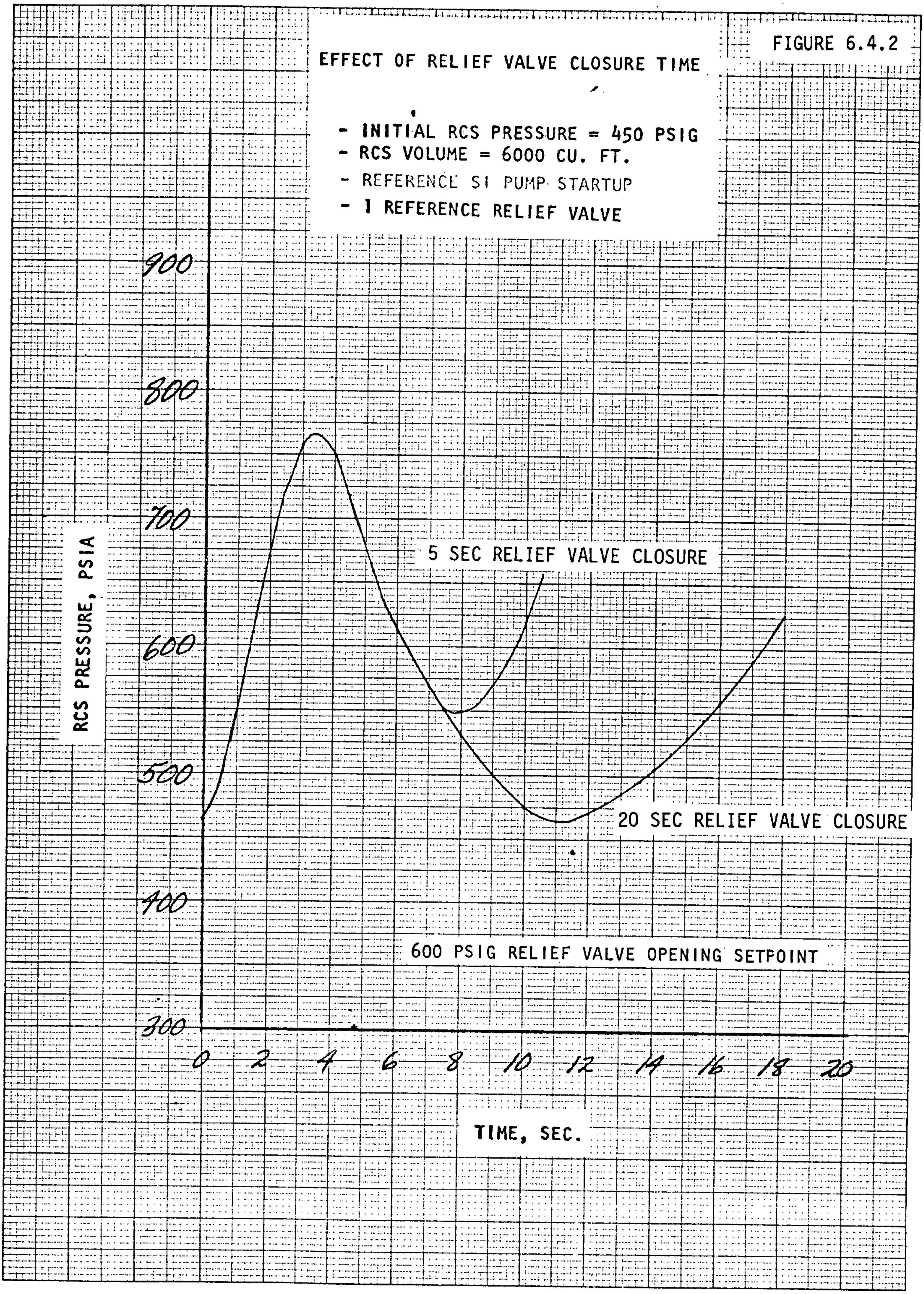
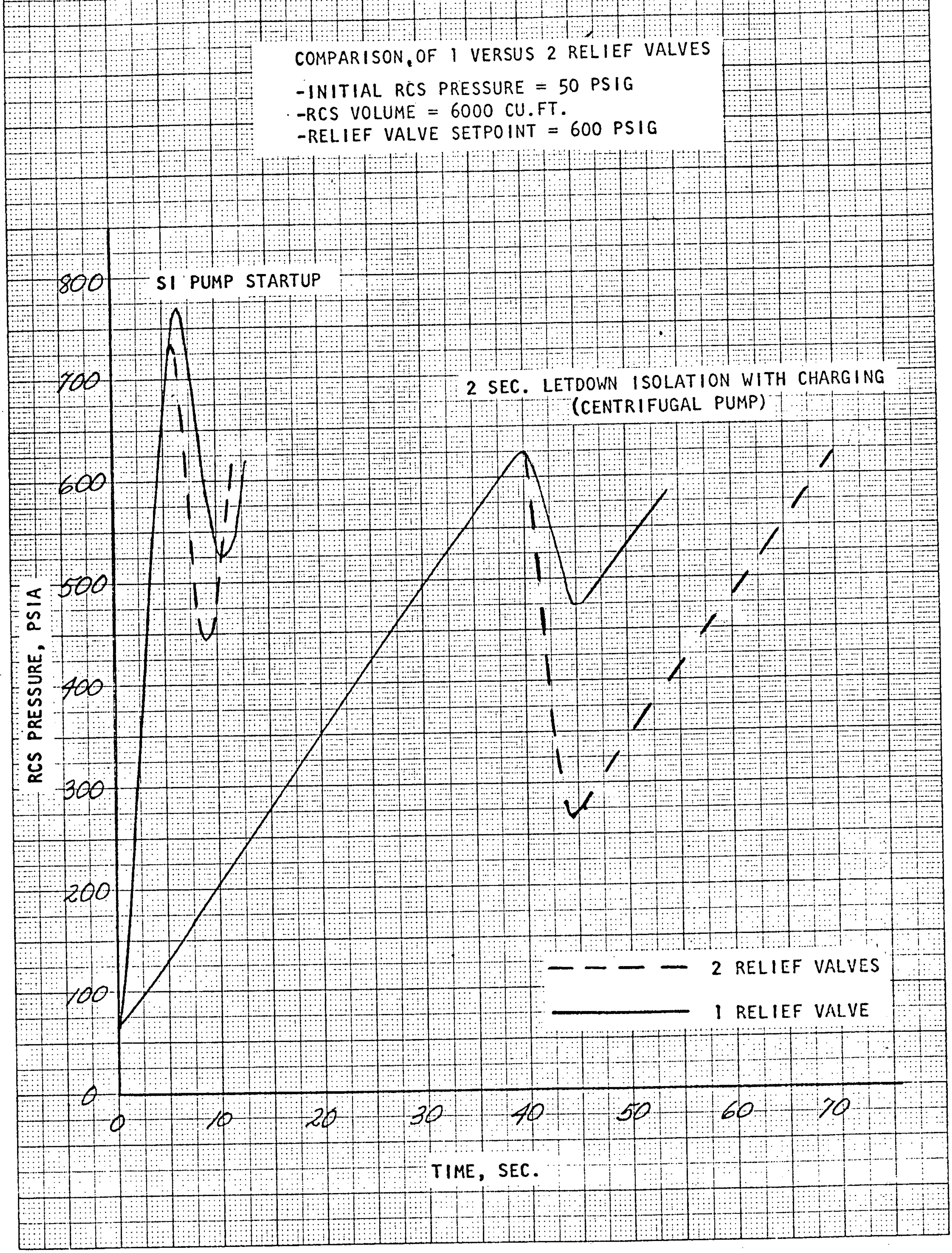


FIGURE 6.4.2
EFFECT OF RELIEF VALVE CLOSURE TIME
- INITIAL RCS PRESSURE = 450 PSIG
- RCS VOLUME = 6000 CU. FT.
- REFERENCE SI PUMP STARTUP
- 1 REFERENCE RELIEF VALVE
RCS PRESSURE, PSIA
900
800
700
600
500
400
300
5 SEC RELIEF VALVE CLOSURE
20 SEC RELIEF VALVE CLOSURE
600 PSIG RELIEF VALVE OPENING SETPOINT
0
2
4
6
8
10
12
14
16
18
20
TIME, SEC.

FIGURE 6.4.3


COMPARISON OF 1 VERSUS 2 RELIEF VALVES
-INITIAL RCS PRESSURE = 50 PSIG
-RCS VOLUME = 6000 CU.FT.
-RELIEF VALVE SETPOINT = 600 PSIG
SI PUMP STARTUP
2 SEC. LETDOWN ISOLATION WITH CHARGING (CENTRIFUGAL PUMP)
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
TIME, SEC.
2 RELIEF VALVES
1 RELIEF VALVE

6.5 RELIEF VALVE CAPACITY CHANGE WITH FLASHING

The reference relief valve for this study is assumed to be located on the pressurizer (i.e., the power operated relief valve) and therefore the properties of the fluid released are those associated with the pressurizer. The analyses presented in this study are primarily based on past experience with operating PWR plants and an evaluation of the most likely conditions under which a relief valve actuation might be required. It was concluded that the cold shutdown, solid water mode of operation was the predominate one to study. However, during plant heatup and cooldown operations when the plant is being continuously monitored and carefully controlled manually by the several trained operators, there is a short period of time when the pressurizer is filled solid and its water temperature is at or near saturation for the particular reactor coolant pressure being maintained (350 to 450 psig). If the relief valve should lift at this time, there would be flashing of the fluid as it passed through the valve, with a consequent decrease in mass relief capacity.

To evaluate the effect of the reduced mass flow on a typical pressure transient, a reference SI pump mass input case was evaluated both with a cold pressurizer and with a relatively hot pressurizer. The cold pressurizer case is presented in other parts of the report and involves a pressurizer with a water temperature of 100°F (equal to reactor coolant temperature). For the hot pressurizer cases, the temperature of the water is considered to be at saturation for a pressure of either 415 psia (448°F) or 615 psia (489°F).

The mass flows of fluid through the relief valve for the saturated water flow cases were based on homogeneous, thermal-equilibrium, isentropic, expansion flow evaluated as follows: †

$$G = \frac{1}{v_c} \sqrt{2 g_c \, J \, (h_o - h_c)}$$

$$= \text{lb/sec - ft}^2$$

where h_o is the enthalpy at the upstream (saturated) condition and v_c and h_c are evaluated for the conditions at the exit plane.

The conditions of pressure and quality at the exit plane are found implicitly for each particular upstream condition and Figure 6.5.1 describes the mass flow through the valve at various upstream pressures for both the subcooled and saturated flow modes. As can be seen from the figure, the capacity of the valve for discharge of saturated flow is reduced to about 71% of the subcooled flow rate for the range of pressures between 350 and 450 psig.

From other parts of this study, the effect of changes in valve capacity can be estimated from the comparison between the transient pressure responses for a particular mass input case with either one (100% capacity) or two (200% capacity) reference relief valves. For this reference case, the pressure increases at about 125-135 psi/sec just prior to and for a short period after the relief valve reaches the setpoint. Therefore, there will be an overshoot of the setpoint of between 75 and 81 psi before the valve starts to relieve due to a 0.6 second time delay to fill the lines and valve operator with motive air.

† ANS proposed standard N-661, Evaluation of Anticipated Transients Without Trip for Pressurized Water Reactors

From an inspection of the results of the pressure transients for the cases of one and two relief valves, it can be determined that the pressure overshoot during the time the valve(s) are relieving is 110 psi for one valve and 62 psi for two valves, both for a setpoint of 415 psia. By extrapolating the capacity of the valve at 200% and 100% to a value of 71% (for saturated flow), it is found the overshoot during the stroke time is 140 psi, giving a peak pressure of 415 + 81 + 140 = 636 psia. This peak pressure is about 30 psi higher than that pressure reached with one relief valve relieving subcooled water flow. Figure 6.5.2 shows graphically the difference in overshoot for the case of flashing flow versus subcooled flow.

A similar comparison was made considering the pressurizer water was initially at a 615 psia saturated condition and again the difference between the flashing flow and the subcooled flow cases resulted in a difference in pressure overshoot of about 30 psi for the limiting mass input case and a relief valve setpoint of 615 psia (see Figure 6.5.3).

At lesser mass input rates relative to the system volume, the difference in pressure overshoot between a subcooled and a flashing flow case would be expected to be less than calculated for the above example. This conclusion can be reached because, at lesser mass input rates, the rate of change of coolant pressure is lower, and, hence, for any given valve stroke time, the pressure change during the stroke interval will be smaller. In the extreme, a zero rate of coolant pressure increase at the setpoint or an instantaneous opening time would theoretically result in a zero overshoot for all cases where the relief valve capacity exceeds the input flow rate.

The pressure transient versus time in the example case with a hot pressurizer is unrealistically conservative because it is based on the entire reactor coolant volume including the pressurizer being at a uniform cold temperature. A more realistic model would include a substantial volume of coolant (pressurizer volume) at a high temperature and, this less dense fluid being more compressible, consequently would be able to absorb some of the effect of the mass input similar to the action of an accumulator in a hydraulic system. (See Section 6.1 for additional discussion.) The result of the higher temperature pressurizer would be to slow the rate of the pressure transient and hence result in a lesser pressure overshoot.

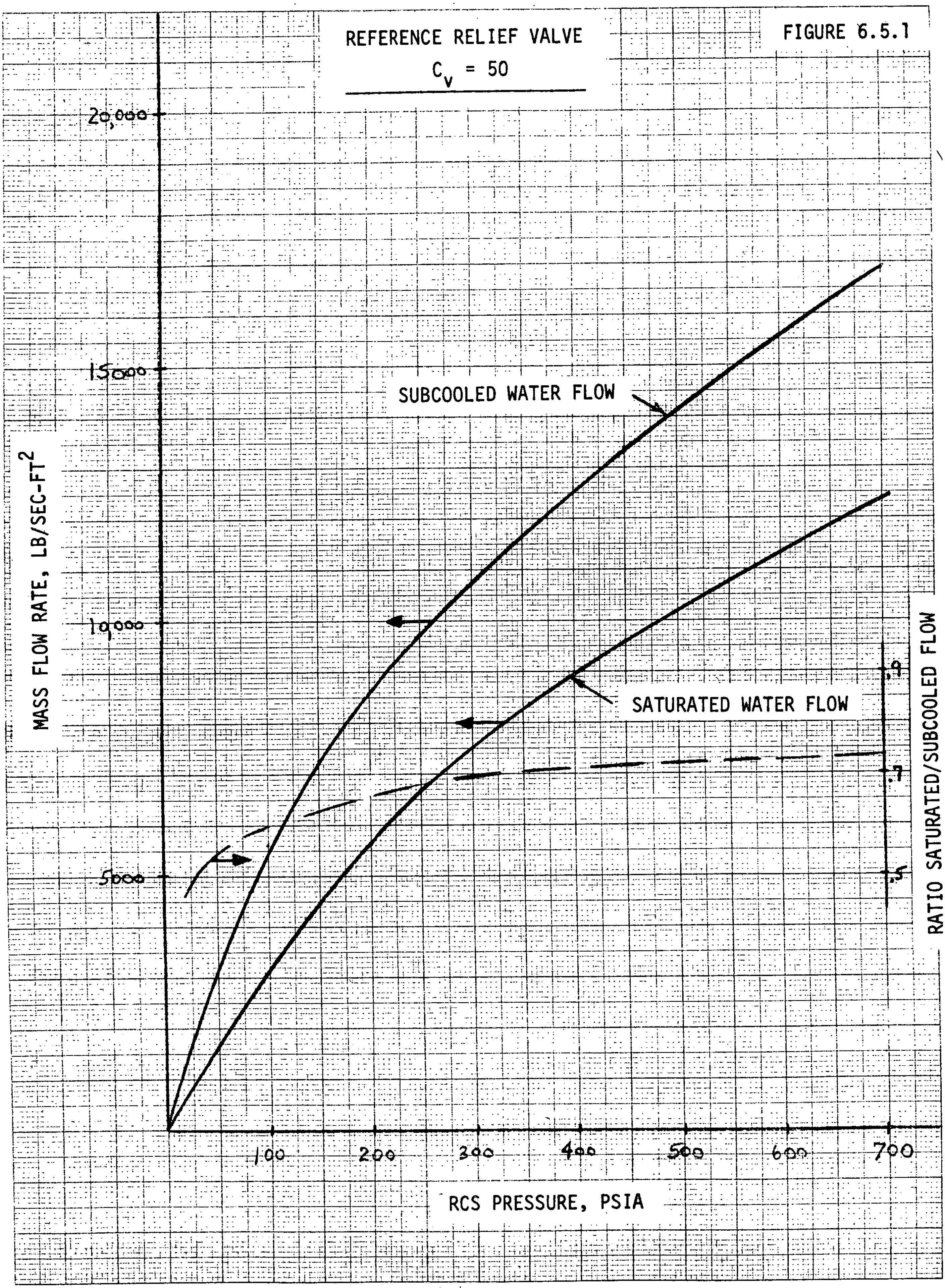
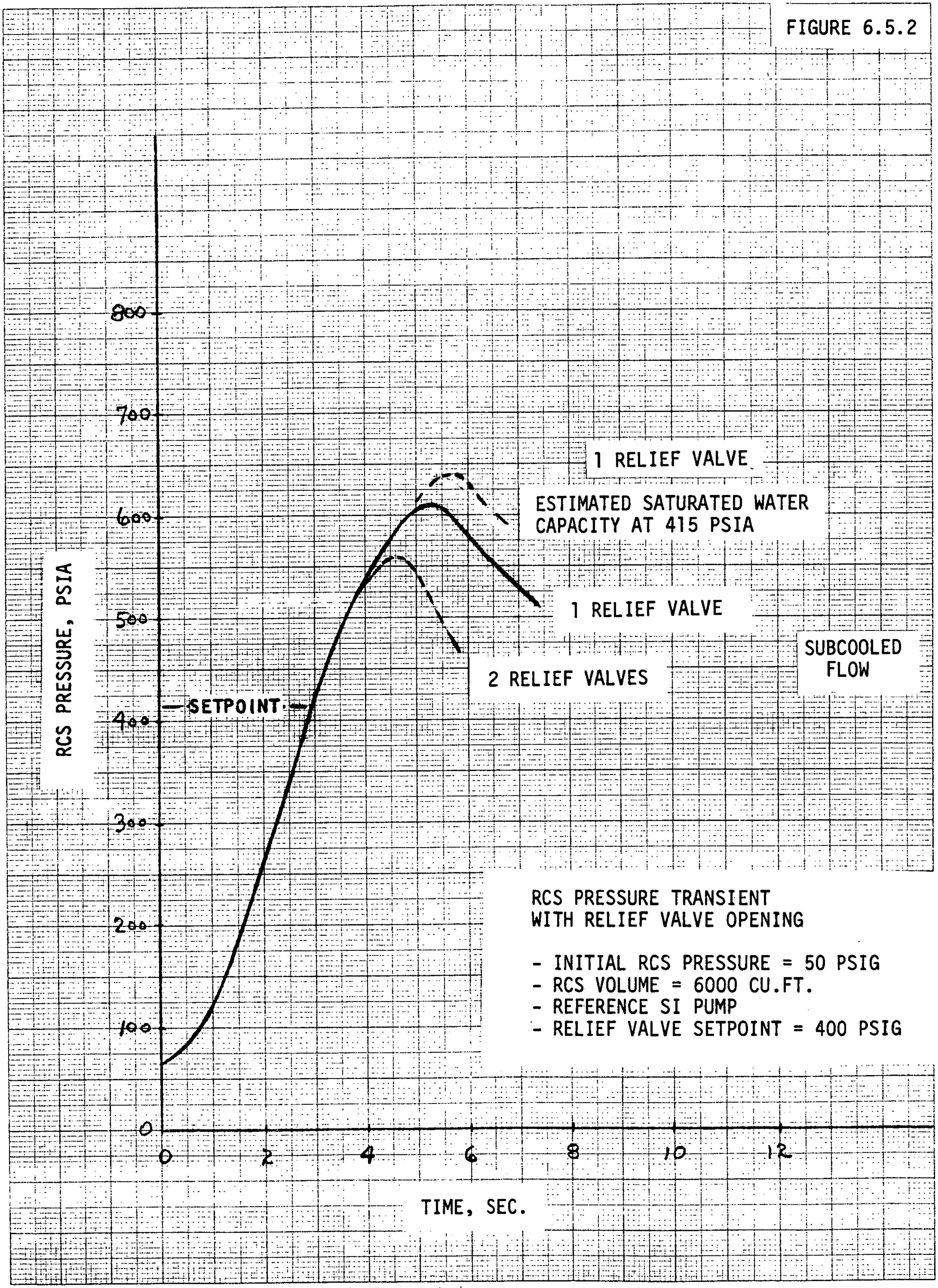


FIGURE 6.5.1
REFERENCE RELIEF VALVE
$C_v = 50$
20,000
15000
10,000
5000
MASS FLOW RATE, LB/SEC-FT^2
SUBCOOLED WATER FLOW
SATURATED WATER FLOW
.9
.7
.5
RATIO SATURATED/SUBCOOLED FLOW
100
200
300
400
500
600
700
RCS PRESSURE, PSIA


RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
2
4
6
8
10
12
TIME, SEC.
SETPOINT
1 RELIEF VALVE
ESTIMATED SATURATED WATER
CAPACITY AT 415 PSIA
1 RELIEF VALVE
SUBCOOLED
FLOW
2 RELIEF VALVES
RCS PRESSURE TRANSIENT
WITH RELIEF VALVE OPENING
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 6000 CU.FT.
- REFERENCE SI PUMP
- RELIEF VALVE SETPOINT = 400 PSIG

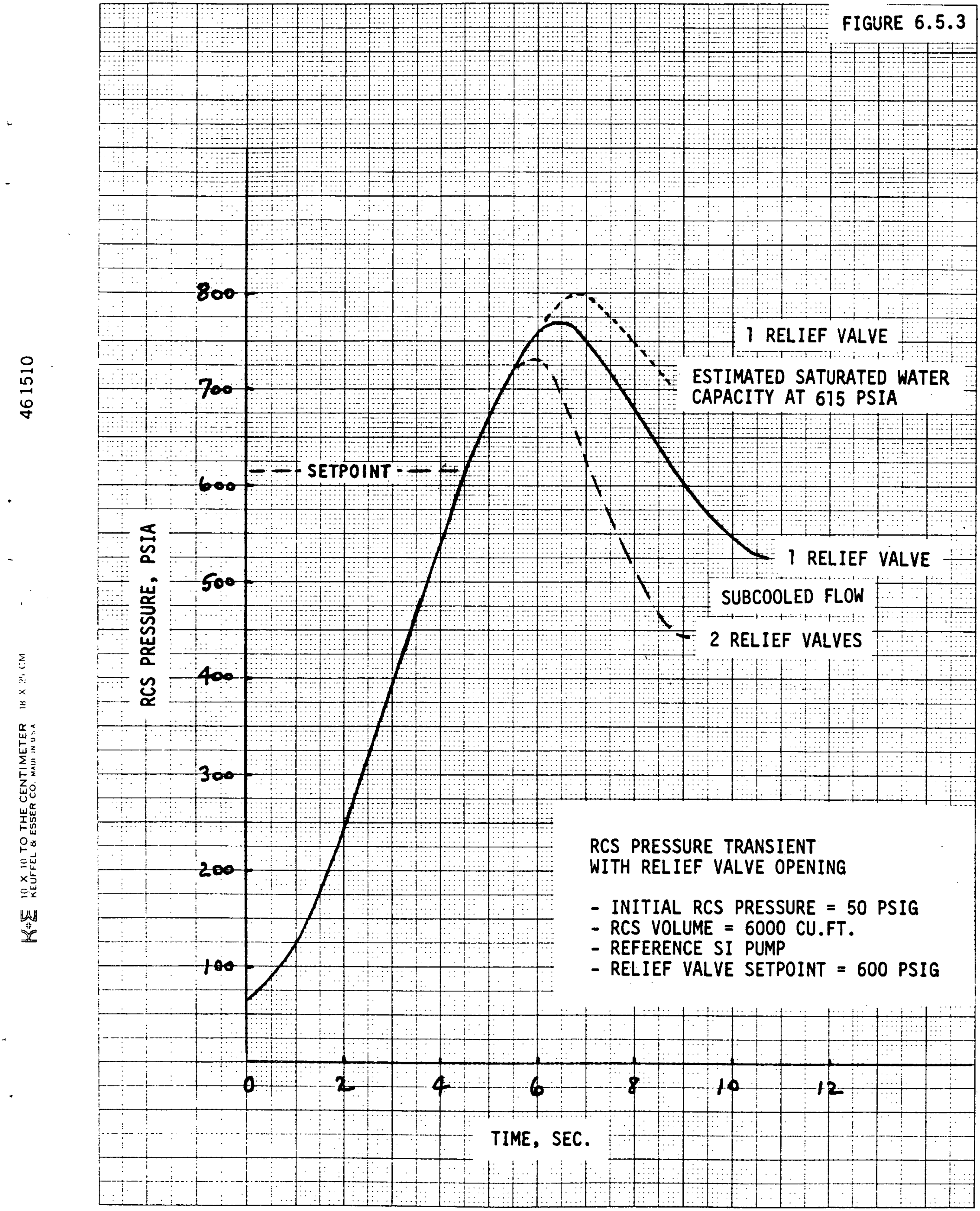


FIGURE 6.5.3
1 RELIEF VALVE
ESTIMATED SATURATED WATER CAPACITY AT 615 PSIA
SETPOINT
1 RELIEF VALVE
SUBCOOLED FLOW
2 RELIEF VALVES
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
2
4
6
8
10
12
TIME, SEC.
RCS PRESSURE TRANSIENT WITH RELIEF VALVE OPENING
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 6000 CU.FT.
- REFERENCE SI PUMP
- RELIEF VALVE SETPOINT = 600 PSIG
10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
461510

APPENDIX A

SUMMARY TABLES

APPENDIX A

SUMMARY TABLE - MASS INPUT RESULTS

RCS VOLUME = 6000 CU.FT.

INITIAL RCS PRESSURE (psig)	RELIEF VALVE					MASS INPUT MECHANISM			RESULTS		
	Setpoint (psig)	Number of Valves	Linear (L) or Non-Linear (NL)	Max. Opening Time (sec)	Valve Opens (O)/ Closes (C)	SI Pump SU (SI) or Charging/Letdown Isolation (C/LI)	CC Pump or PD Pump	Letdown Isolation Δt, sec	RCS P_{MAX} (psig)	$P_{MAX}-P_{SETPOINT}$ (psi)	Appendix B Figure Number(s)
50	600	1	L	3.0	O	SI	---	---	755	155	M18, M22, M26, M34, M4
50	600	1	L	3.0	O/C	SI	---	---	755	155	M9, M12, M28, M30, M32
50	600	2	L	3.0	O	SI	---	---	720	120	M26
50	600	2	L	3.0	O/C	SI	---	---	720	120	M12, M28
50	600	1	NL	3.0	O/C	SI	---	---	741	141	M30, M31, M32, M33
50	600	2	NL	3.0	O/C	SI	---	---	720	120	M32, M33
50	600	1	L	1.5	O	SI	---	---	662	62	M26
50	600	2	L	1.5	O	SI	---	---	635	35	M26
450	600	1	L	3.0	O	SI	---	---	751	151	M20, M24
450	600	1	L	3.0	O/C	SI	---	---	751	151	M29
450	600	2	L	3.0	O	SI	---	---	717	117	---
450	500	1	L	3.0	O	SI	---	---	667	167	M20, M25
450	500	2	L	3.0	O	SI	---	---	626	126	---

APPENDIX A

SUMMARY TABLE - MASS INPUT RESULTS

RCS VOLUME = 6000 CU.FT.

INITIAL RCS PRESSURE (psig)	RELIEF VALVE					MASS INPUT MECHANISM			RESULTS		
	Setpoint (psig)	Number of Valves	Linear (L) or Non-Linear (NL)	Max. Opening Time (sec)	Valve Opens (O)/ Closes (C)	SI Pump SU (SI) or Charging/Letdown Isolation (C/LI)	CC Pump or PD Pump	Letdown Isolation Δt, sec	RCS P_{MAX} (psig)	$P_{MAX}-P_{SETPOINT}$ (psi)	Appendix B Figure Number(s)
50	400	1	L	3.0	O	SI	---	---	592	192	M18, M23, M27, M4
50	400	2	L	3.0	O	SI	---	---	544	144	M27
50	400	1	NL	3.0	O/C	SI	---	---	566	166	M31
50	400	2	NL	3.0	O/C	SI	---	---	543	143	M33
50	400	1	L	1.5	O	SI	---	---	485	85	M27
50	400	2	L	1.5	O	SI	---	---	449	49	M27
50	600	1	L	3.0	O/C	C/LI	CCP	2	610	10	M6, M9, M10
50	600	2	L	3.0	O/C	C/LI	CCP	2	610	10	M6, M10
50	600	1	L	3.0	O	C/LI	CCP	10	610	10	M8
50	600	1	L	3.0	O/C	C/LI	PDP	2	605	5	M7, M9
450	600	1	L	3.0	O/C	C/LI	CCP	2	610	10	M6
50	500	1	L	3.0	O/C	C/LI	PDP	2	505	5	M7
50	400	1	L	3.0	O/C	C/LI	CCP	2	405	5	M6
50	400	1	L	3.0	O	C/LI	CCP	10	410	10	M8

APPENDIX A

SUMMARY TABLE - MASS INPUT RESULTS

RCS VOLUME = 13,000 CU.FT.

INITIAL RCS PRESSURE (psig)	RELIEF VALVE					MASS INPUT MECHANISM			RESULTS		
	Setpoint (psig)	Number of Valves	Linear (L) or Non-Linear (NL)	Max. Opening Time (sec)	Valve Opens (O)/ Closes (C)	SI Pump SU (SI) or Charging/Letdown Isolation (C/LI)	CC Pump or PD Pump	Letdown Isolation Δt, sec	RCS P_{MAX} (psig)	$P_{MAX}-P_{SETPOINT}$ (psi)	Appendix B Figure Number(s)
50	600	1	L	3.0	O	SI	---	---	675	75	M19, M22, M4
50	600	2	L	3.0	O	SI	---	---	657	57	---
50	600	1	NL	3.0	O	SI	---	---	667	67	---
50	600	2	NL	3.0	O	SI	---	---	658	58	---
50	600	1	L	1.5	O	SI	---	---	628	28	---
50	600	2	L	1.5	O	SI	---	---	616	16	---
450	600	1	L	3.0	O	SI	---	---	673	73	M21, M24
450	600	2	L	3.0	O	SI	---	---	656	56	---
450	500	1	L	3.0	O	SI	---	---	583	83	M21, M25
450	500	2	L	3.0	O	SI	---	---	562	62	---
50	400	1	L	3.0	O	SI	---	---	495	95	M19, M23, M4
50	400	2	L	3.0	O	SI	---	---	470	70	---
50	400	1	NL	3.0	O	SI	---	---	480	80	---

APPENDIX A

SUMMARY TABLE - MASS INPUT RESULTS

RCS VOLUME = 13,000 CU.FT.

INITIAL RCS PRESSURE (psig)	RELIEF VALVE					MASS INPUT MECHANISM			RESULTS		
	Setpoint (psig)	Number of Valves	Linear (L) or Non-Linear (NL)	Max. Opening Time (sec)	Valve Opens (O)/ Closes (C)	SI Pump SU (SI) or Charging/Letdown Isolation (C/LI)	CC Pump or PD Pump	Letdown Isolation Δt, sec	RCS P_{MAX} (psig)	$P_{MAX}-P_{SETPOINT}$ (psi)	Appendix B Figure Number(s)
50	400	2	NL	3.0	O	SI	---	---	469	69	---
50	400	1	L	1.5	O	SI	---	---	440	40	---
50	400	2	L	1.5	O	SI	---	---	422	22	---
50	600	1	L	3.0	O	CL/I	CCP	2	605	5	M11
50	600	1	L	3.0	O/C	CL/I	CCP	2	605	5	M13
50	600	1	L	3.0	O	CL/I	CCP	10	605	5	M12
50	400	1	L	3.0	O	CL/I	CCP	10	605	5	M12
50	400	1	L	3.0	O	CL/I	CCP	2	605	5	M11
50	400	1	L	3.0	O/C	SI	---	---	495	95	M36

APPENDIX A

SUMMARY TABLE - HEAT INPUT RESULTS

RCS VOLUME = 6000 CU.FT.

INITIAL SYSTEM TEMPERATURES (°F)			REFERENCE RELIEF VALVE		SG MODEL	RESULTS		
ΔT	RCS	SG	Setpoint (psig)	Number	Conservative (C) or Less Conservative (LC)	RCS P_{MAX} (psig)	$P_{MAX}-P_{SETPOINT}$ (psi)	Appendix B Figure Number(s)
20	180	200	500	1	C	515	15	H19
50	100	150	500	1	C	531	31	H1, H4, H6
50	140	190	500	1	C	562	62	H1, H4, H6
50	180	230	500	1	C	598	98	H1, H4, H6, H19
50	250	300	500	1	C	657	157	H1, H6
100	100	200	600	1	C	745	145	H20, H22, H25
100	100	200	600	2	C	710	110	H20
100	100	200	600	1	LC	650	50	H22
100	140	240	600	1	C	845	245	H23
100	140	240	600	2	C	775	175	H23
100	180	280	600	1	C	935	335	H24, H25, H27, H28, H36, H37
100	180	280	600	2	C	825	225	H24
100	180	280	600	1	LC	775	175	H27

APPENDIX A

SUMMARY TABLE - HEAT INPUT RESULTS

RCS VOLUME = 6000 CU.FT.

INITIAL SYSTEM TEMPERATURES (°F)			REFERENCE RELIEF VALVE		SG MODEL	RESULTS		
ΔT	RCS	SG	Setpoint (psig)	Number	Conservative (C) or Less Conservative (LC)	RCS P_{MAX} (psig)	$P_{MAX}-P_{SETPOINT}$ (psi)	Appendix B Figure Number(s)
100	100	200	500	1	C	640	140	H4, H20
100	100	200	500	2	C	610	110	H20
100	140	240	500	1	C	730	230	H4, H23
100	140	240	500	2	C	655	155	H23
100	180	280	500	1	C	780	280	H4, H24, H37
100	180	280	500	2	C	665	165	H24
100	100	200	400	1	C	540	140	H20, H21
100	100	200	400	2	C	510	110	H20
100	100	200	400	1	LC	460	60	H21
100	140	240	400	1	C	545	145	H23
100	140	240	400	2	C	485	85	H23
100	180	280	400	1	C	665	265	H24, H26, H37
100	180	280	400	2	C	515	115	H24
100	180	280	400	1	LC	547	147	H26

APPENDIX A

SUMMARY TABLE - HEAT INPUT RESULTS

RCS VOLUME = 13,000 CU.FT.

INITIAL SYSTEM TEMPERATURES (°F)			REFERENCE RELIEF VALVE		SG MODEL	RESULTS		
ΔT	RCS	SG	Setpoint (psig)	Number	Conservative (C) or Less Conservative (LC)	RCS P_{MAX} (psig)	$P_{MAX}-P_{SETPOINT}$ (psi)	Appendix B Figure Number(s)
50	100	150	500	1	C	527	27	H5
50	140	190	500	1	C	550	50	H5
50	180	230	500	1	C	569	69	H5
100	100	200	600	1	C	710	110	H29, H31
100	100	200	600	2	C	680	80	H29
100	100	200	600	1	LC	650	50	H31
100	140	240	600	1	C	775	175	H32
100	140	240	600	2	C	725	125	H32
100	180	280	600	1	C	908	308	H33, H36, H37
100	180	280	600	2	C	765	165	H33
100	180	280	600	1	LC	725	125	H34
100	100	200	500	1	C	608	108	H5, H29
100	100	200	500	2	C	575	75	H29

APPENDIX A

SUMMARY TABLE - HEAT INPUT RESULTS

RCS VOLUME = 13,000 CU.FT.

INITIAL SYSTEM TEMPERATURES (°F)			REFERENCE RELIEF VALVE		SG MODEL	RESULTS		
ΔT	RCS	SG	Setpoint (psig)	Number	Conservative (C) or Less Conservative (LC)	RCS P_{MAX} (psig)	$P_{MAX}-P_{SETPOINT}$ (psi)	Appendix B Figure Number(s)
100	140	240	500	1	C	667	167	H5, H32
100	140	240	500	2	C	615	115	H32
100	180	280	500	1	C	855	355	H5, H33, H37
100	180	280	500	2	C	650	150	H33
100	100	200	400	1	C	495	95	H29, H30
100	100	200	400	2	C	465	65	H29
100	100	200	400	1	LC	435	35	H30
100	140	240	400	1	C	577	177	H32
100	140	240	400	2	C	490	90	H32
100	180	280	400	1	C	793	393	H33, H37
100	180	280	400	2	C	500	100	H33
100	180	280	400	1	LC	505	105	H35

APPENDIX B

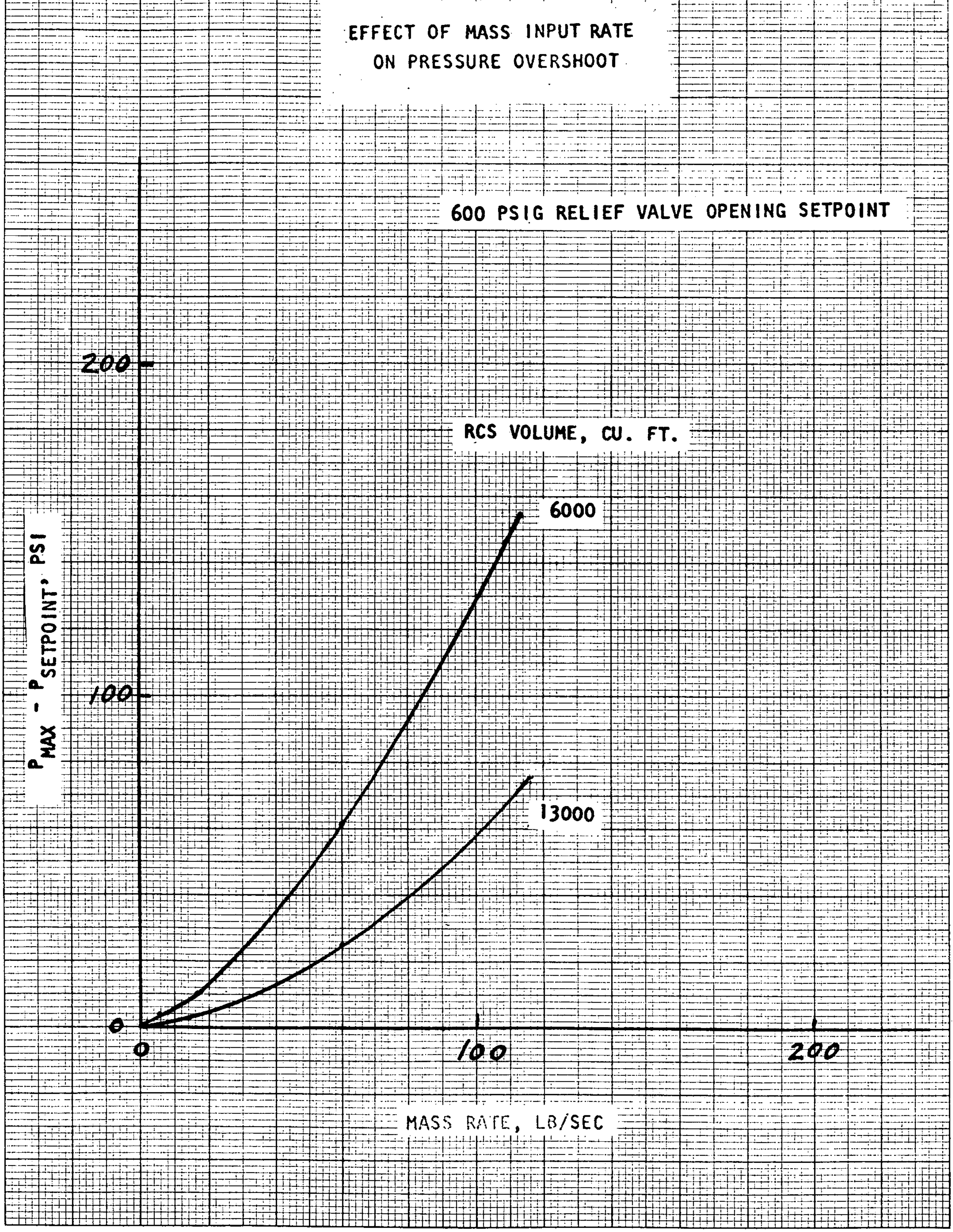
FIGURES

MASS INPUT

APPENDIX B

FIGURES

FIGURE M1


EFFECT OF MASS INPUT RATE
ON PRESSURE OVERSHOOT
600 PSIG RELIEF VALVE OPENING SETPOINT
RCS VOLUME, CU. FT.
6000
13000
$P_{MAX} - P_{SETPOINT}$, PSI
200
100
0
0
100
200
MASS RATE, LB/SEC

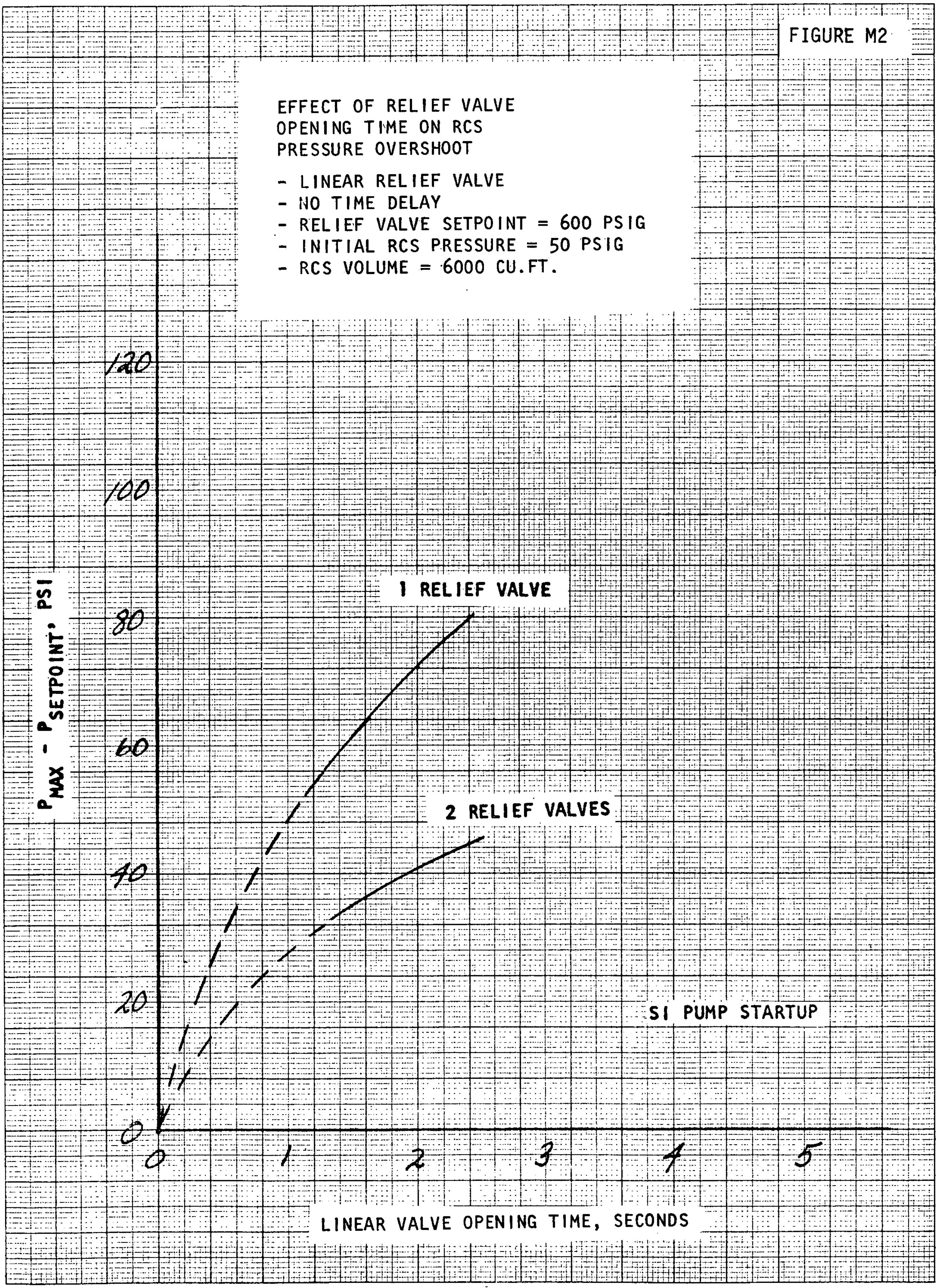


FIGURE M2
EFFECT OF RELIEF VALVE
OPENING TIME ON RCS
PRESSURE OVERSHOOT
- LINEAR RELIEF VALVE
- NO TIME DELAY
- RELIEF VALVE SETPOINT = 600 PSIG
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 6000 CU.FT.
120
100
80
60
40
20
0
$P_{MAX} - P_{SETPOINT}$, PSI
1 RELIEF VALVE
2 RELIEF VALVES
SI PUMP STARTUP
0
1
2
3
4
5
LINEAR VALVE OPENING TIME, SECONDS

FIGURE M3

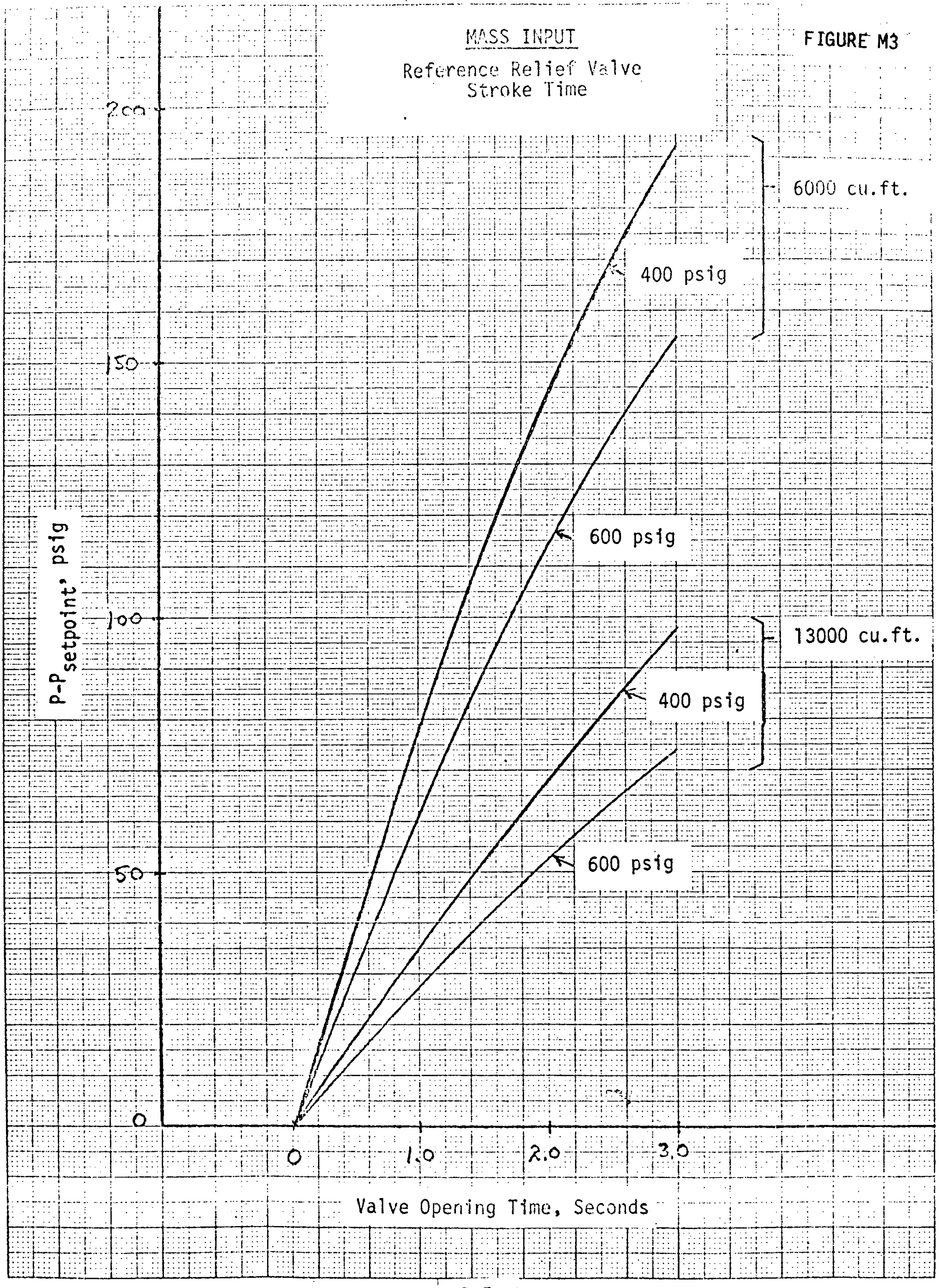
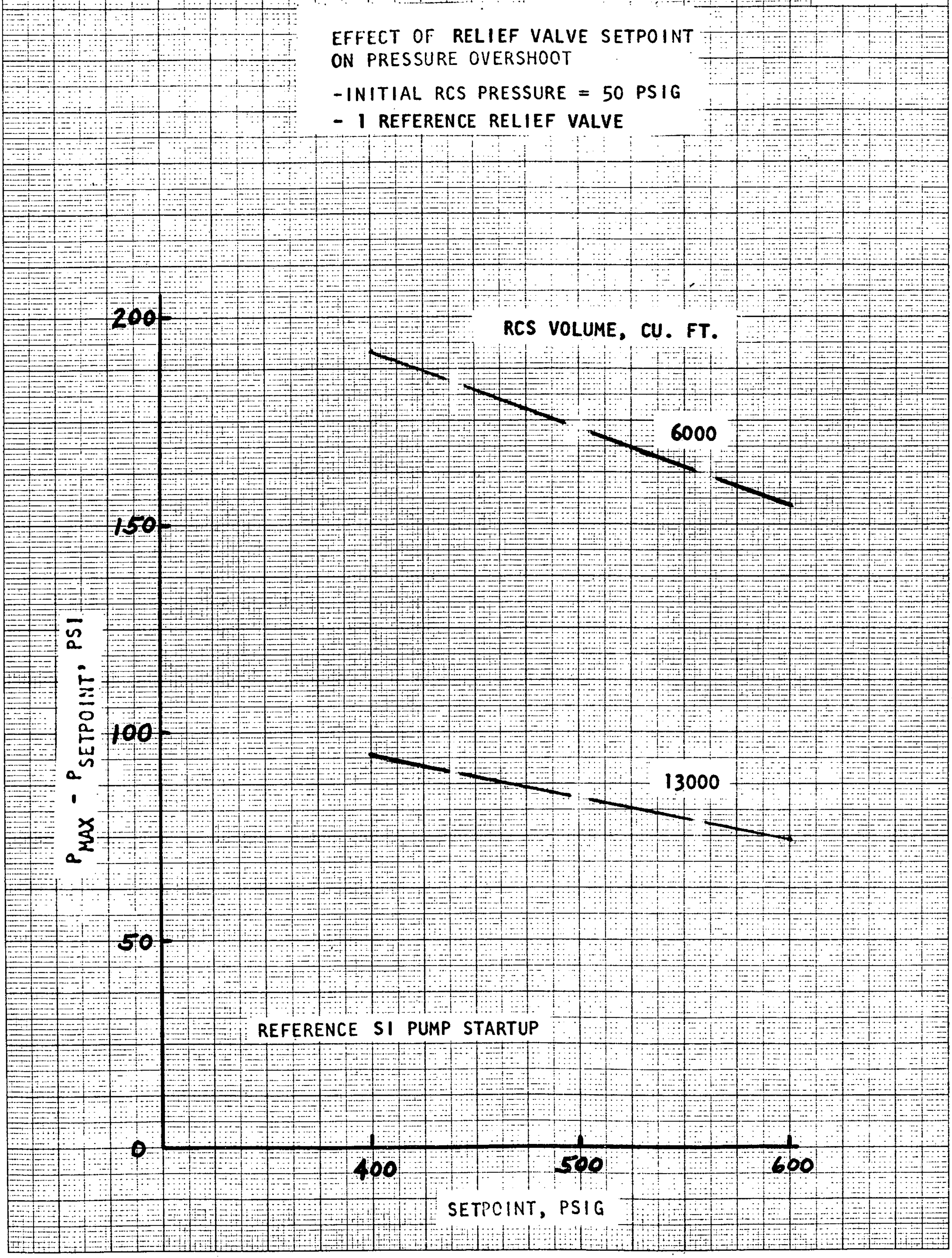

MASS INPUT
Reference Relief Valve
Stroke Time
200
150
100
50
0
6000 cu.ft.
400 psig
600 psig
13000 cu.ft.
400 psig
600 psig
$P-P_{setpoint}$, psig
0
1.0
2.0
3.0
Valve Opening Time, Seconds

FIGURE M4



EFFECT OF RELIEF VALVE SETPOINT ON PRESSURE OVERSHOOT
-INITIAL RCS PRESSURE = 50 PSIG
- 1 REFERENCE RELIEF VALVE
RCS VOLUME, CU. FT.
6000
13000
200
150
100
50
0
$P_{MAX} - P_{SETPOINT}$, PSI
REFERENCE SI PUMP STARTUP
400
500
600
SETPOINT, PSIG

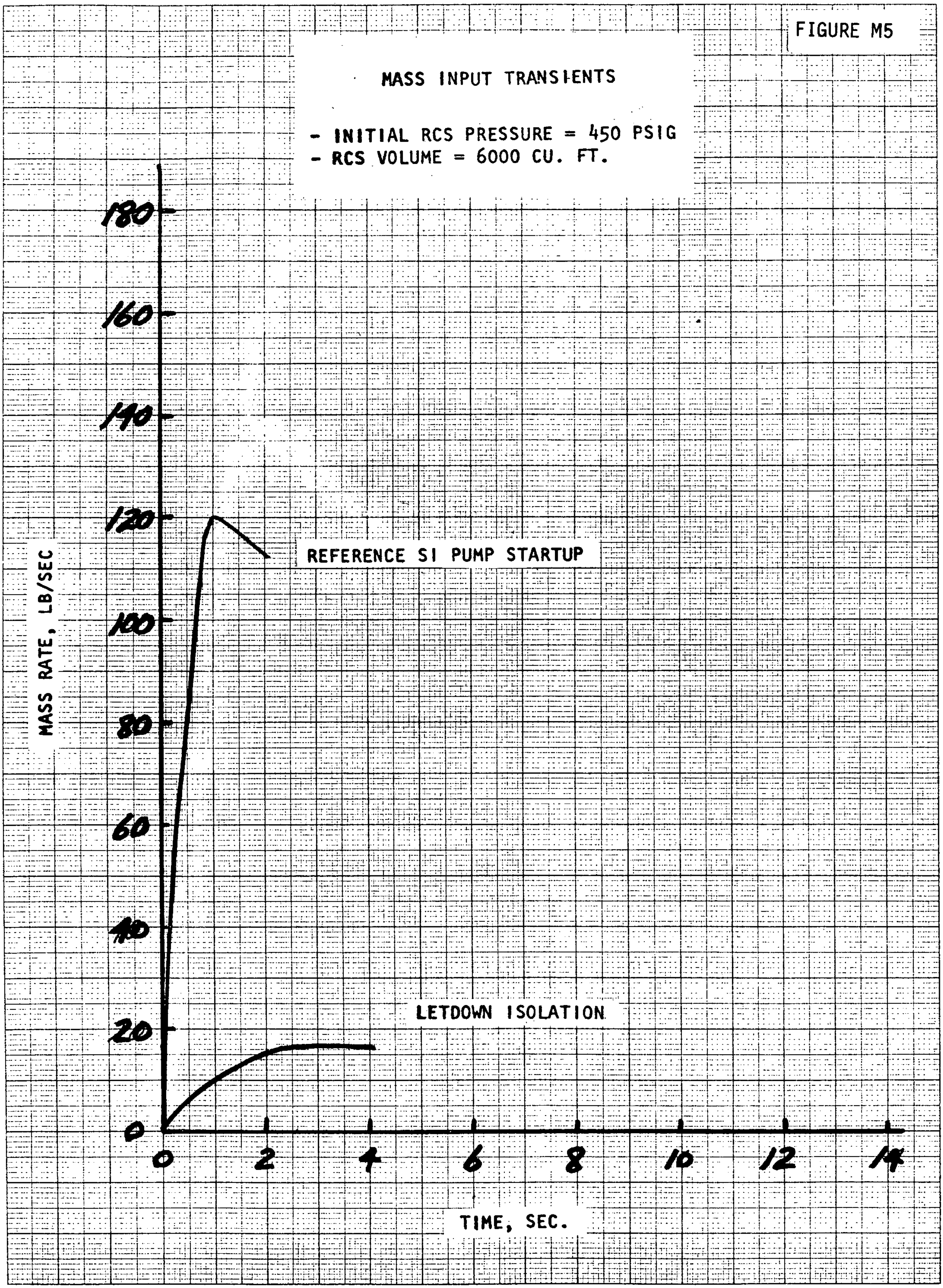


FIGURE M5
MASS INPUT TRANSIENTS
- INITIAL RCS PRESSURE = 450 PSIG
- RCS VOLUME = 6000 CU. FT.
MASS RATE, LB/SEC
180
160
140
120
100
80
60
40
20
0
REFERENCE SI PUMP STARTUP
LETDOWN ISOLATION
0
2
4
6
8
10
12
14
TIME, SEC.

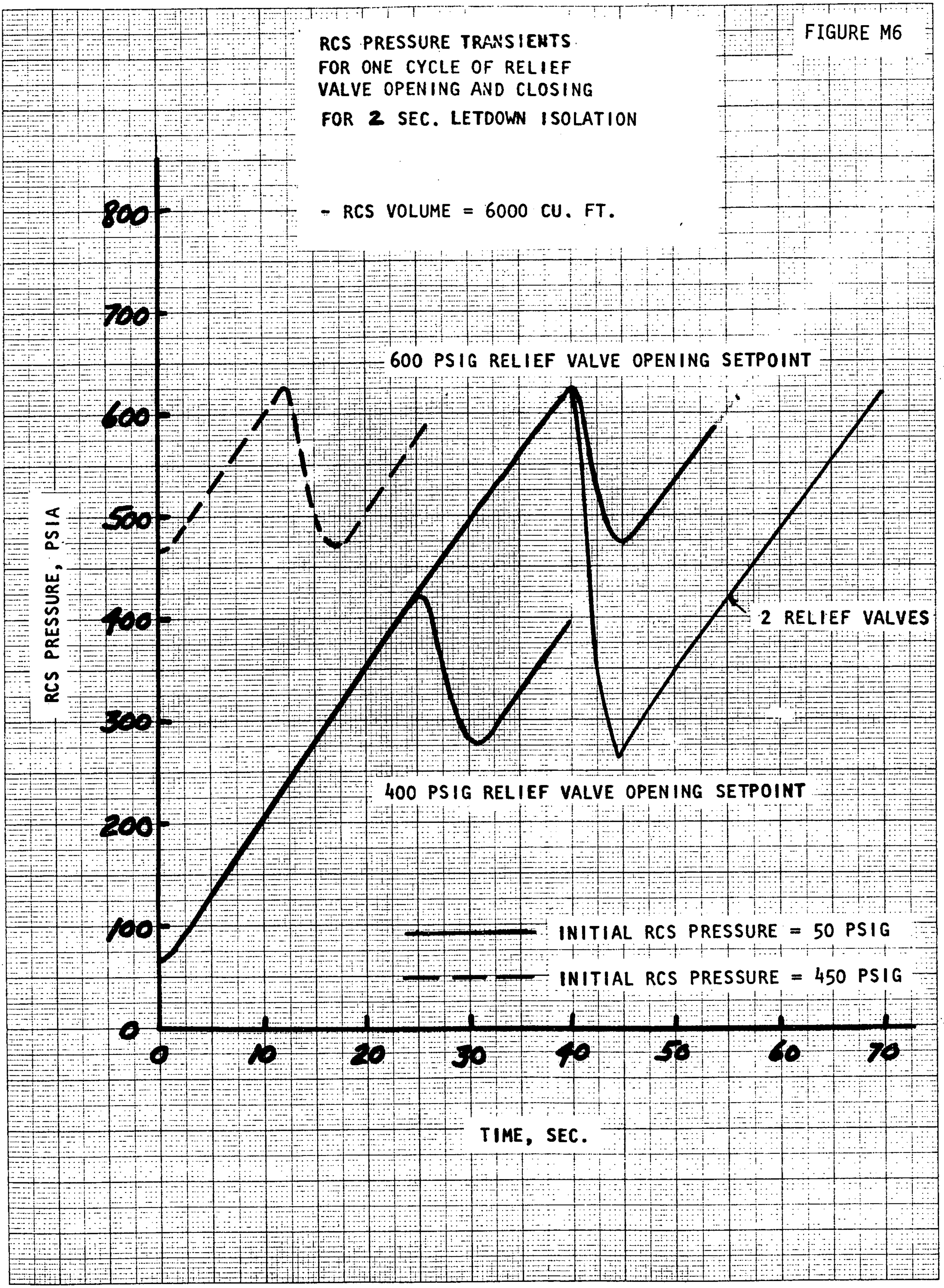
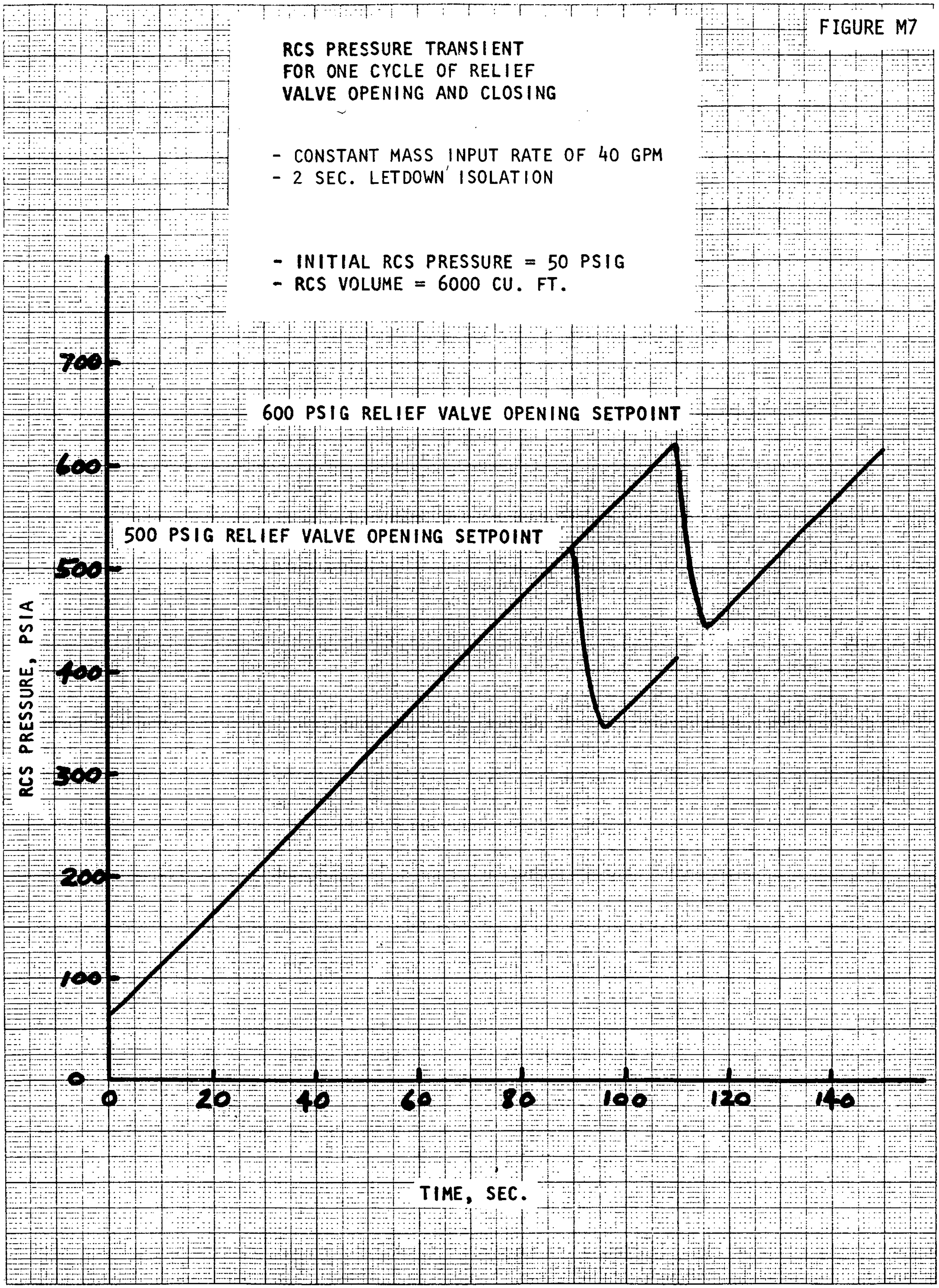


FIGURE M6
RCS PRESSURE TRANSIENTS
FOR ONE CYCLE OF RELIEF
VALVE OPENING AND CLOSING
FOR 2 SEC. LETDOWN ISOLATION
- RCS VOLUME = 6000 CU. FT.
600 PSIG RELIEF VALVE OPENING SETPOINT
2 RELIEF VALVES
400 PSIG RELIEF VALVE OPENING SETPOINT
INITIAL RCS PRESSURE = 50 PSIG
INITIAL RCS PRESSURE = 450 PSIG
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
TIME, SEC.

FIGURE M7



RCS PRESSURE TRANSIENT
FOR ONE CYCLE OF RELIEF
VALVE OPENING AND CLOSING
- CONSTANT MASS INPUT RATE OF 40 GPM
- 2 SEC. LETDOWN ISOLATION
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 6000 CU. FT.
600 PSIG RELIEF VALVE OPENING SETPOINT
500 PSIG RELIEF VALVE OPENING SETPOINT
RCS PRESSURE, PSIA
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
TIME, SEC.

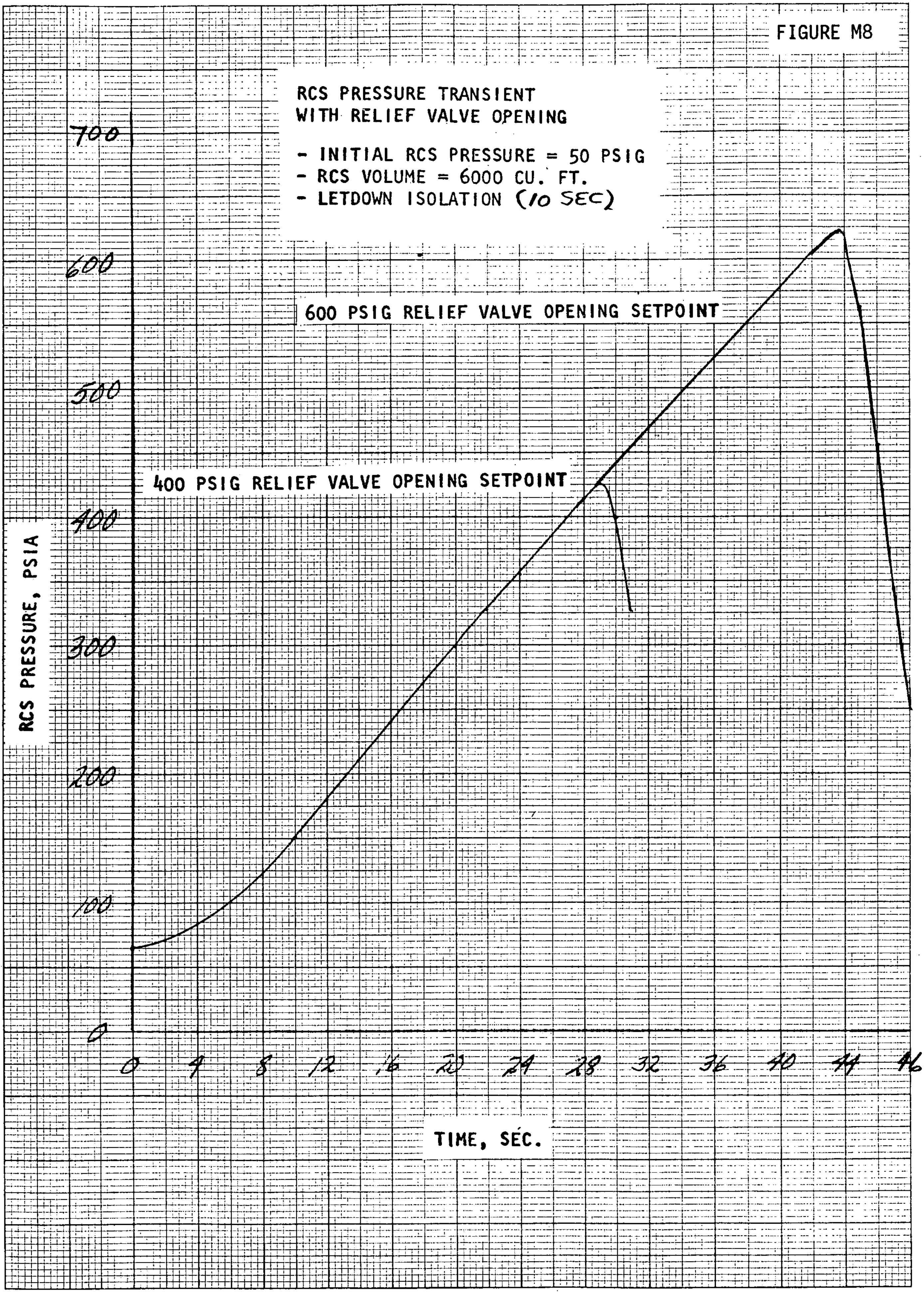


FIGURE M8
RCS PRESSURE TRANSIENT
WITH RELIEF VALVE OPENING
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 6000 CU. FT.
- LETDOWN ISOLATION (10 SEC)
600 PSIG RELIEF VALVE OPENING SETPOINT
400 PSIG RELIEF VALVE OPENING SETPOINT
RCS PRESSURE, PSIA
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
28
32
36
40
44
46
TIME, SEC.

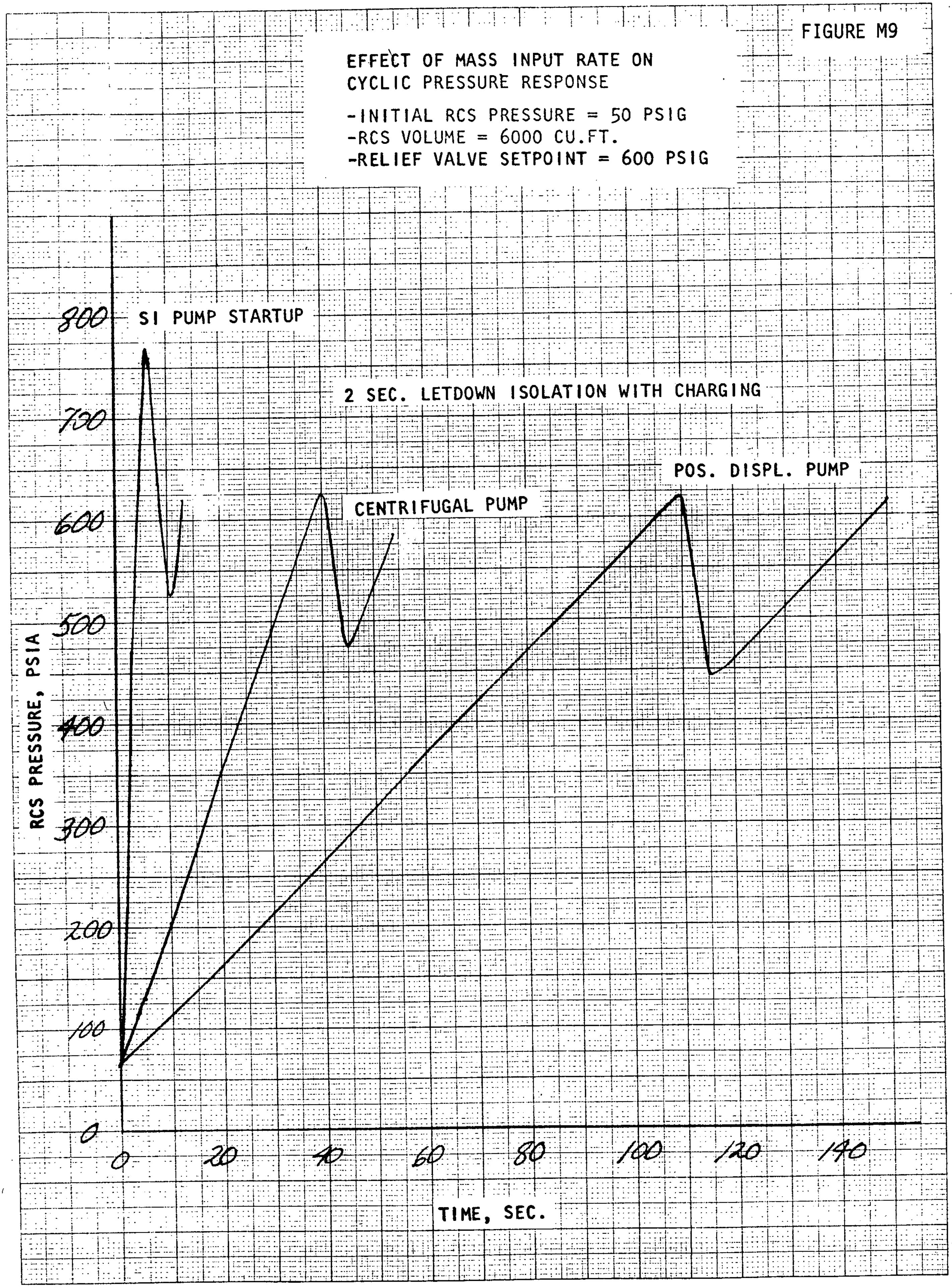


FIGURE M9
EFFECT OF MASS INPUT RATE ON
CYCLIC PRESSURE RESPONSE
-INITIAL RCS PRESSURE = 50 PSIG
-RCS VOLUME = 6000 CU.FT.
-RELIEF VALVE SETPOINT = 600 PSIG
SI PUMP STARTUP
2 SEC. LETDOWN ISOLATION WITH CHARGING
POS. DISPL. PUMP
CENTRIFUGAL PUMP
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
TIME, SEC.
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10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

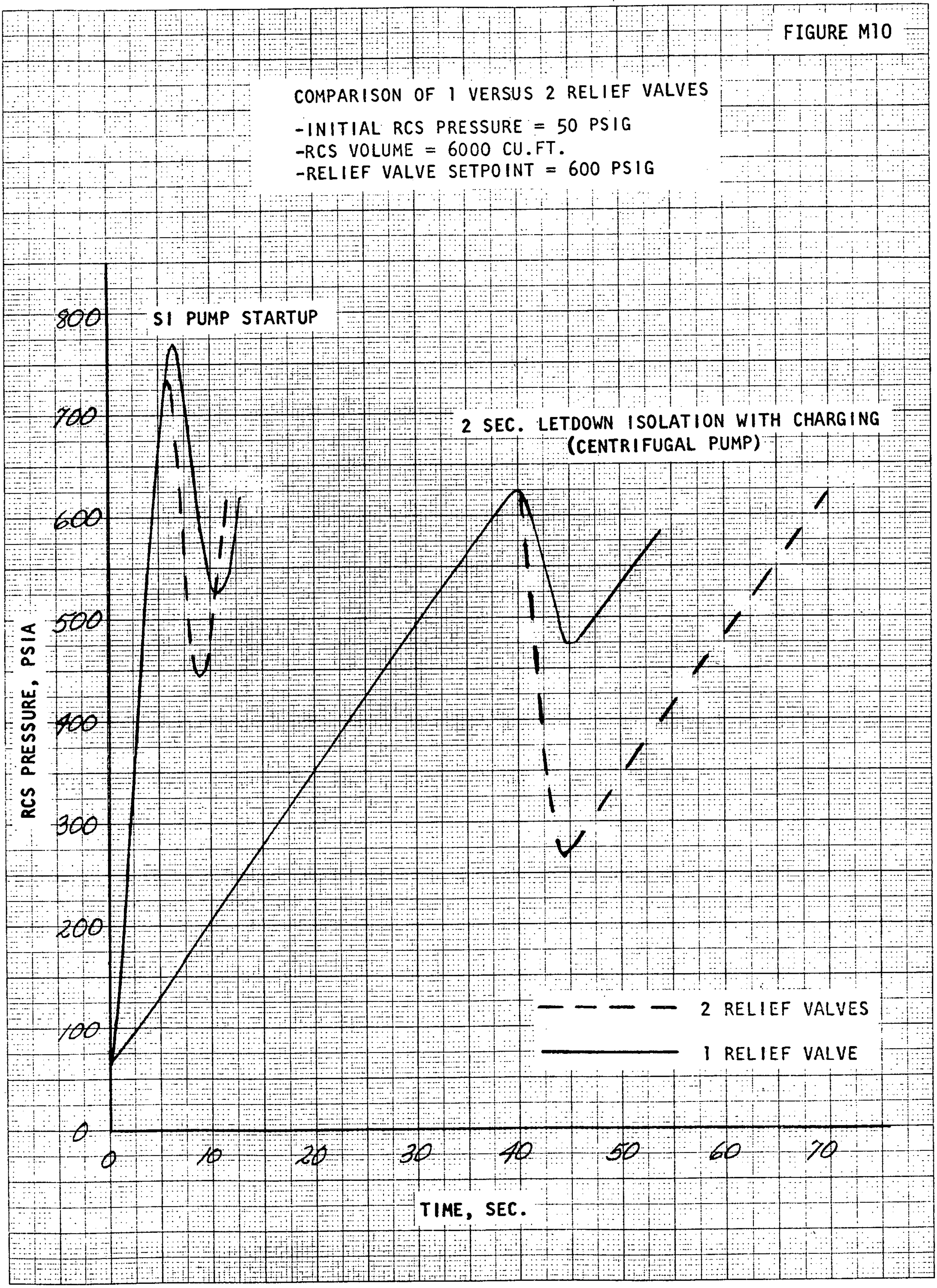


FIGURE M10
COMPARISON OF 1 VERSUS 2 RELIEF VALVES
-INITIAL RCS PRESSURE = 50 PSIG
-RCS VOLUME = 6000 CU.FT.
-RELIEF VALVE SETPOINT = 600 PSIG
SI PUMP STARTUP
2 SEC. LETDOWN ISOLATION WITH CHARGING
(CENTRIFUGAL PUMP)
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
TIME, SEC.
2 RELIEF VALVES
1 RELIEF VALVE

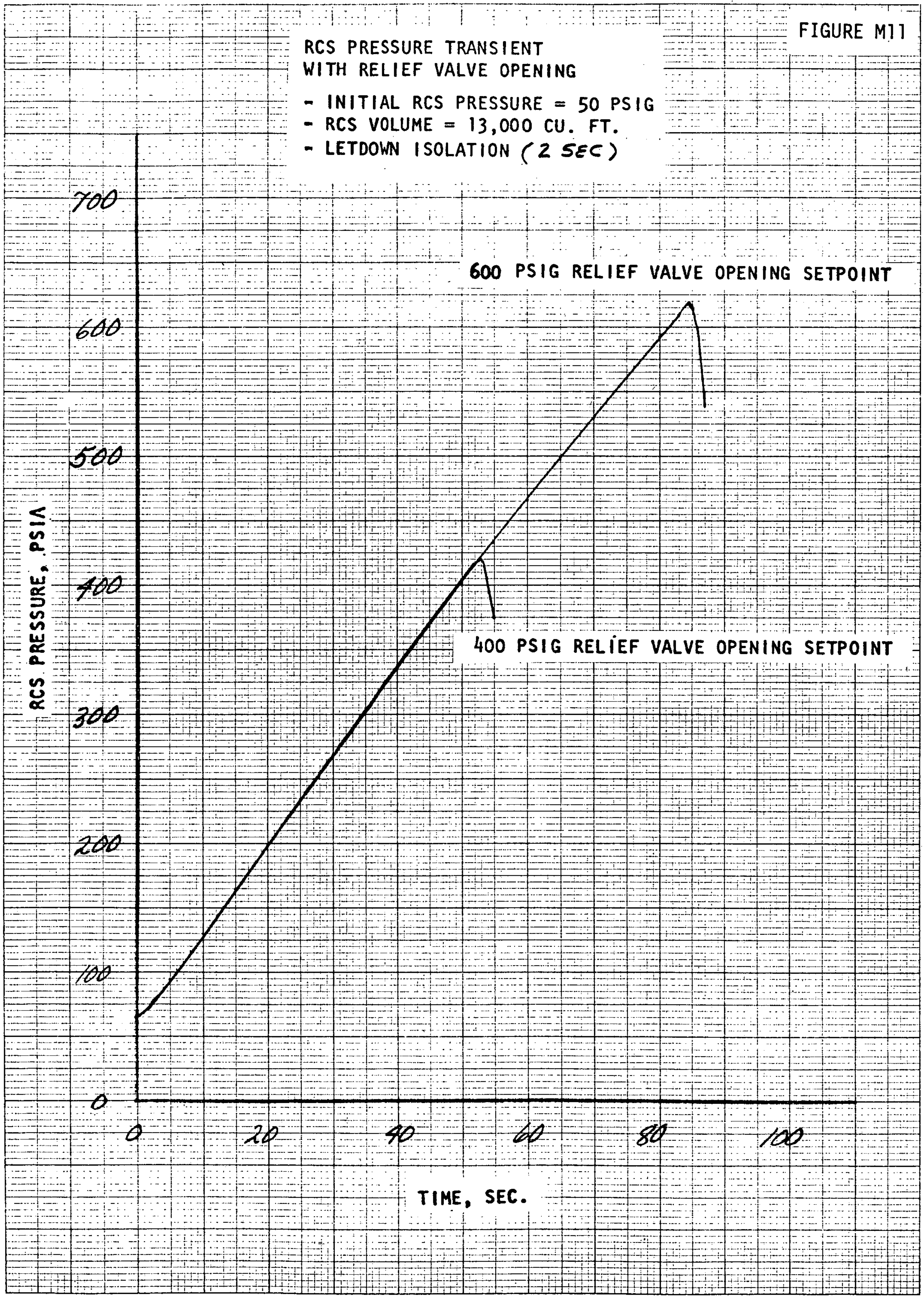
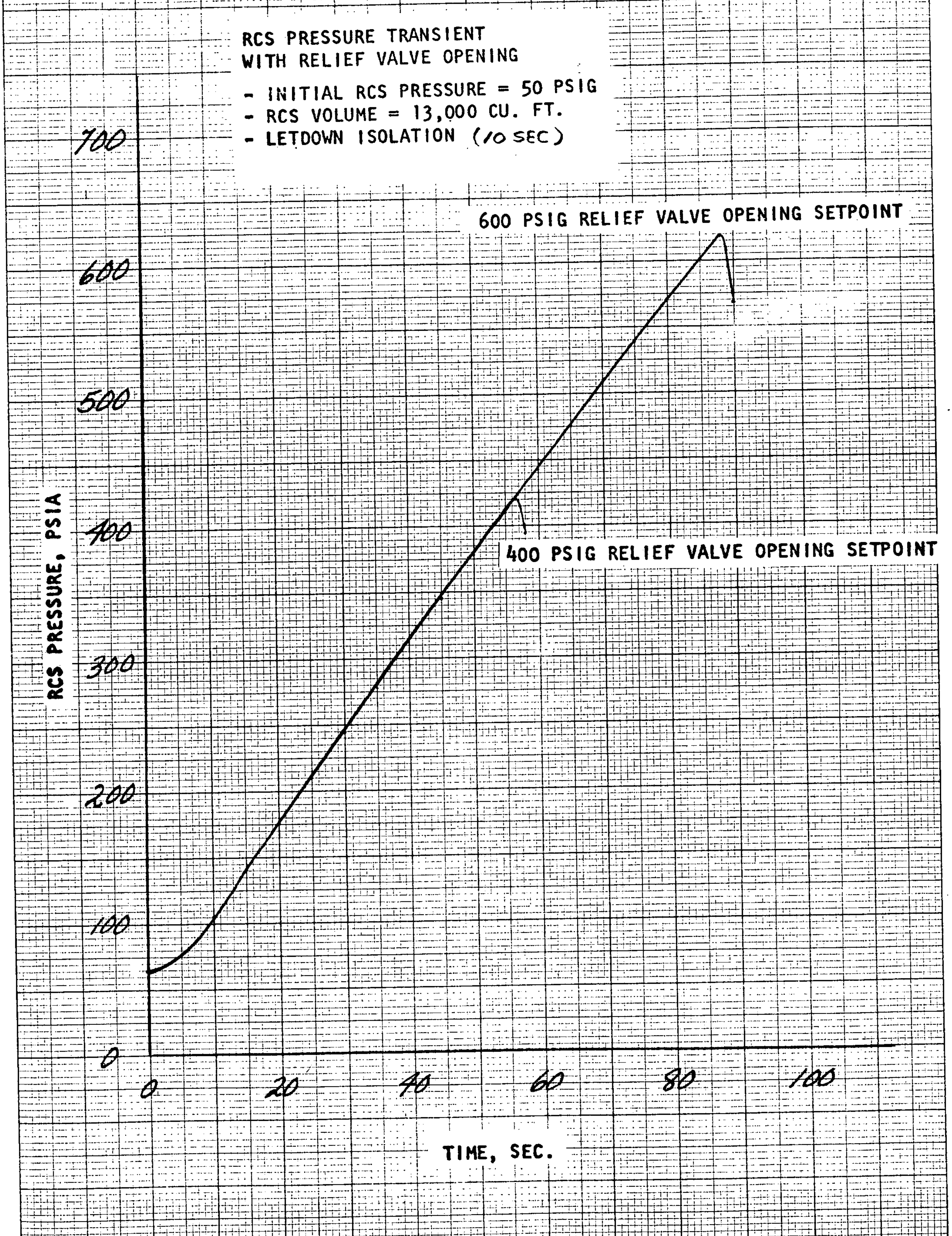
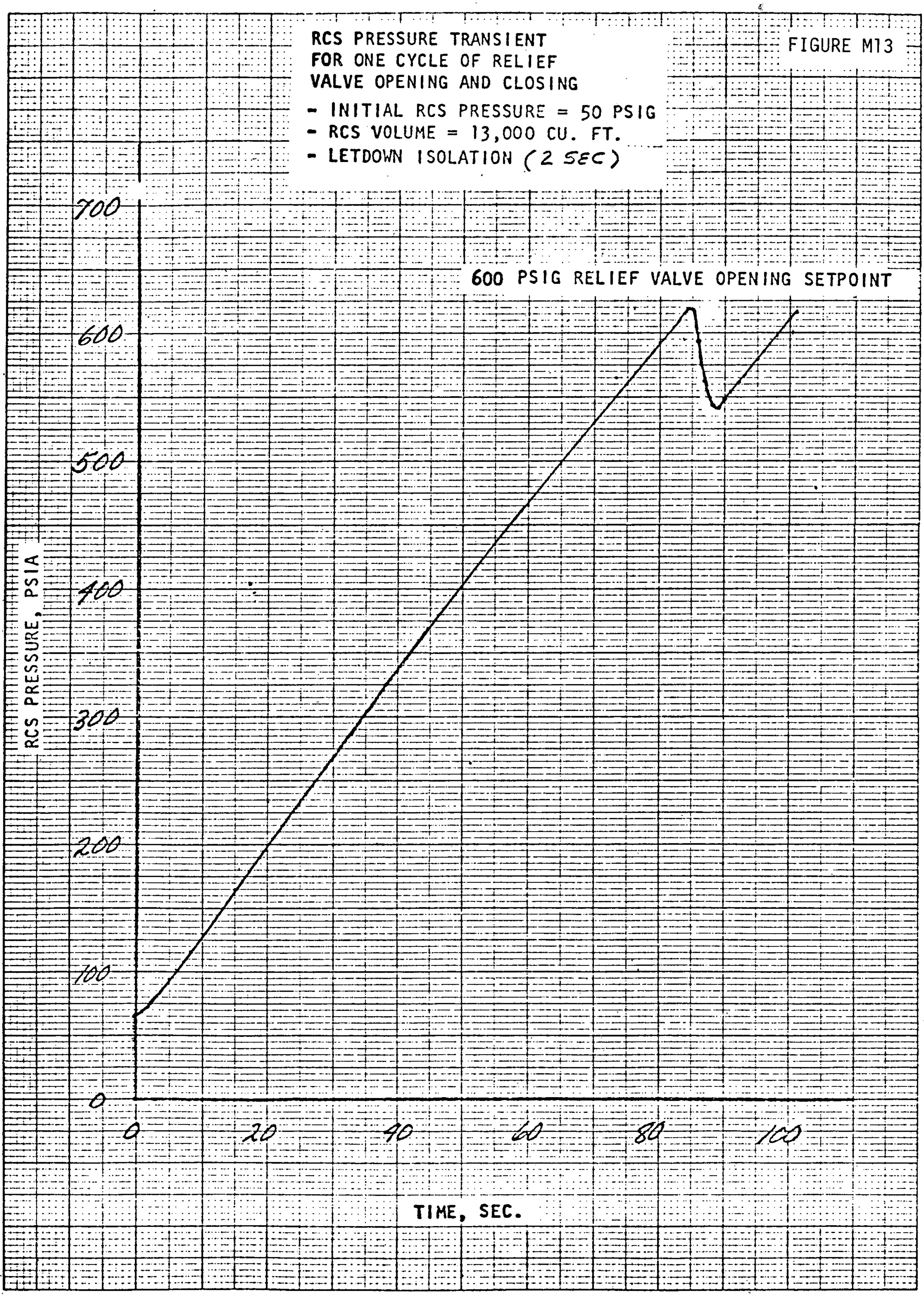


FIGURE M11
RCS PRESSURE TRANSIENT
WITH RELIEF VALVE OPENING
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 13,000 CU. FT.
- LETDOWN ISOLATION (2 SEC)
600 PSIG RELIEF VALVE OPENING SETPOINT
400 PSIG RELIEF VALVE OPENING SETPOINT
RCS PRESSURE, PSIA
700
600
500
400
300
200
100
0
0
20
40
60
80
100
TIME, SEC.

FIGURE M12


RCS PRESSURE TRANSIENT
WITH RELIEF VALVE OPENING
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 13,000 CU. FT.
- LETDOWN ISOLATION (10 SEC)
600 PSIG RELIEF VALVE OPENING SETPOINT
400 PSIG RELIEF VALVE OPENING SETPOINT
RCS PRESSURE, PSIA
700
600
500
400
300
200
100
0
0
20
40
60
80
100
TIME, SEC.


RCS PRESSURE TRANSIENT
FOR ONE CYCLE OF RELIEF
VALVE OPENING AND CLOSING
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 13,000 CU. FT.
- LETDOWN ISOLATION (2 SEC)
FIGURE M13
600 PSIG RELIEF VALVE OPENING SETPOINT
RCS PRESSURE, PSIA
700
600
500
400
300
200
100
0
0
20
40
60
80
100
TIME, SEC.

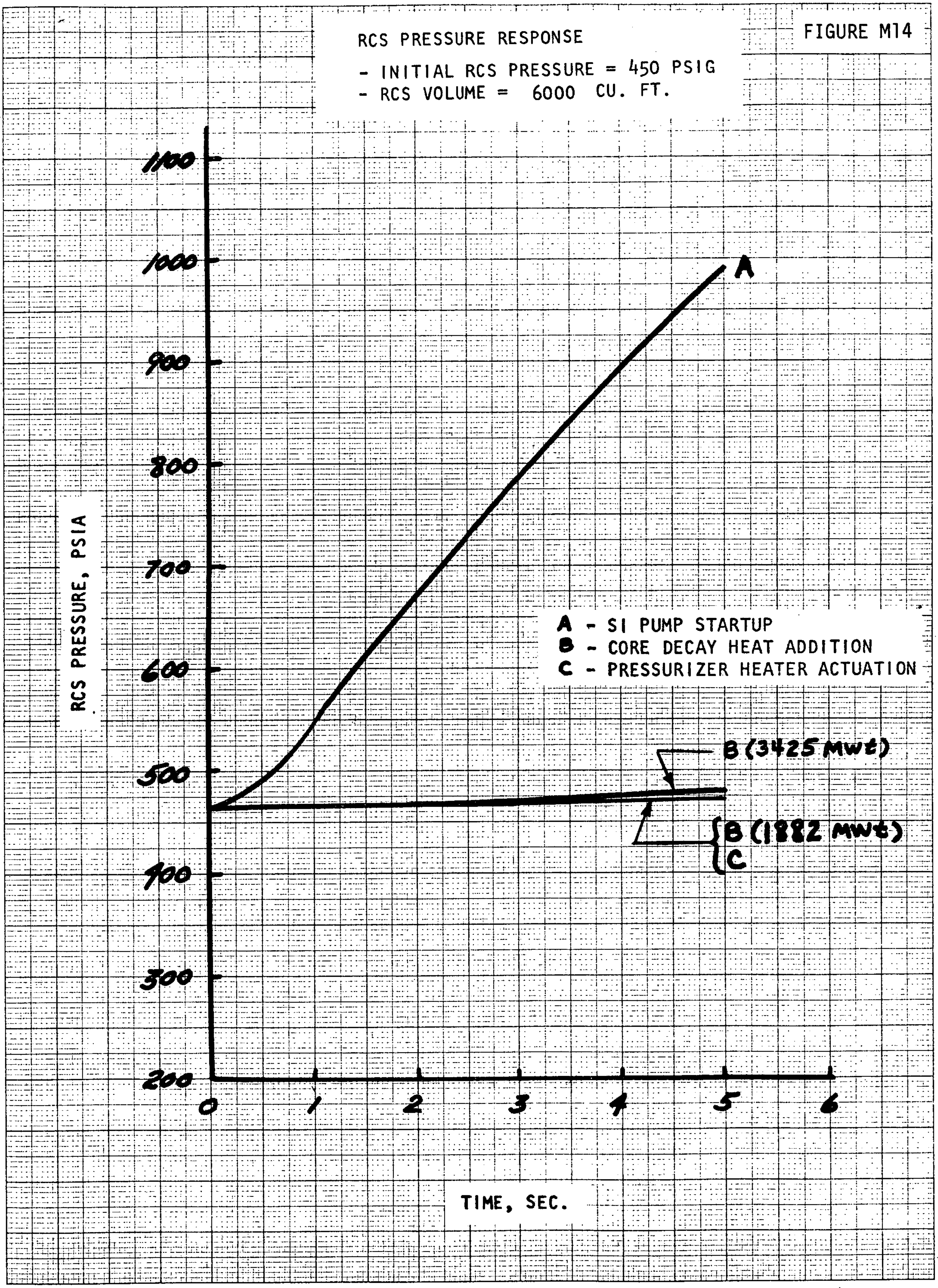
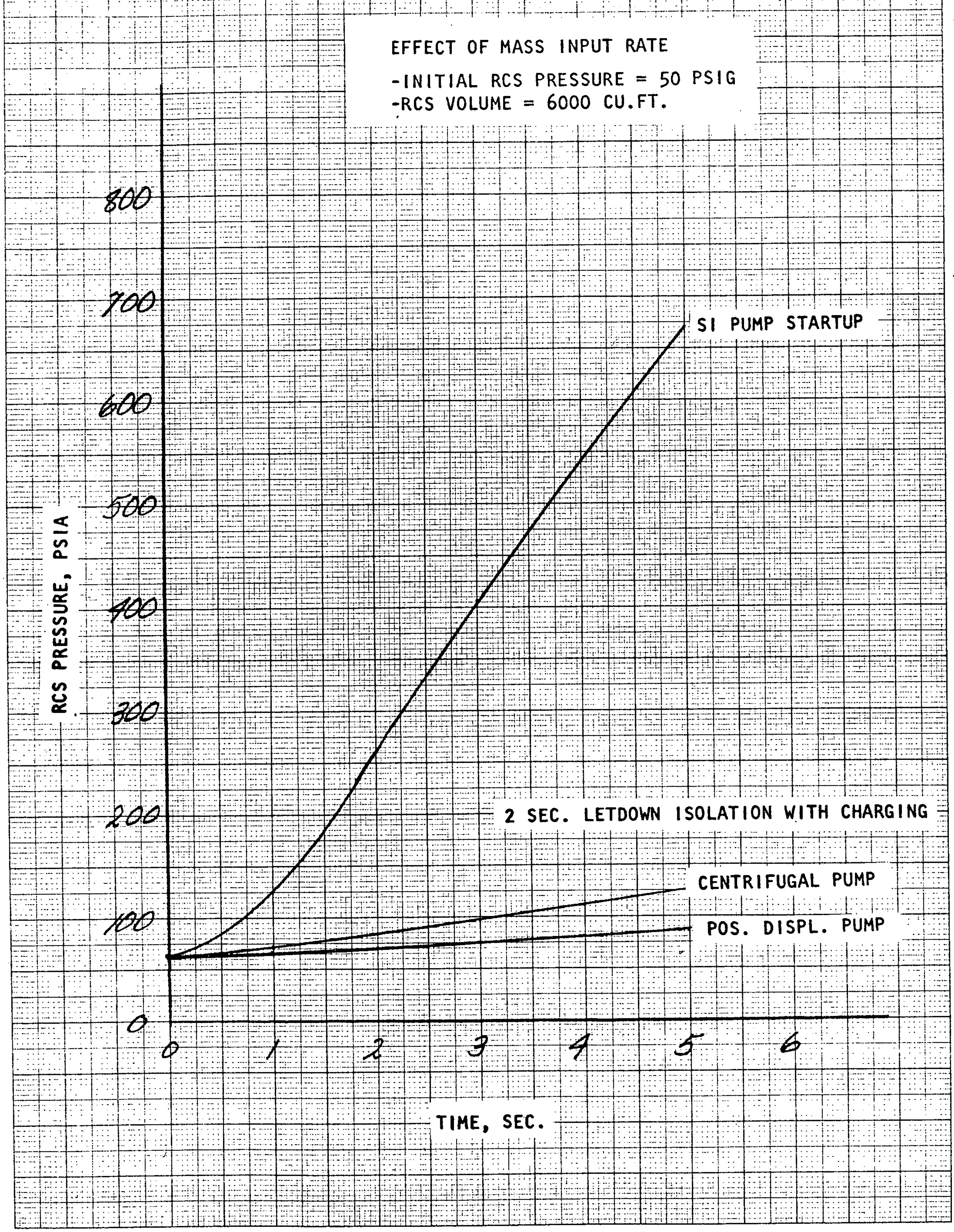


FIGURE M14
RCS PRESSURE RESPONSE
- INITIAL RCS PRESSURE = 450 PSIG
- RCS VOLUME = 6000 CU. FT.
RCS PRESSURE, PSIA
1100
1000
900
800
700
600
500
400
300
200
0
1
2
3
4
5
6
TIME, SEC.
A
A - SI PUMP STARTUP
B - CORE DECAY HEAT ADDITION
C - PRESSURIZER HEATER ACTUATION
B (3425 MWt)
B (1882 MWt)
C

FIGURE M15


EFFECT OF MASS INPUT RATE
-INITIAL RCS PRESSURE = 50 PSIG
-RCS VOLUME = 6000 CU.FT.
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
SI PUMP STARTUP
2 SEC. LETDOWN ISOLATION WITH CHARGING
CENTRIFUGAL PUMP
POS. DISPL. PUMP
0
1
2
3
4
5
6
TIME, SEC.

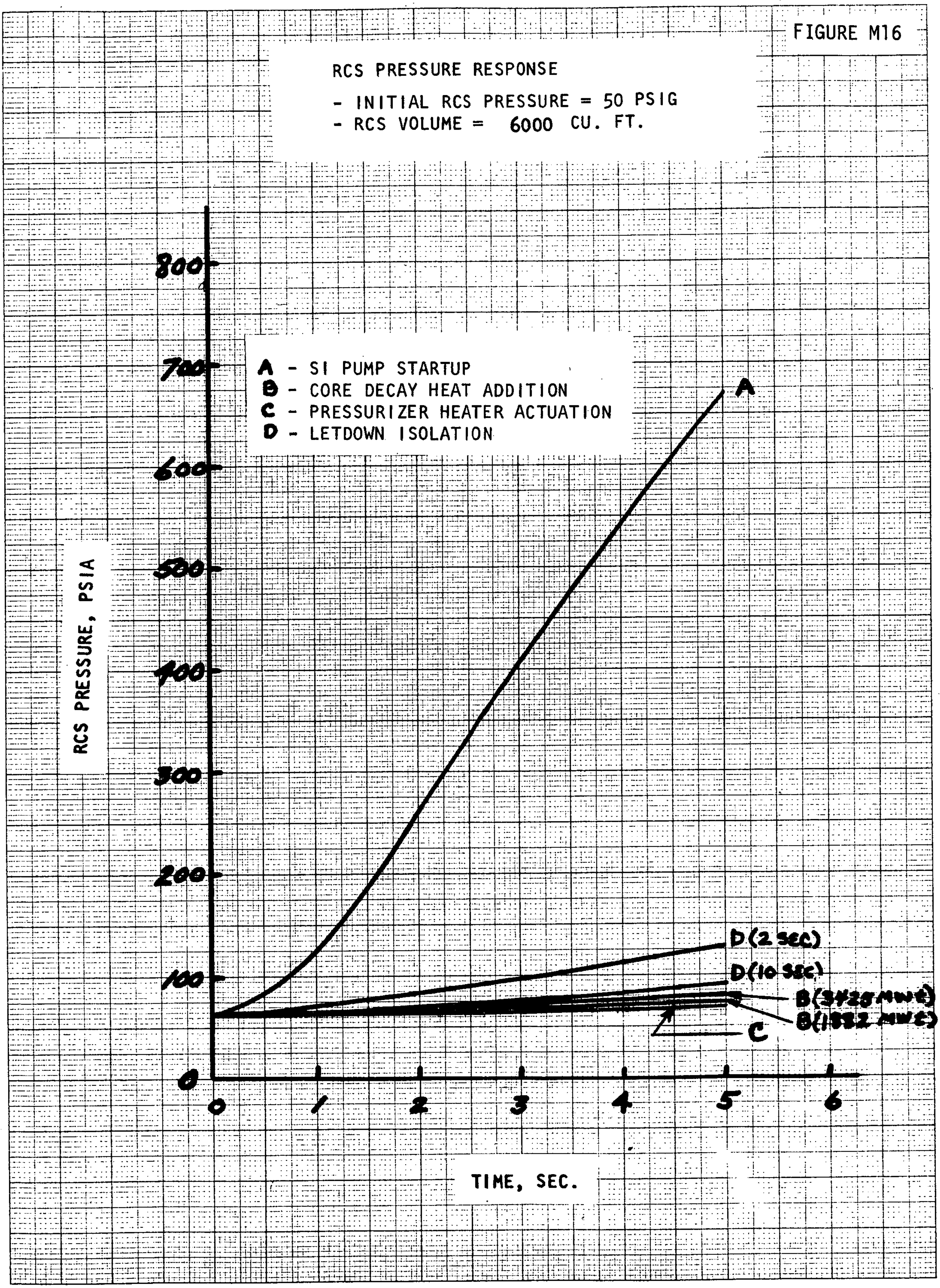


FIGURE M16
RCS PRESSURE RESPONSE
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 6000 CU. FT.
A - SI PUMP STARTUP
B - CORE DECAY HEAT ADDITION
C - PRESSURIZER HEATER ACTUATION
D - LETDOWN ISOLATION
RCS PRESSURE, PSIA
0
100
200
300
400
500
600
700
800
0
1
2
3
4
5
6
TIME, SEC.
A
D(2 SEC)
D(10 SEC)
B(3425 MWt)
C

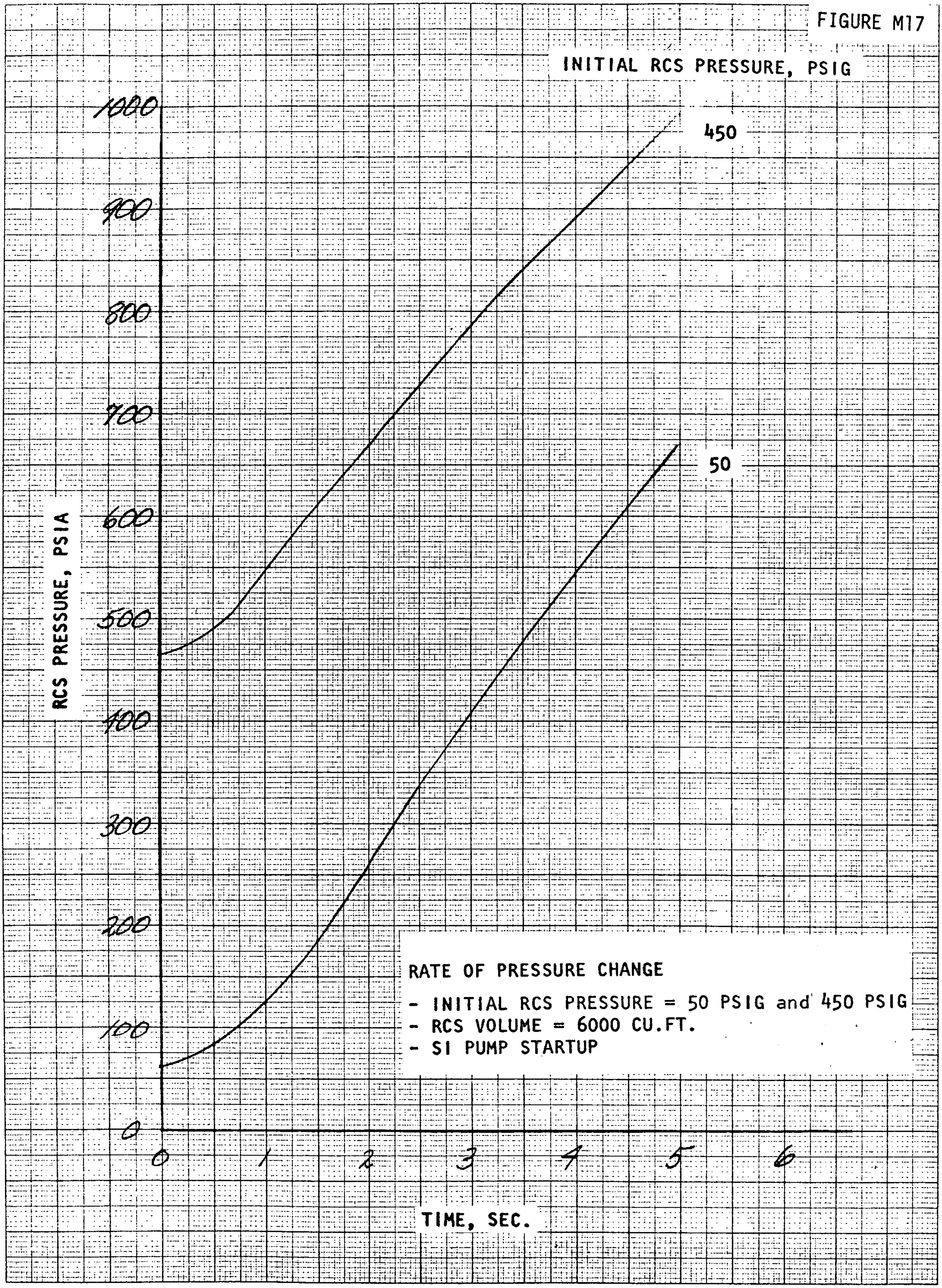
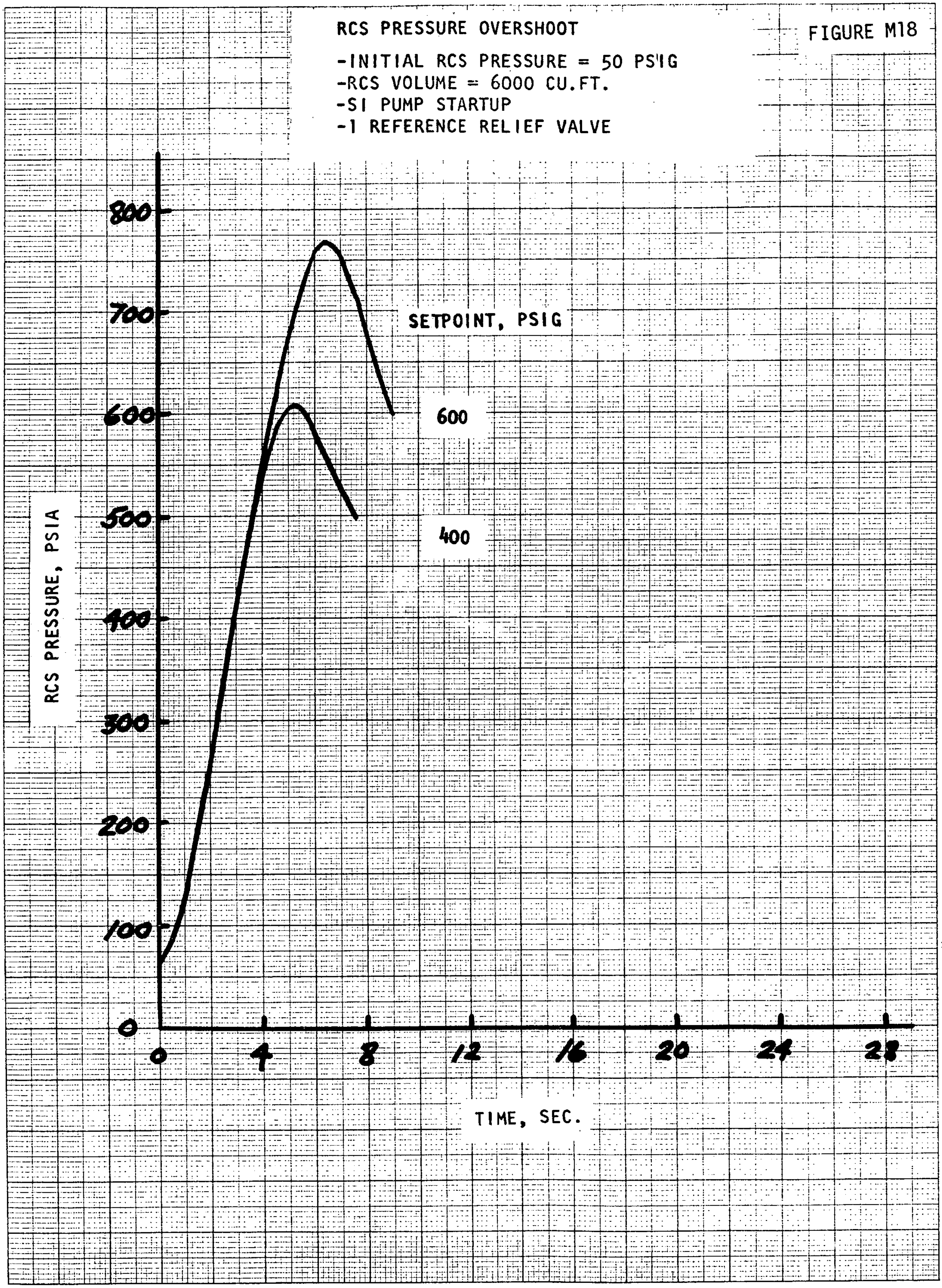


FIGURE M17
INITIAL RCS PRESSURE, PSIG
450
50
RCS PRESSURE, PSIA
1000
900
800
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
TIME, SEC.
RATE OF PRESSURE CHANGE
- INITIAL RCS PRESSURE = 50 PSIG and 450 PSIG
- RCS VOLUME = 6000 CU.FT.
- SI PUMP STARTUP



RCS PRESSURE OVERSHOOT
-INITIAL RCS PRESSURE = 50 PSIG
-RCS VOLUME = 6000 CU.FT.
-SI PUMP STARTUP
-1 REFERENCE RELIEF VALVE
FIGURE M18
SETPOINT, PSIG
600
400
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
28
TIME, SEC.

FIGURE M19

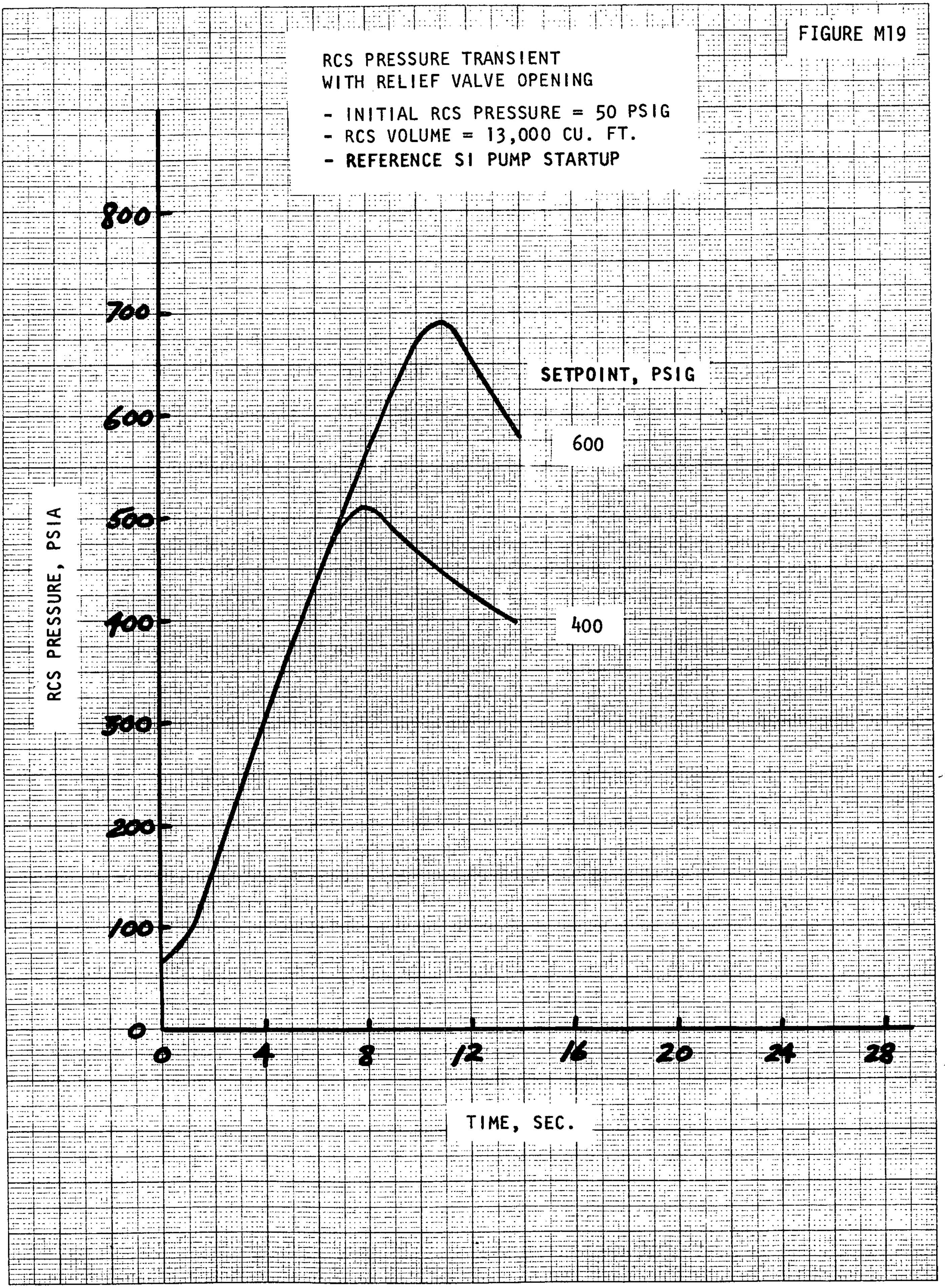


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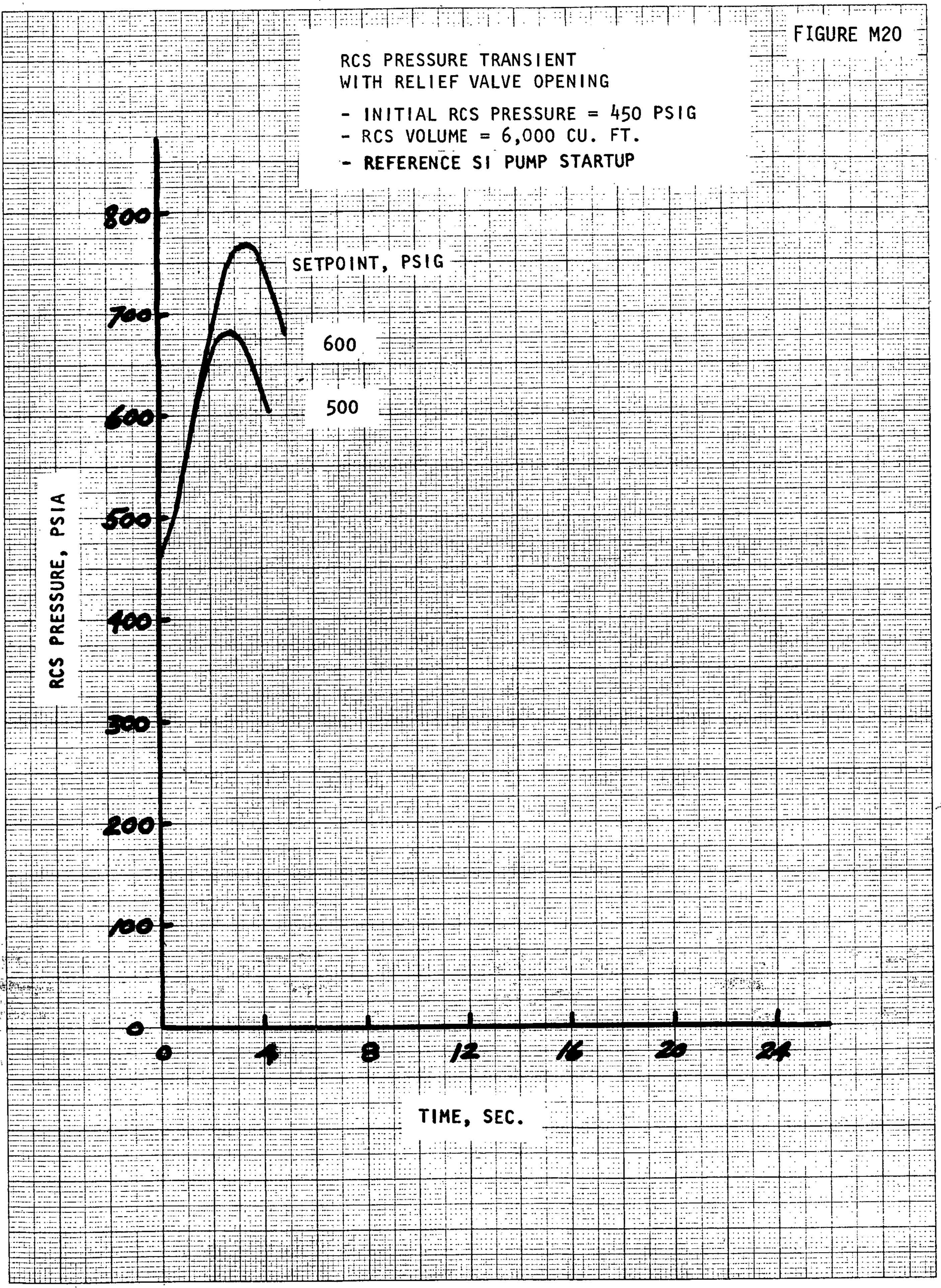
FIGURE M20


RCS PRESSURE TRANSIENT
WITH RELIEF VALVE OPENING
- INITIAL RCS PRESSURE = 450 PSIG
- RCS VOLUME = 6,000 CU. FT.
- REFERENCE SI PUMP STARTUP
SETPOINT, PSIG
600
500
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
TIME, SEC.

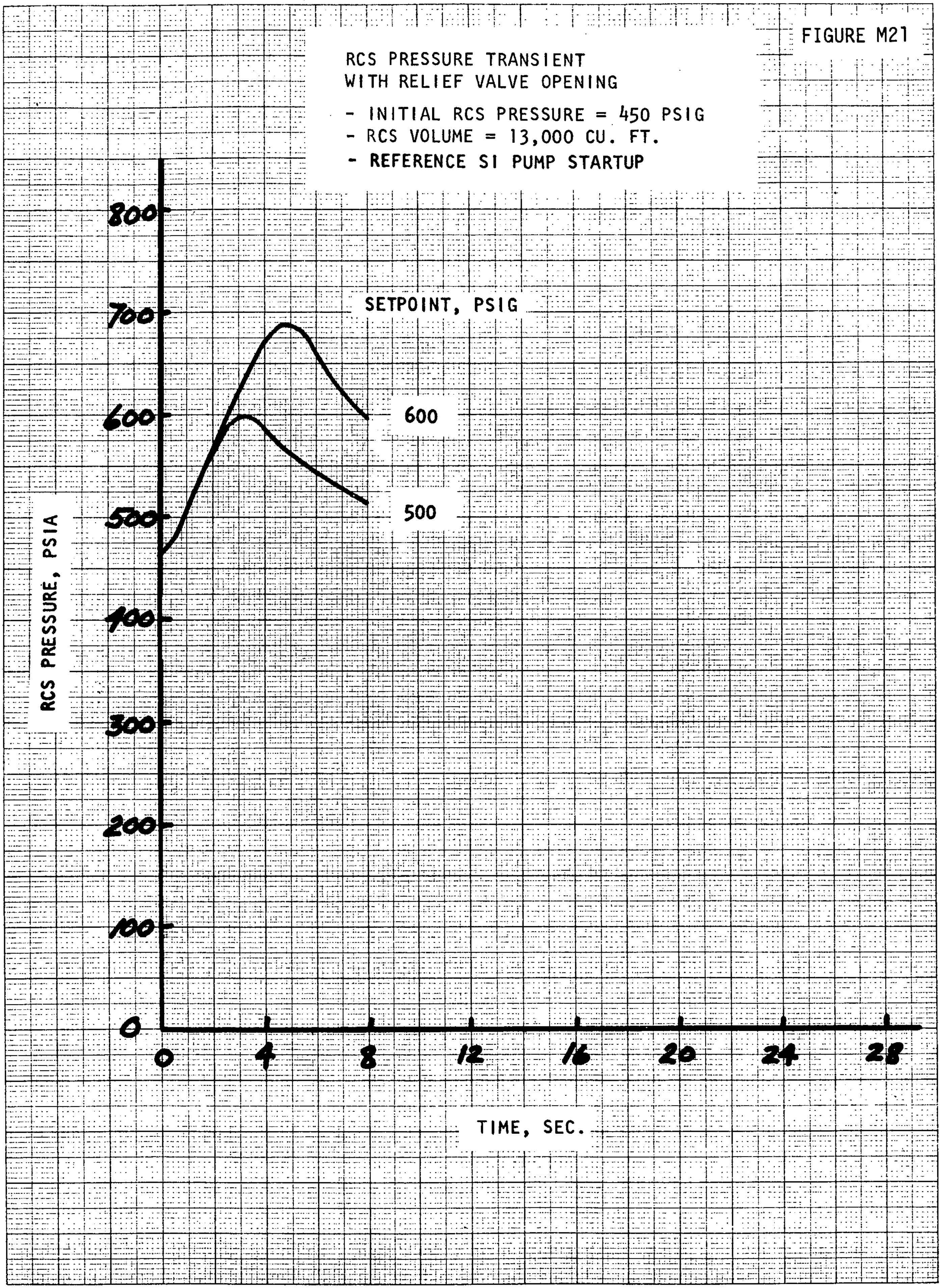


FIGURE M21
RCS PRESSURE TRANSIENT
WITH RELIEF VALVE OPENING
- INITIAL RCS PRESSURE = 450 PSIG
- RCS VOLUME = 13,000 CU. FT.
- REFERENCE SI PUMP STARTUP
SETPOINT, PSIG
600
500
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
28
TIME, SEC.

FIGURE M22

EFFECT OF RCS VOLUME ENVELOPE ON PRESSURE OVERSHOOT

-INITIAL RCS PRESSURE = 50 PSIG
-REF. SI PUMP STARTUP
-RELIEF VALVE SETPOINT = 600 PSIG

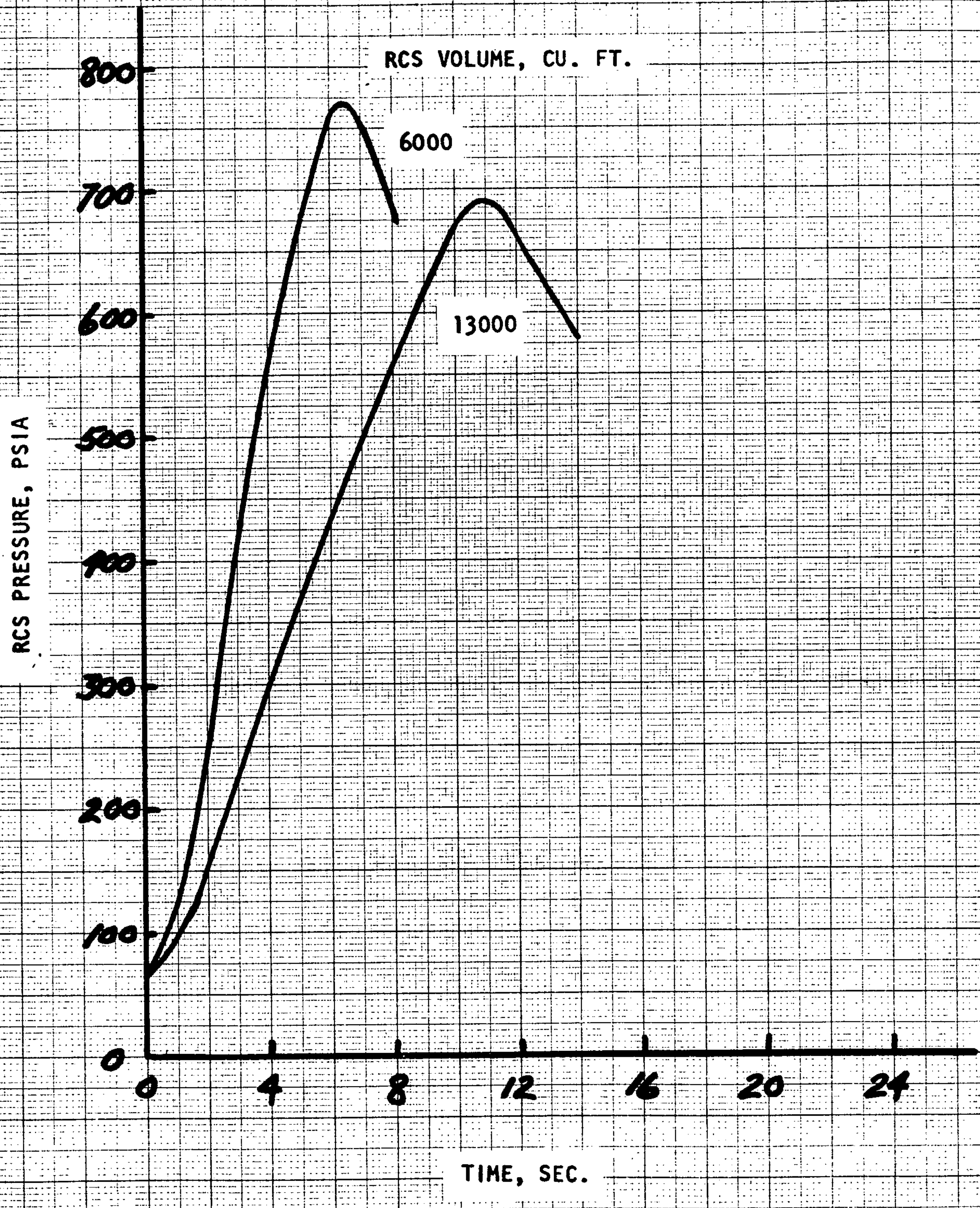
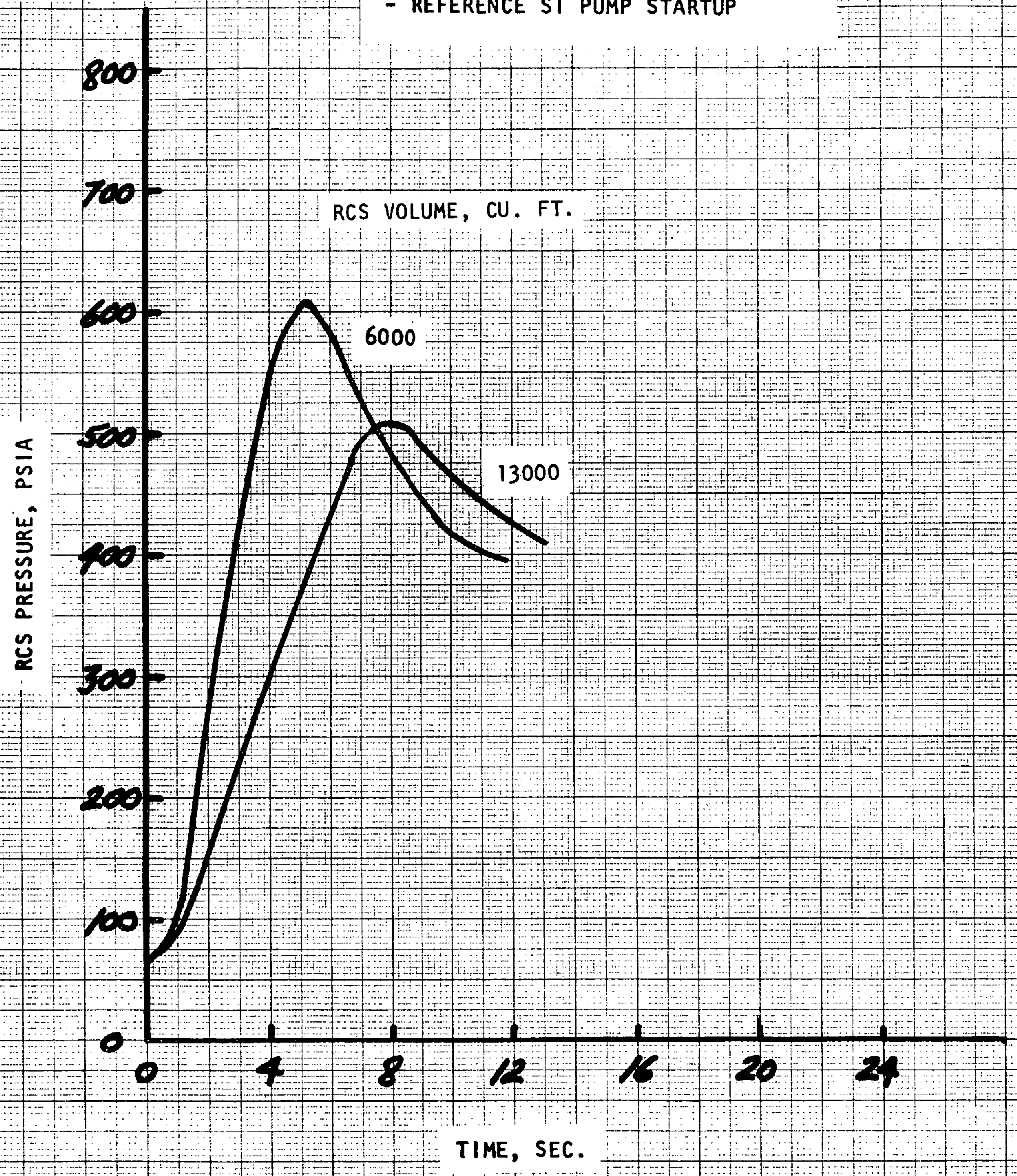


FIGURE M23

RCS PRESSURE TRANSIENT
WITH RELIEF VALVE
ACTUATION 400 PSIG

- INITIAL RCS PRESSURE = 50 PSIG
- REFERENCE SI PUMP STARTUP



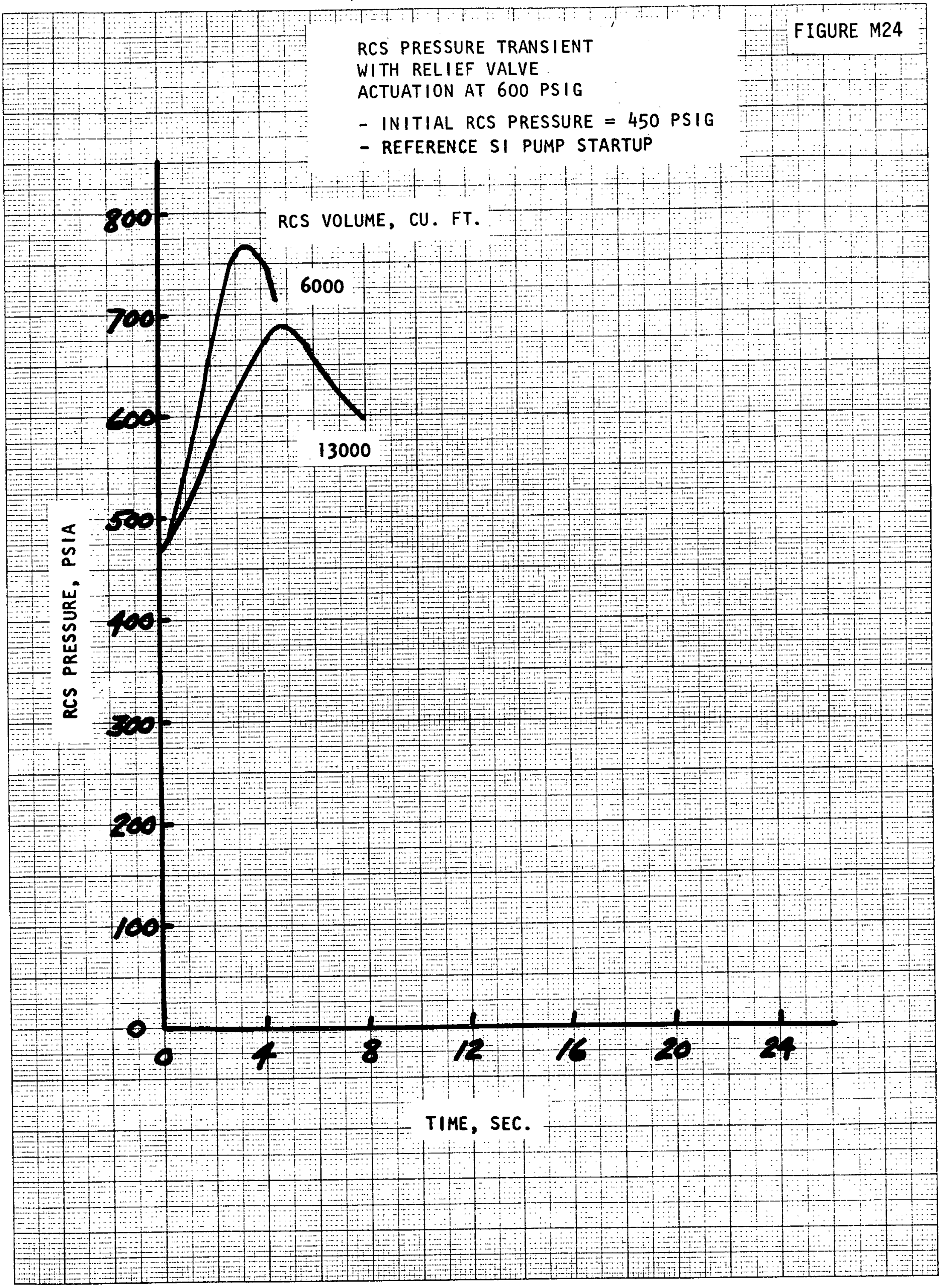


FIGURE M24
RCS PRESSURE TRANSIENT
WITH RELIEF VALVE
ACTUATION AT 600 PSIG
- INITIAL RCS PRESSURE = 450 PSIG
- REFERENCE SI PUMP STARTUP
RCS VOLUME, CU. FT.
6000
13000
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
TIME, SEC.

FIGURE M25

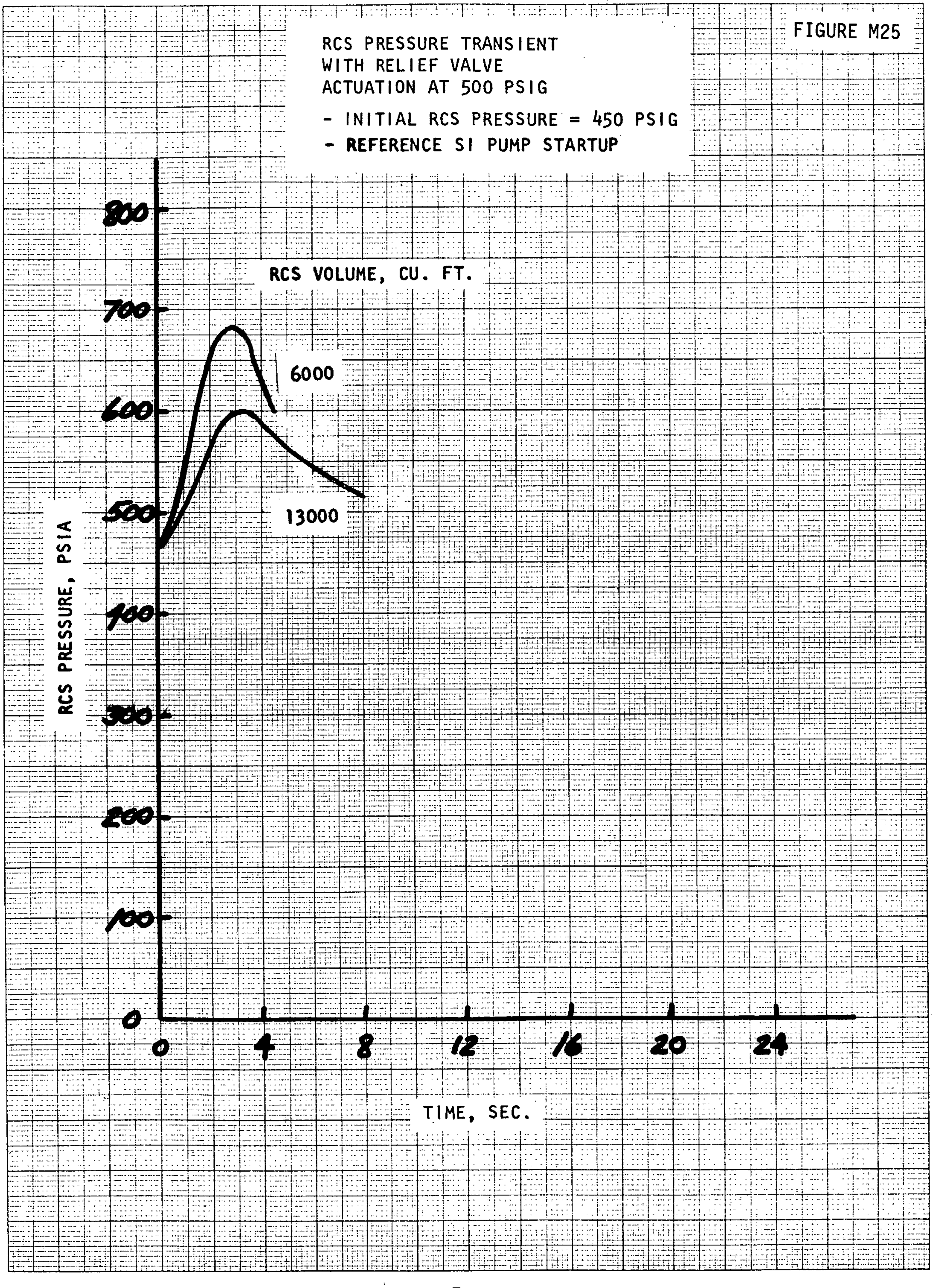


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FIGURE M26

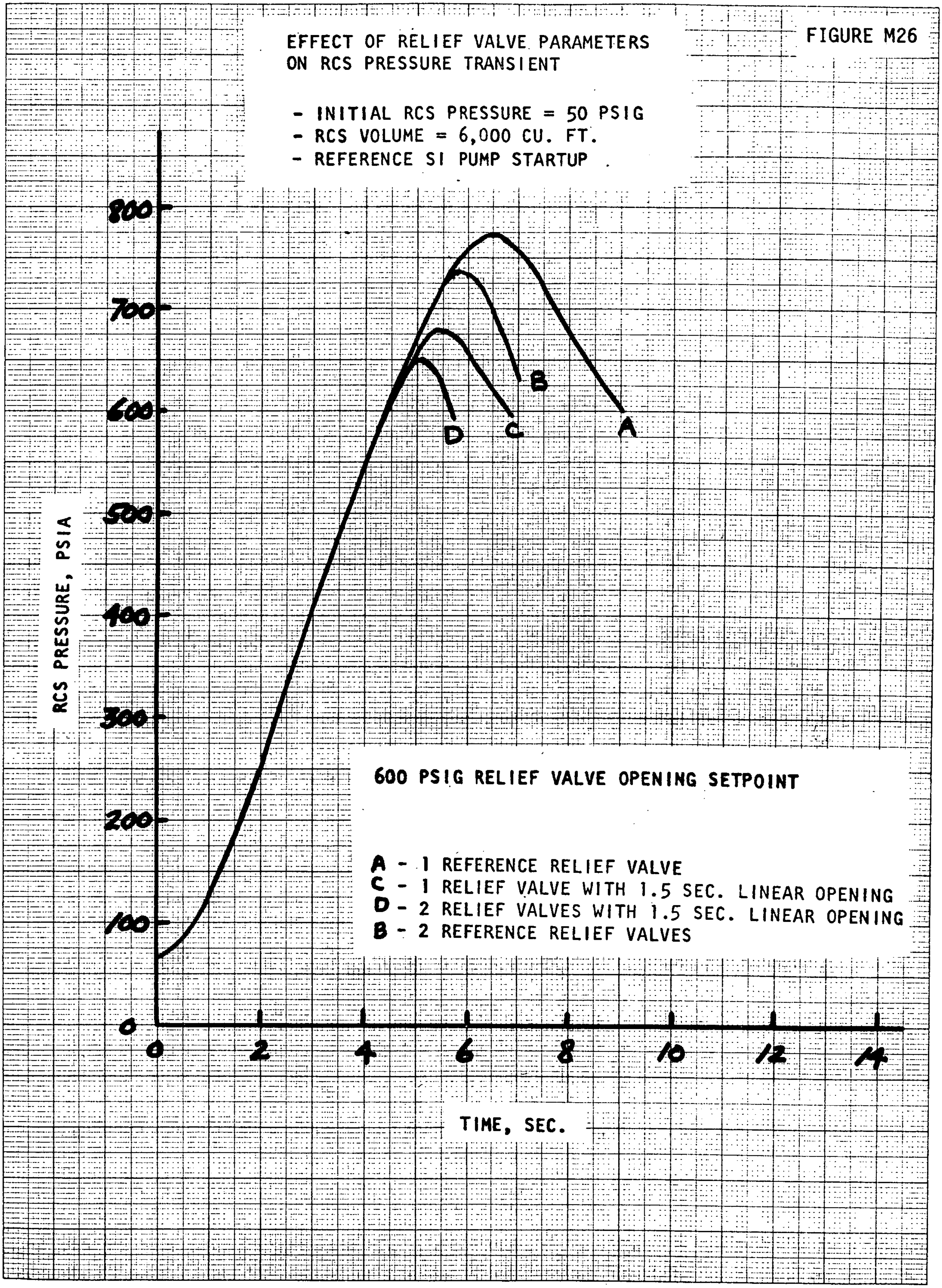

EFFECT OF RELIEF VALVE PARAMETERS ON RCS PRESSURE TRANSIENT
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 6,000 CU. FT.
- REFERENCE SI PUMP STARTUP
800
700
600
500
400
300
200
100
0
RCS PRESSURE, PSIA
A
B
C
D
600 PSIG RELIEF VALVE OPENING SETPOINT
A - 1 REFERENCE RELIEF VALVE
C - 1 RELIEF VALVE WITH 1.5 SEC. LINEAR OPENING
D - 2 RELIEF VALVES WITH 1.5 SEC. LINEAR OPENING
B - 2 REFERENCE RELIEF VALVES
0
2
4
6
8
10
12
14
TIME, SEC.

FIGURE M27

EFFECT OF RELIEF VALVE PARAMETERS
ON RCS PRESSURE TRANSIENT

- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 6,000 CU. FT.
- REFERENCE SI PUMP STARTUP

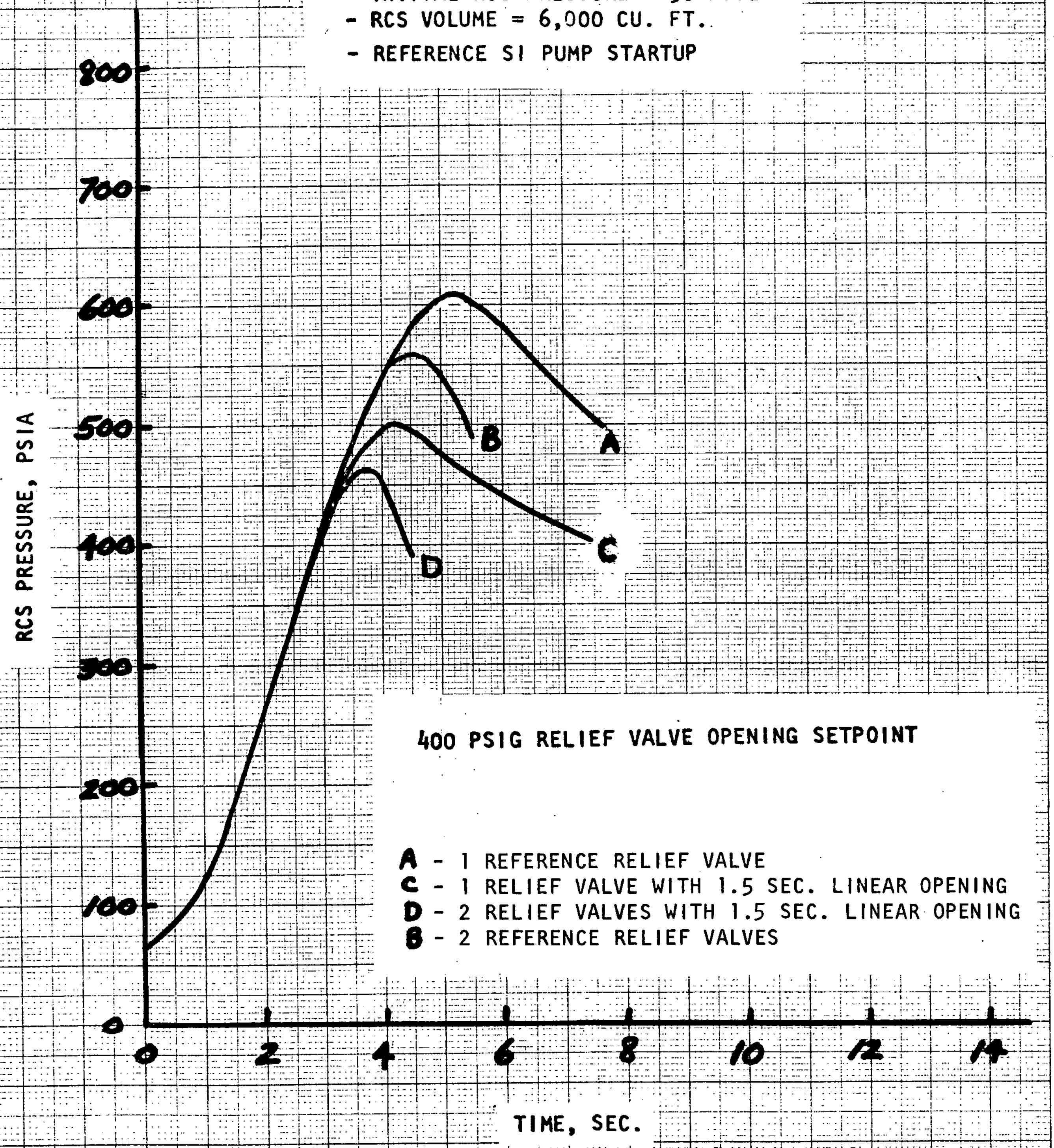
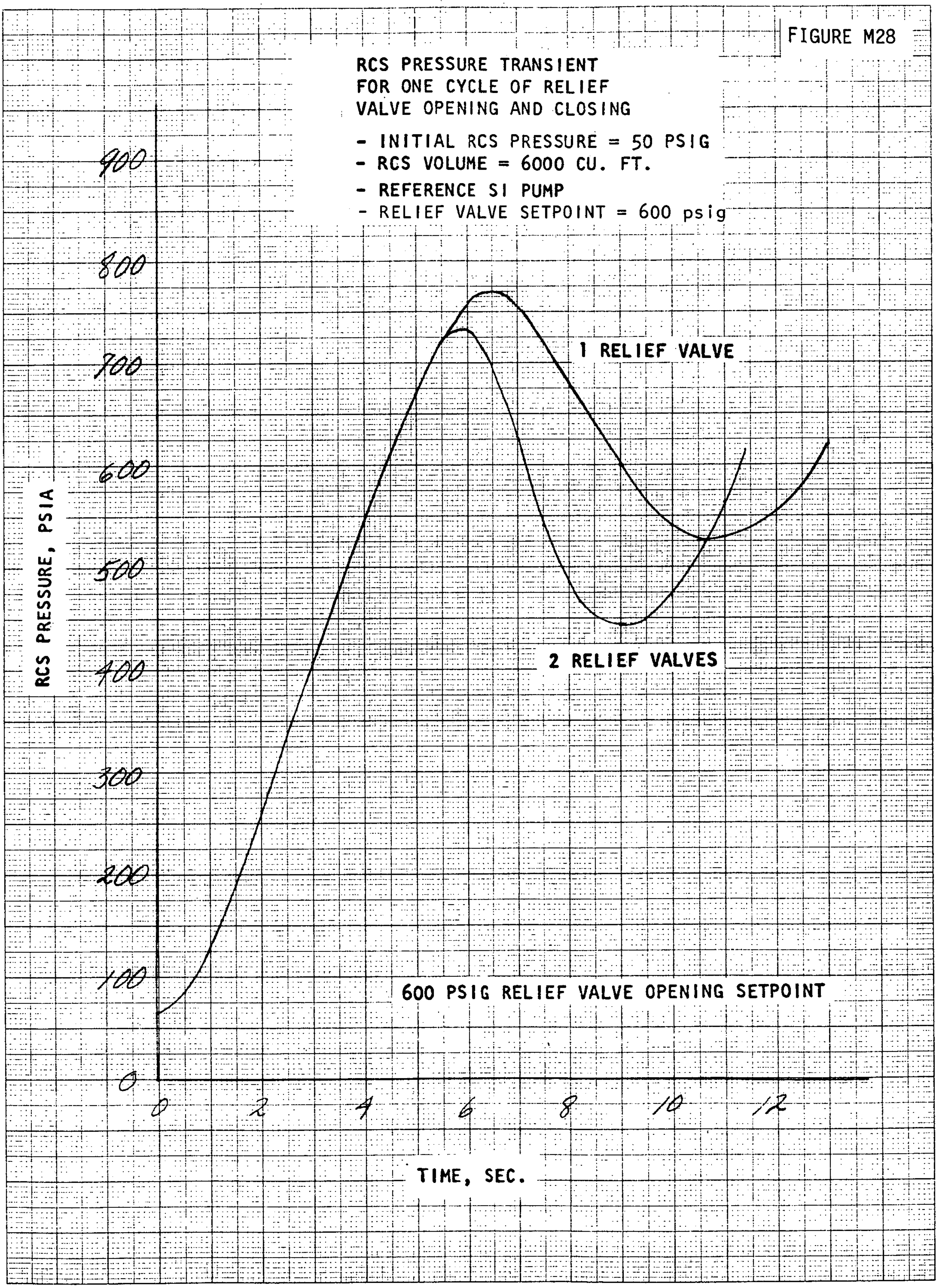


FIGURE M28


RCS PRESSURE TRANSIENT
FOR ONE CYCLE OF RELIEF
VALVE OPENING AND CLOSING
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 6000 CU. FT.
- REFERENCE SI PUMP
- RELIEF VALVE SETPOINT = 600 psig
1 RELIEF VALVE
2 RELIEF VALVES
600 PSIG RELIEF VALVE OPENING SETPOINT
RCS PRESSURE, PSIA
900
800
700
600
500
400
300
200
100
0
0
2
4
6
8
10
12
TIME, SEC.

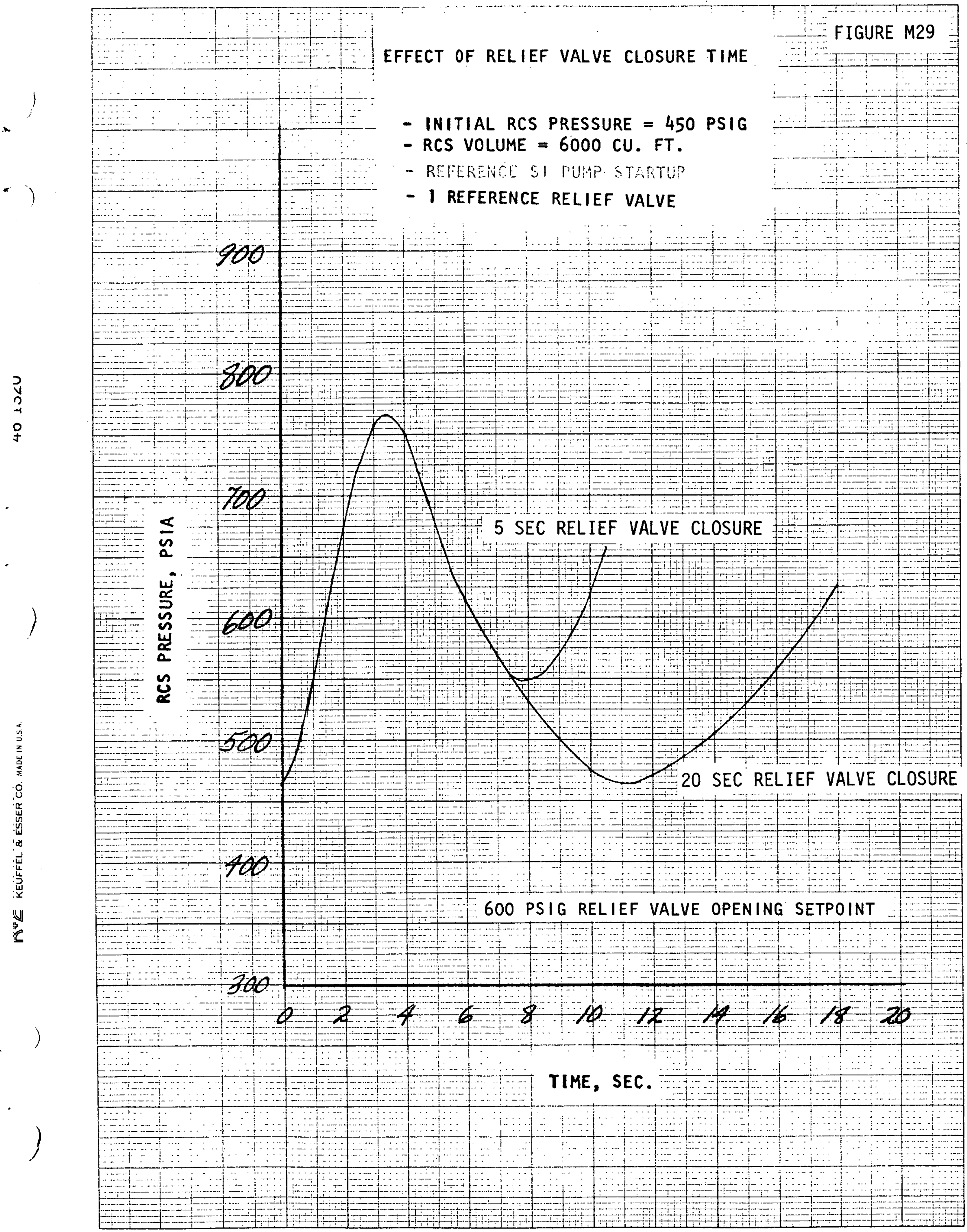


FIGURE M29
EFFECT OF RELIEF VALVE CLOSURE TIME
- INITIAL RCS PRESSURE = 450 PSIG
- RCS VOLUME = 6000 CU. FT.
- REFERENCE SI PUMP STARTUP
- 1 REFERENCE RELIEF VALVE
RCS PRESSURE, PSIA
900
800
700
600
500
400
300
5 SEC RELIEF VALVE CLOSURE
20 SEC RELIEF VALVE CLOSURE
600 PSIG RELIEF VALVE OPENING SETPOINT
0
2
4
6
8
10
12
14
16
18
20
TIME, SEC.
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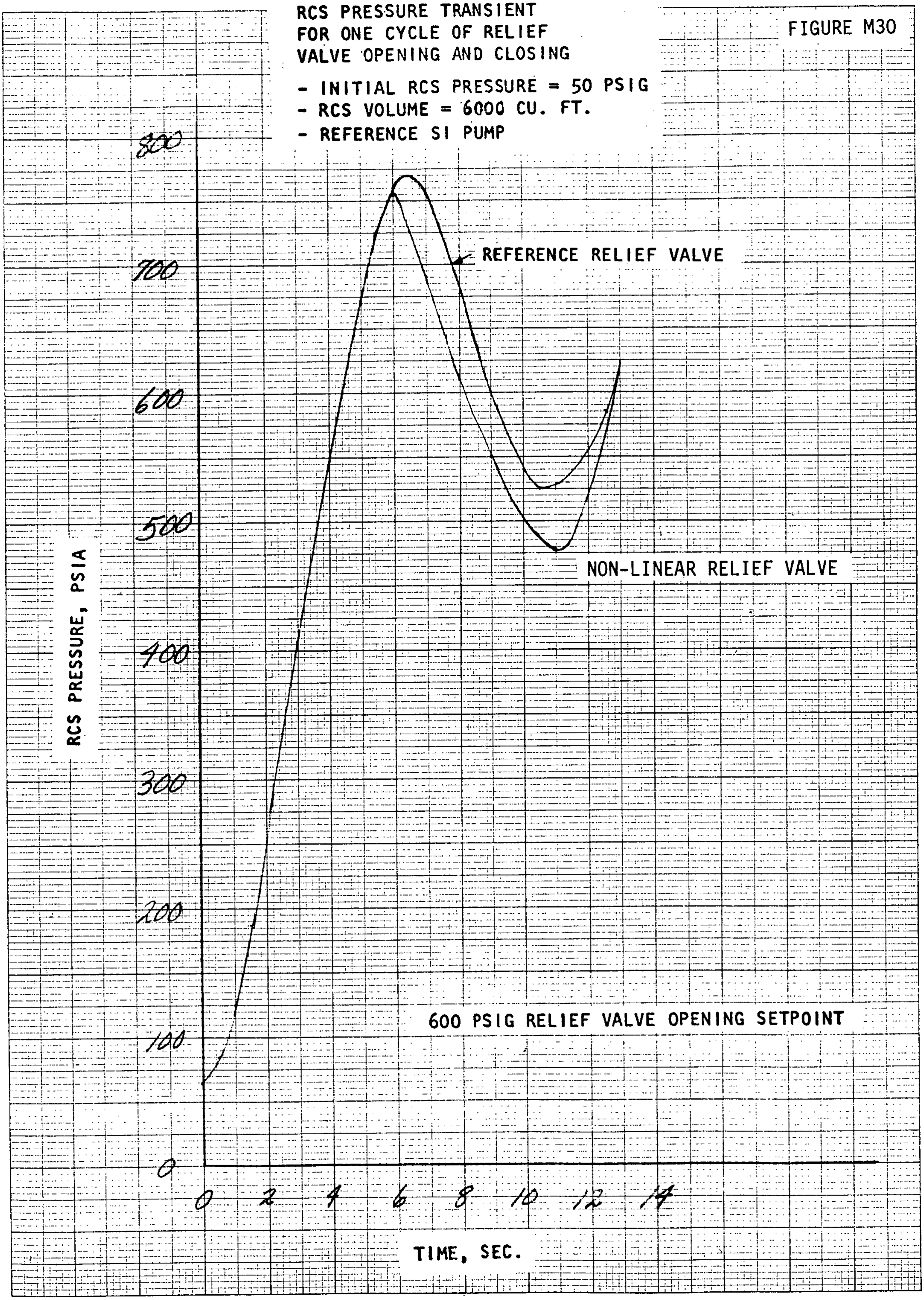
46 1320



RCS PRESSURE TRANSIENT
FOR ONE CYCLE OF RELIEF
VALVE OPENING AND CLOSING
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 6000 CU. FT.
- REFERENCE SI PUMP
FIGURE M30
REFERENCE RELIEF VALVE
NON-LINEAR RELIEF VALVE
600 PSIG RELIEF VALVE OPENING SETPOINT
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
2
4
6
8
10
12
14
TIME, SEC.

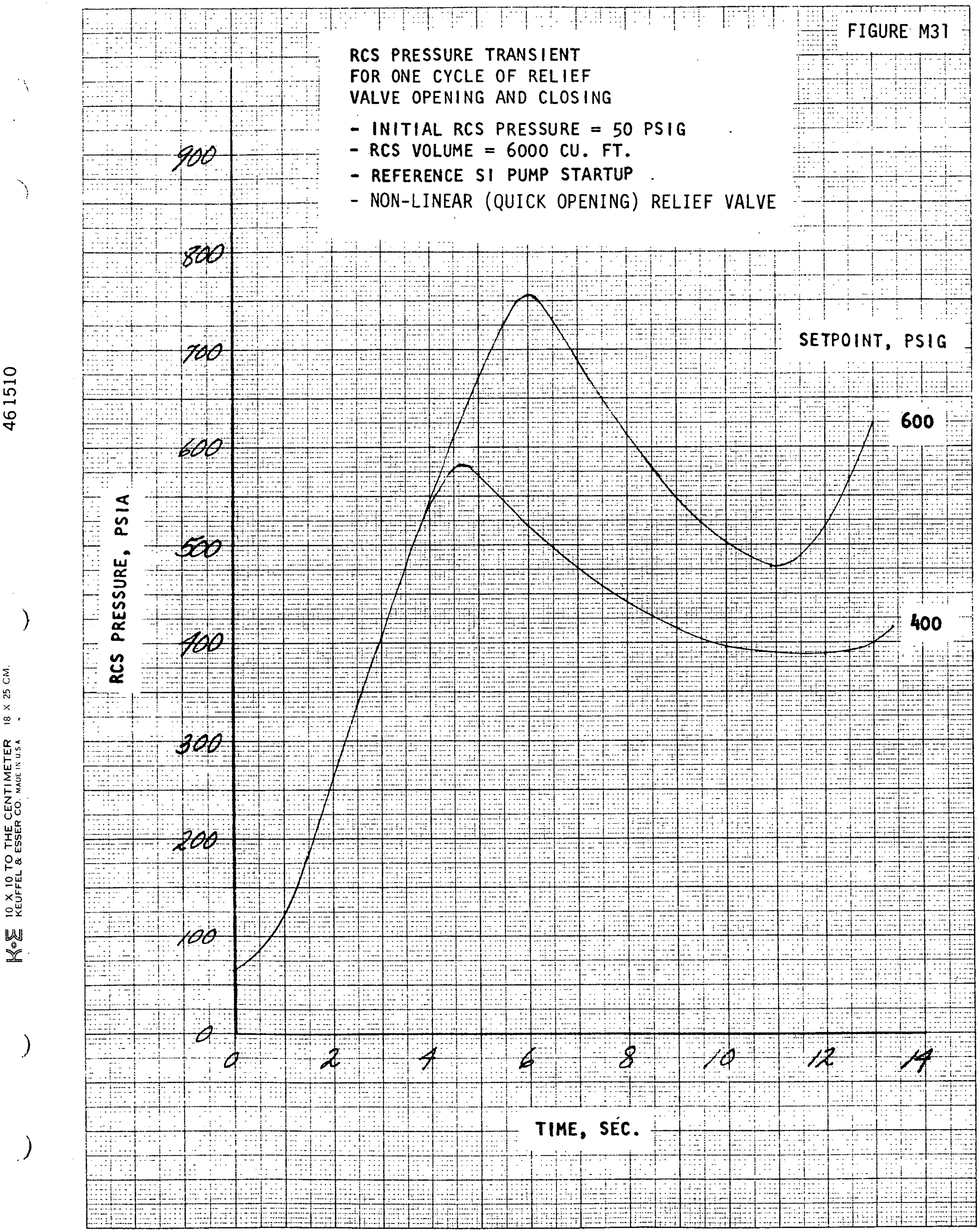


FIGURE M31
RCS PRESSURE TRANSIENT
FOR ONE CYCLE OF RELIEF
VALVE OPENING AND CLOSING
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 6000 CU. FT.
- REFERENCE SI PUMP STARTUP
- NON-LINEAR (QUICK OPENING) RELIEF VALVE
SETPOINT, PSIG
600
400
RCS PRESSURE, PSIA
900
800
700
600
500
400
300
200
100
0
0
2
4
6
8
10
12
14
TIME, SEC.
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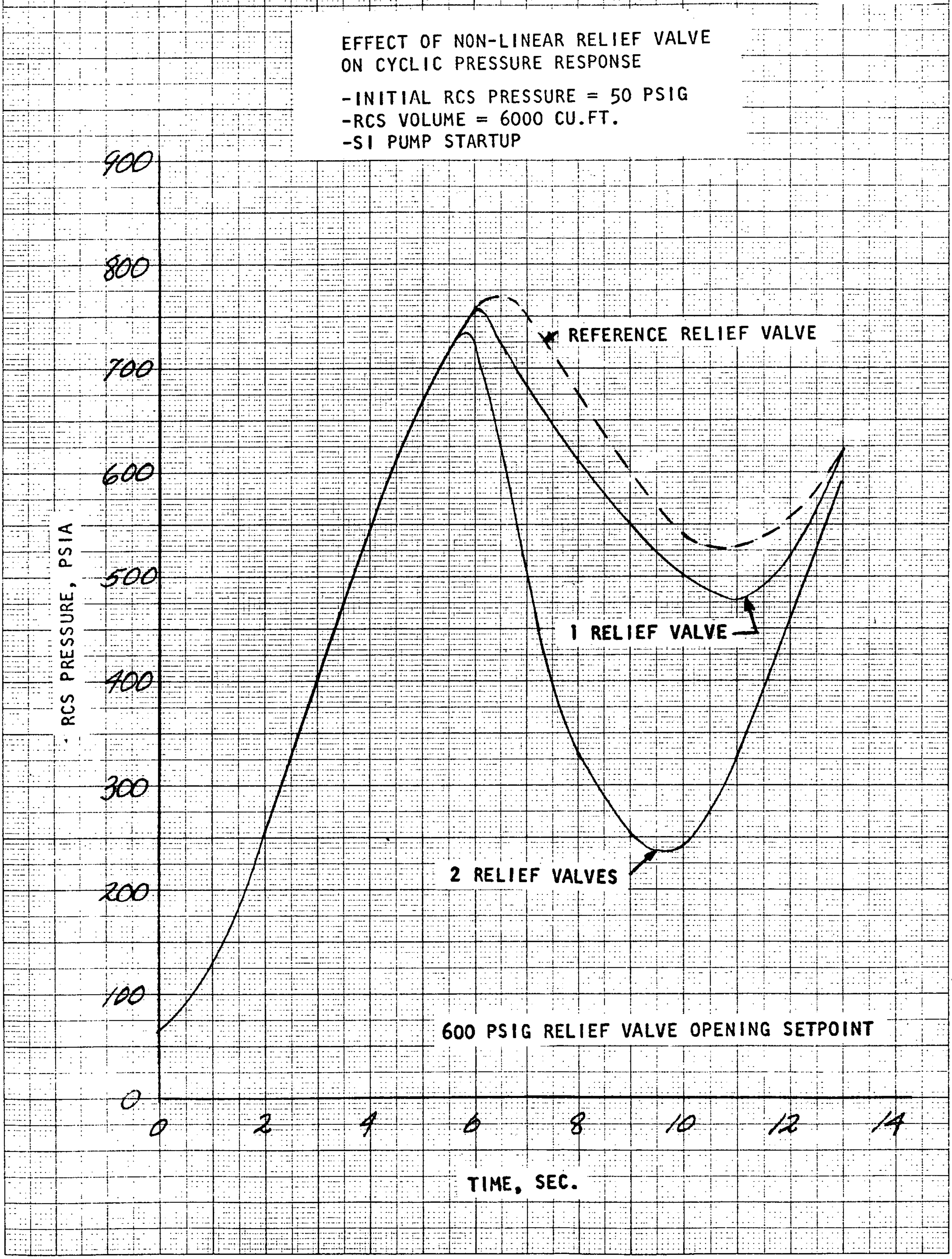
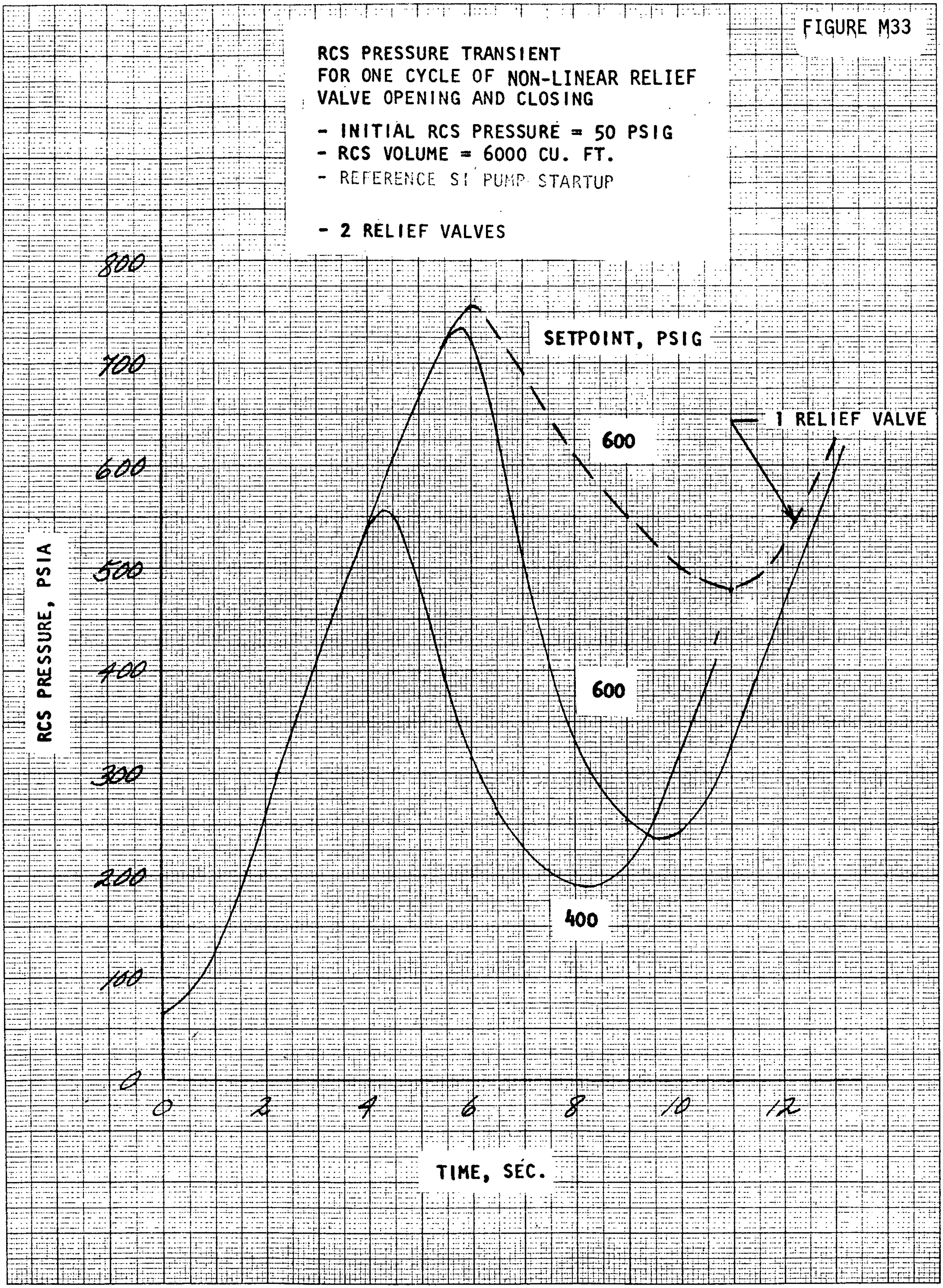

EFFECT OF NON-LINEAR RELIEF VALVE
ON CYCLIC PRESSURE RESPONSE
-INITIAL RCS PRESSURE = 50 PSIG
-RCS VOLUME = 6000 CU.FT.
-SI PUMP STARTUP
REFERENCE RELIEF VALVE
1 RELIEF VALVE
2 RELIEF VALVES
600 PSIG RELIEF VALVE OPENING SETPOINT
RCS PRESSURE, PSIA
TIME, SEC.
0
100
200
300
400
500
600
700
800
900
0
2
4
6
8
10
12
14

FIGURE M33


RCS PRESSURE TRANSIENT
FOR ONE CYCLE OF NON-LINEAR RELIEF
VALVE OPENING AND CLOSING
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 6000 CU. FT.
- REFERENCE SI PUMP STARTUP
- 2 RELIEF VALVES
SETPOINT, PSIG
600
1 RELIEF VALVE
600
400
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
2
4
6
8
10
12
TIME, SEC.

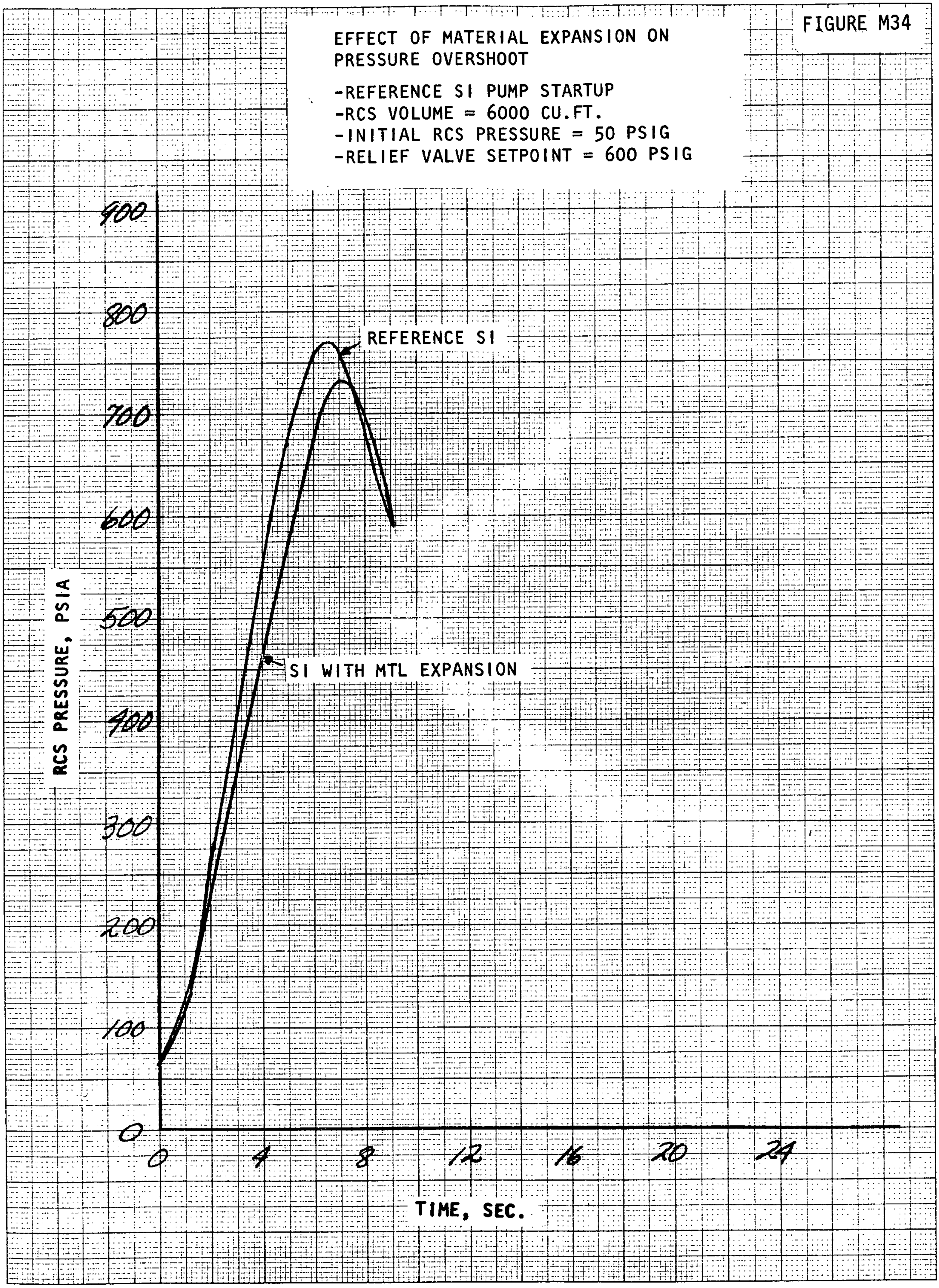
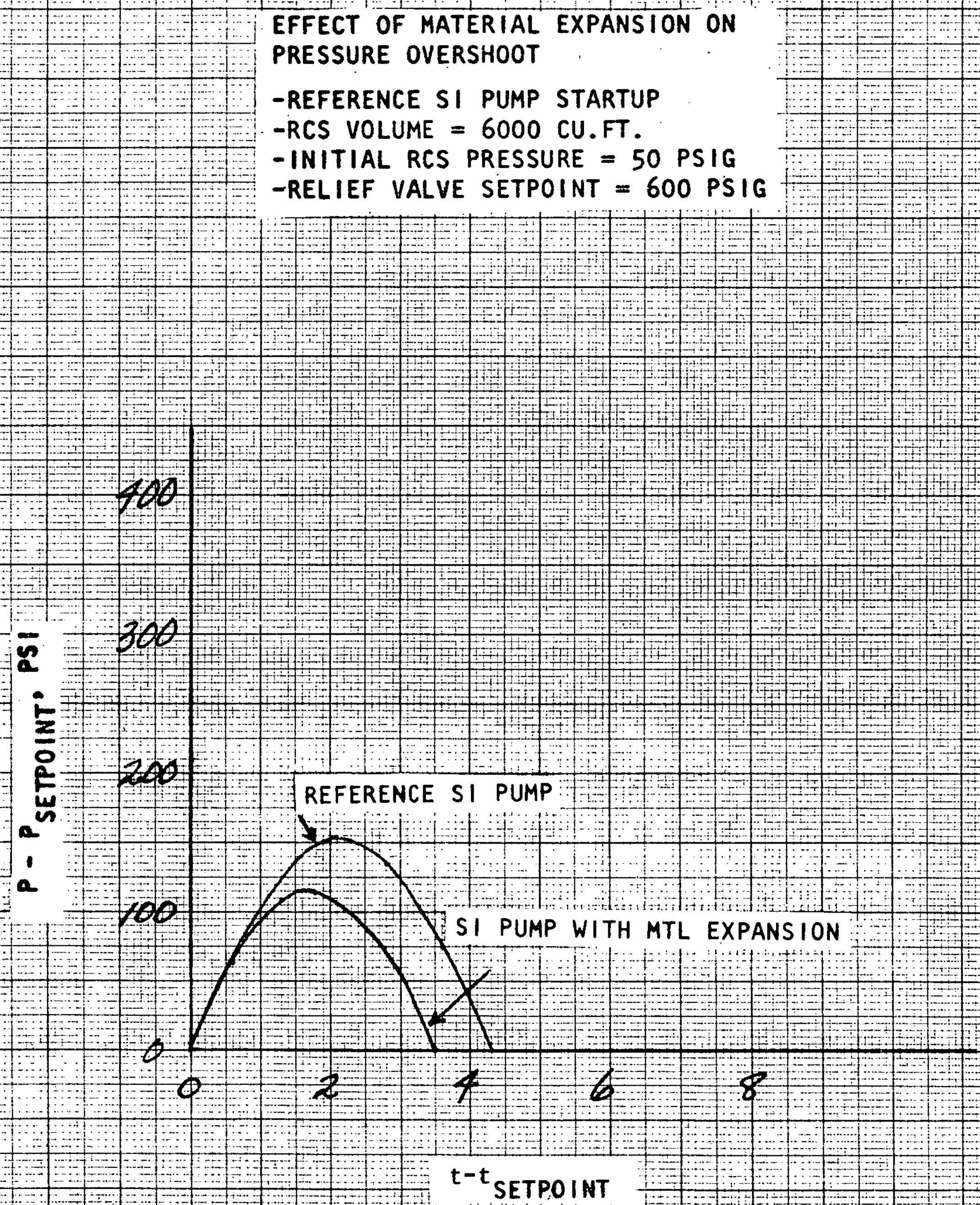
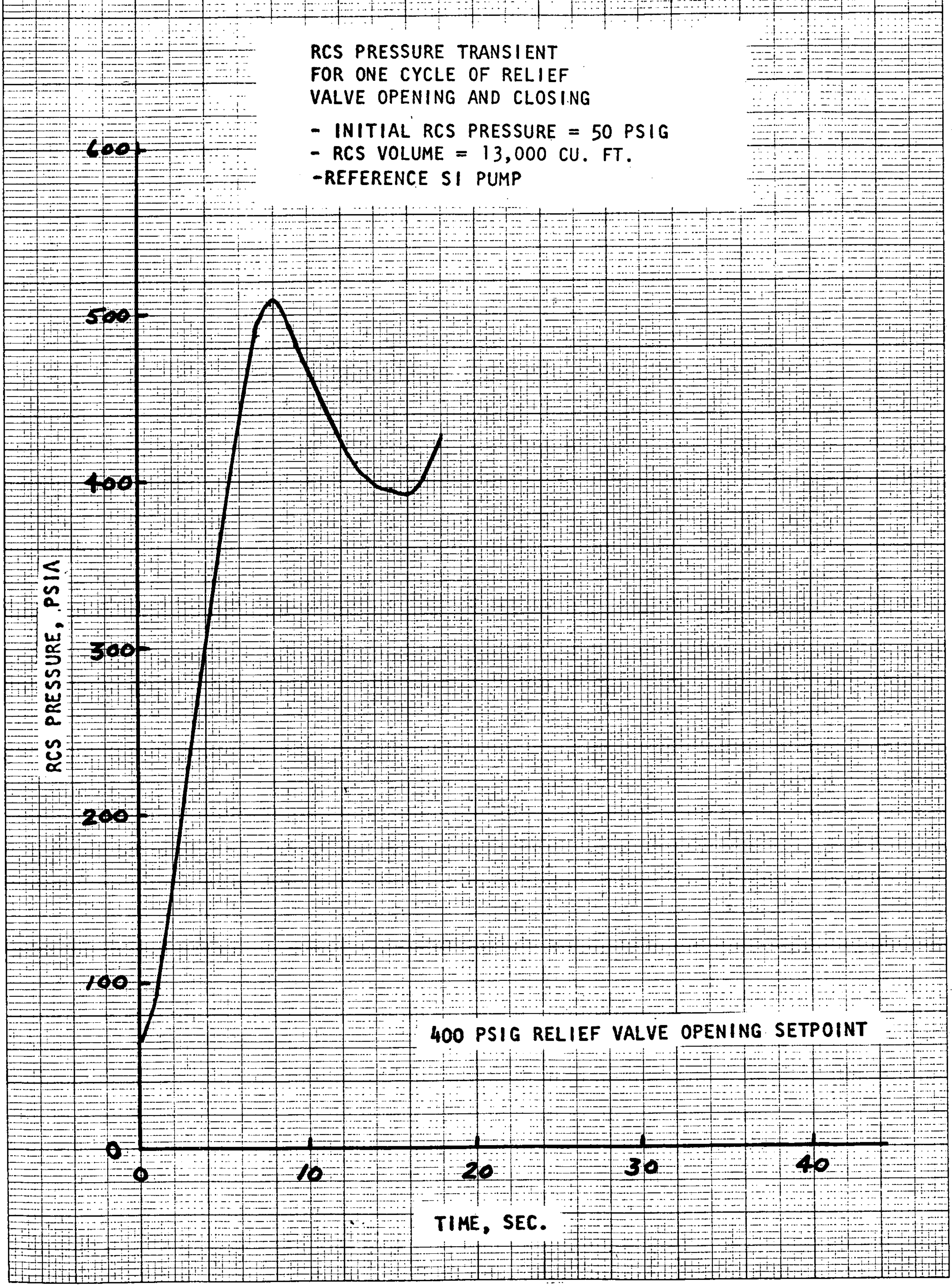


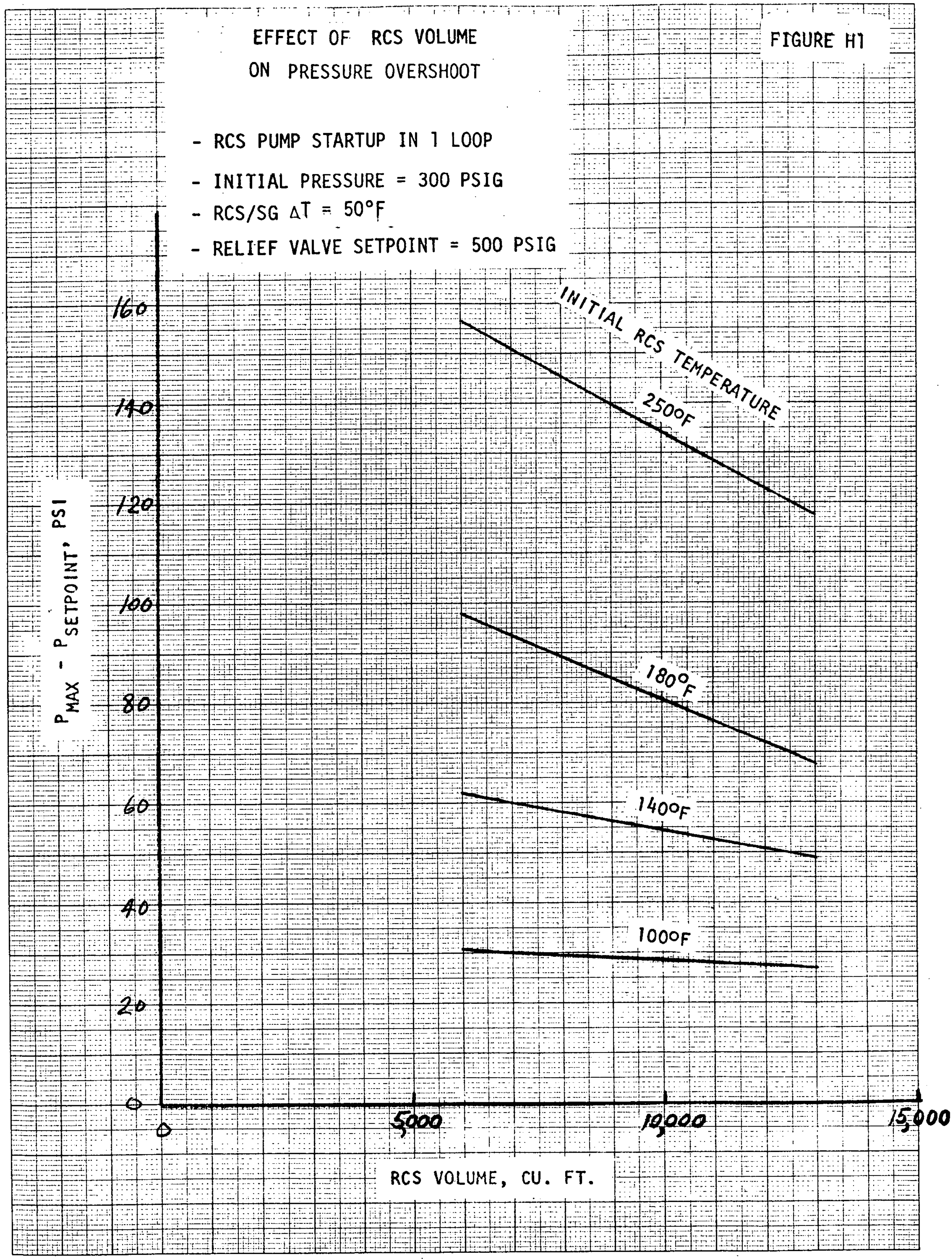
FIGURE M34
EFFECT OF MATERIAL EXPANSION ON PRESSURE OVERSHOOT
-REFERENCE SI PUMP STARTUP
-RCS VOLUME = 6000 CU.FT.
-INITIAL RCS PRESSURE = 50 PSIG
-RELIEF VALVE SETPOINT = 600 PSIG
REFERENCE SI
SI WITH MTL EXPANSION
RCS PRESSURE, PSIA
TIME, SEC.
900
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24

FIGURE M35


EFFECT OF MATERIAL EXPANSION ON
PRESSURE OVERSHOOT
-REFERENCE SI PUMP STARTUP
-RCS VOLUME = 6000 CU.FT.
-INITIAL RCS PRESSURE = 50 PSIG
-RELIEF VALVE SETPOINT = 600 PSIG
400
300
200
100
0
P - P SETPOINT, PSI
REFERENCE SI PUMP
SI PUMP WITH MTL EXPANSION
0
2
4
6
8
t-t SETPOINT


RCS PRESSURE TRANSIENT
FOR ONE CYCLE OF RELIEF
VALVE OPENING AND CLOSING
- INITIAL RCS PRESSURE = 50 PSIG
- RCS VOLUME = 13,000 CU. FT.
-REFERENCE SI PUMP
600
500
400
300
200
100
0
RCS PRESSURE, PSIA
400 PSIG RELIEF VALVE OPENING SETPOINT
0
10
20
30
40
TIME, SEC.

HEAT INPUT


EFFECT OF RCS VOLUME
ON PRESSURE OVERSHOOT
FIGURE H1
- RCS PUMP STARTUP IN 1 LOOP
- INITIAL PRESSURE = 300 PSIG
- RCS/SG ΔT = 50°F
- RELIEF VALVE SETPOINT = 500 PSIG
INITIAL RCS TEMPERATURE
250°F
180°F
140°F
100°F
160
140
120
100
80
60
40
20
0
0
5000
10,000
15,000
P_MAX - P_SETPOINT, PSI
RCS VOLUME, CU. FT.

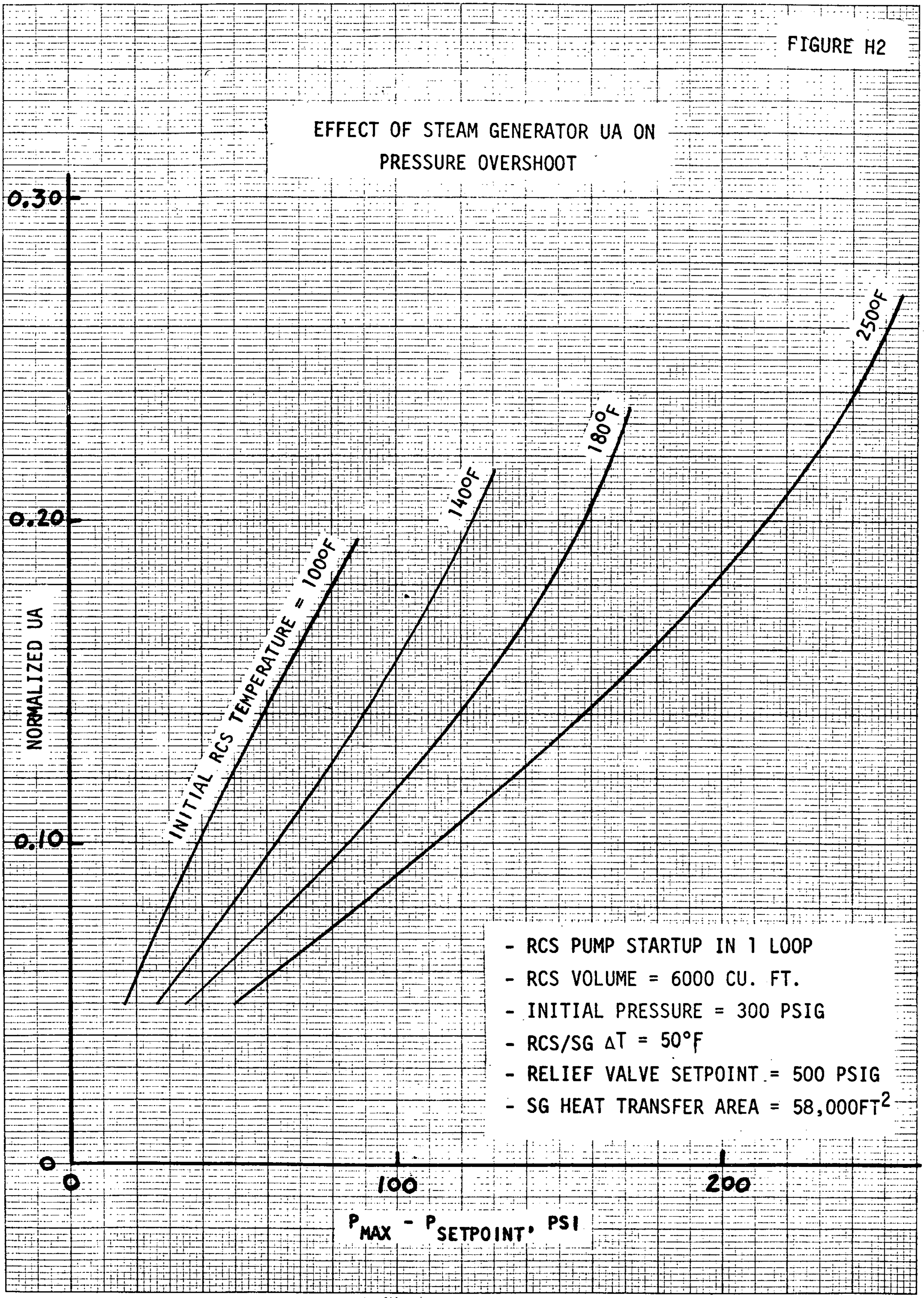


FIGURE H2
EFFECT OF STEAM GENERATOR UA ON
PRESSURE OVERSHOOT
0.30
0.20
0.10
0
NORMALIZED UA
INITIAL RCS TEMPERATURE = 100°F
140°F
180°F
250°F
- RCS PUMP STARTUP IN 1 LOOP
- RCS VOLUME = 6000 CU. FT.
- INITIAL PRESSURE = 300 PSIG
- RCS/SG ΔT = 50°F
- RELIEF VALVE SETPOINT = 500 PSIG
- SG HEAT TRANSFER AREA = 58,000FT2
0
100
200
PMAX - PSETPOINT, PSI

FIGURE H3

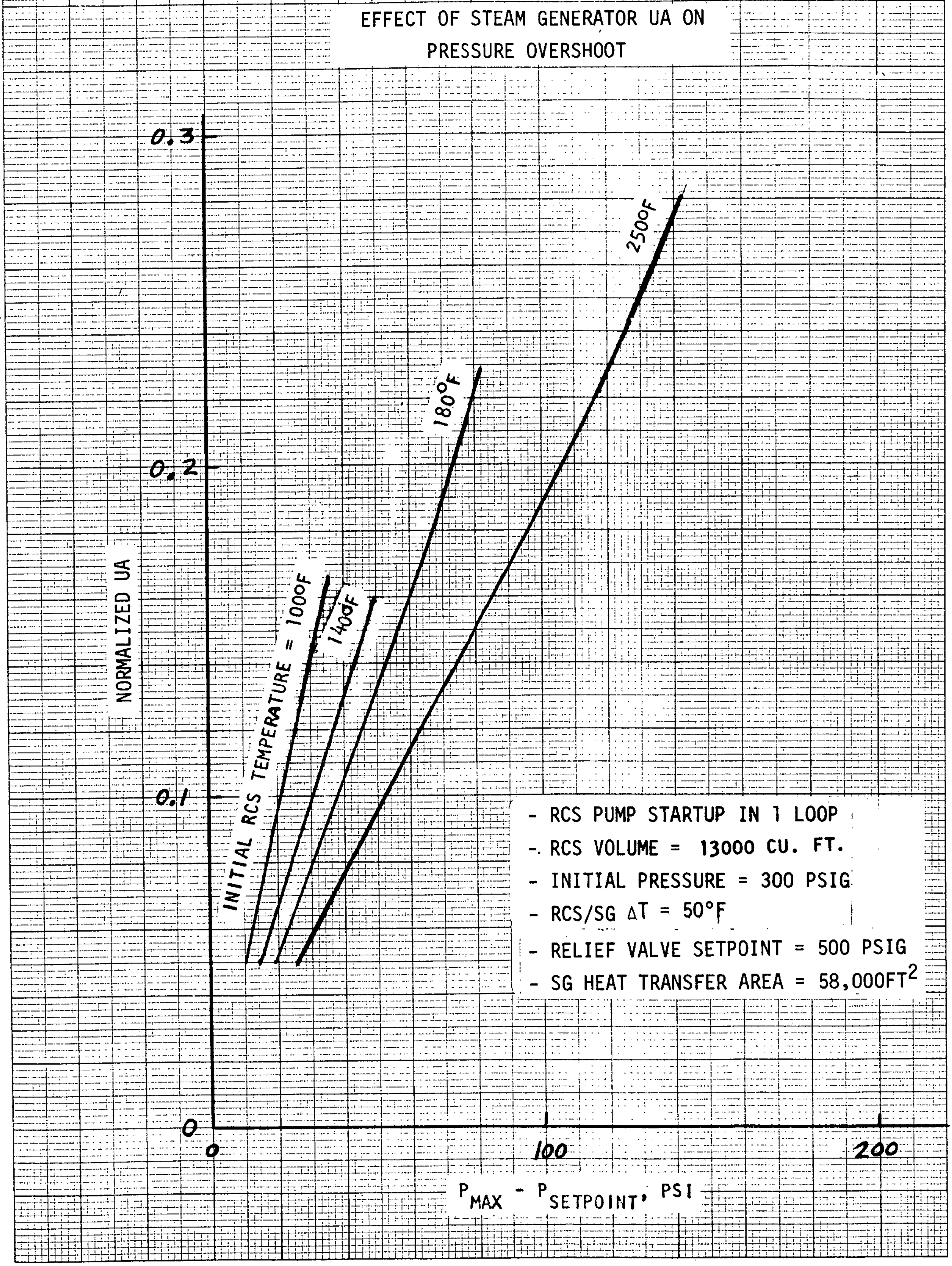
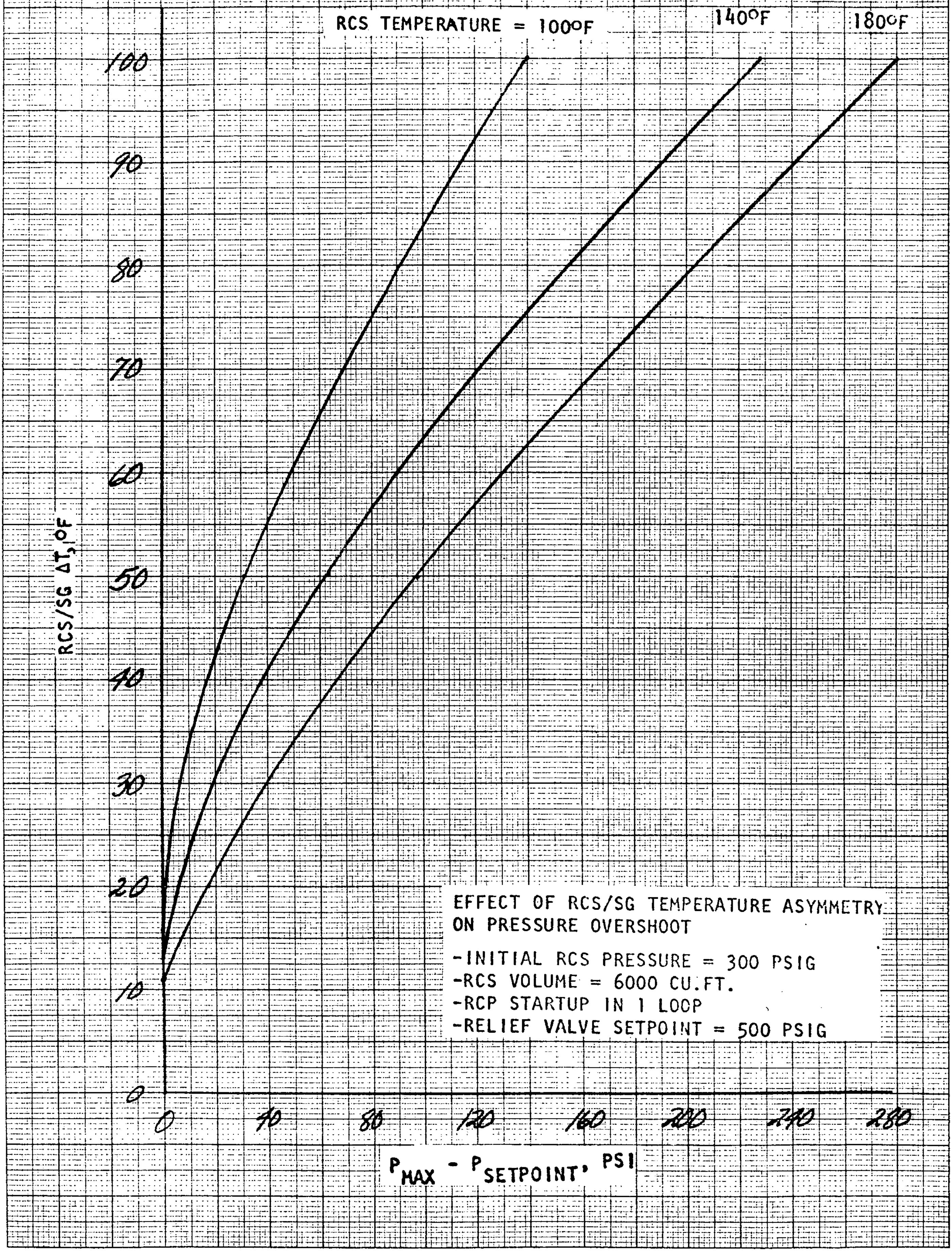

EFFECT OF STEAM GENERATOR UA ON
PRESSURE OVERSHOOT
NORMALIZED UA
0.3
0.2
0.1
0
0
100
200
$P_{MAX} - P_{SETPOINT}$, PSI
INITIAL RCS TEMPERATURE = 100°F
140°F
180°F
250°F
- RCS PUMP STARTUP IN 1 LOOP
- RCS VOLUME = 13000 CU. FT.
- INITIAL PRESSURE = 300 PSIG
- RCS/SG ΔT = 50°F
- RELIEF VALVE SETPOINT = 500 PSIG
- SG HEAT TRANSFER AREA = 58,000FT²

FIGURE H4


RCS TEMPERATURE = 100°F
140°F
180°F
100
90
80
70
60
50
40
30
20
10
0
RCS/SG ΔT, °F
0
40
80
120
160
200
240
280
P MAX - P SETPOINT, PSI
EFFECT OF RCS/SG TEMPERATURE ASYMMETRY ON PRESSURE OVERSHOOT
-INITIAL RCS PRESSURE = 300 PSIG
-RCS VOLUME = 6000 CU.FT.
-RCP STARTUP IN 1 LOOP
-RELIEF VALVE SETPOINT = 500 PSIG

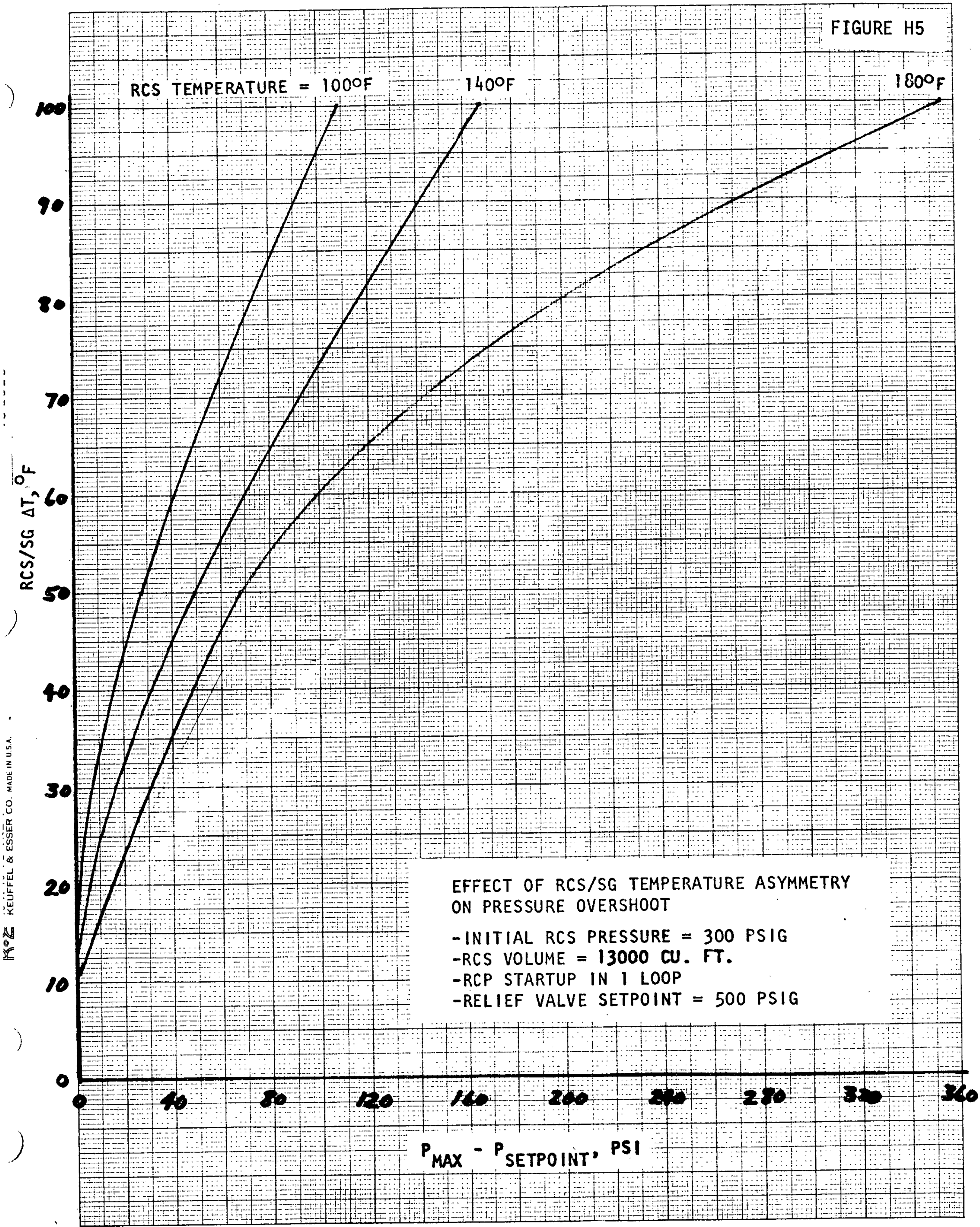


FIGURE H5
RCS TEMPERATURE = 100°F
140°F
180°F
RCS/SG ΔT, °F
100
90
80
70
60
50
40
30
20
10
0
0
40
80
120
160
200
240
280
320
360
$P_{MAX} - P_{SETPOINT}$, PSI
EFFECT OF RCS/SG TEMPERATURE ASYMMETRY
ON PRESSURE OVERSHOOT
-INITIAL RCS PRESSURE = 300 PSIG
-RCS VOLUME = 13000 CU. FT.
-RCP STARTUP IN 1 LOOP
-RELIEF VALVE SETPOINT = 500 PSIG
KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE H6

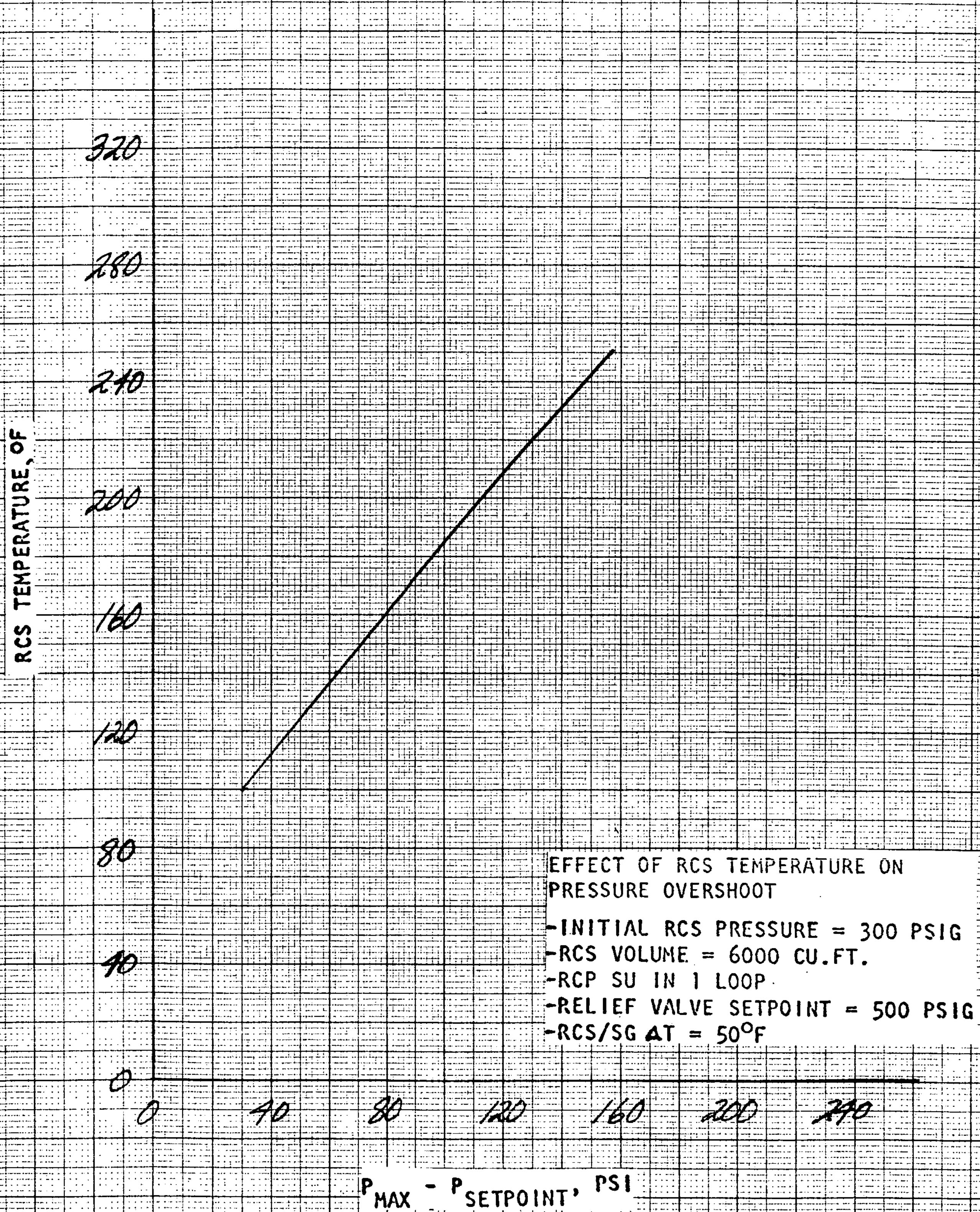
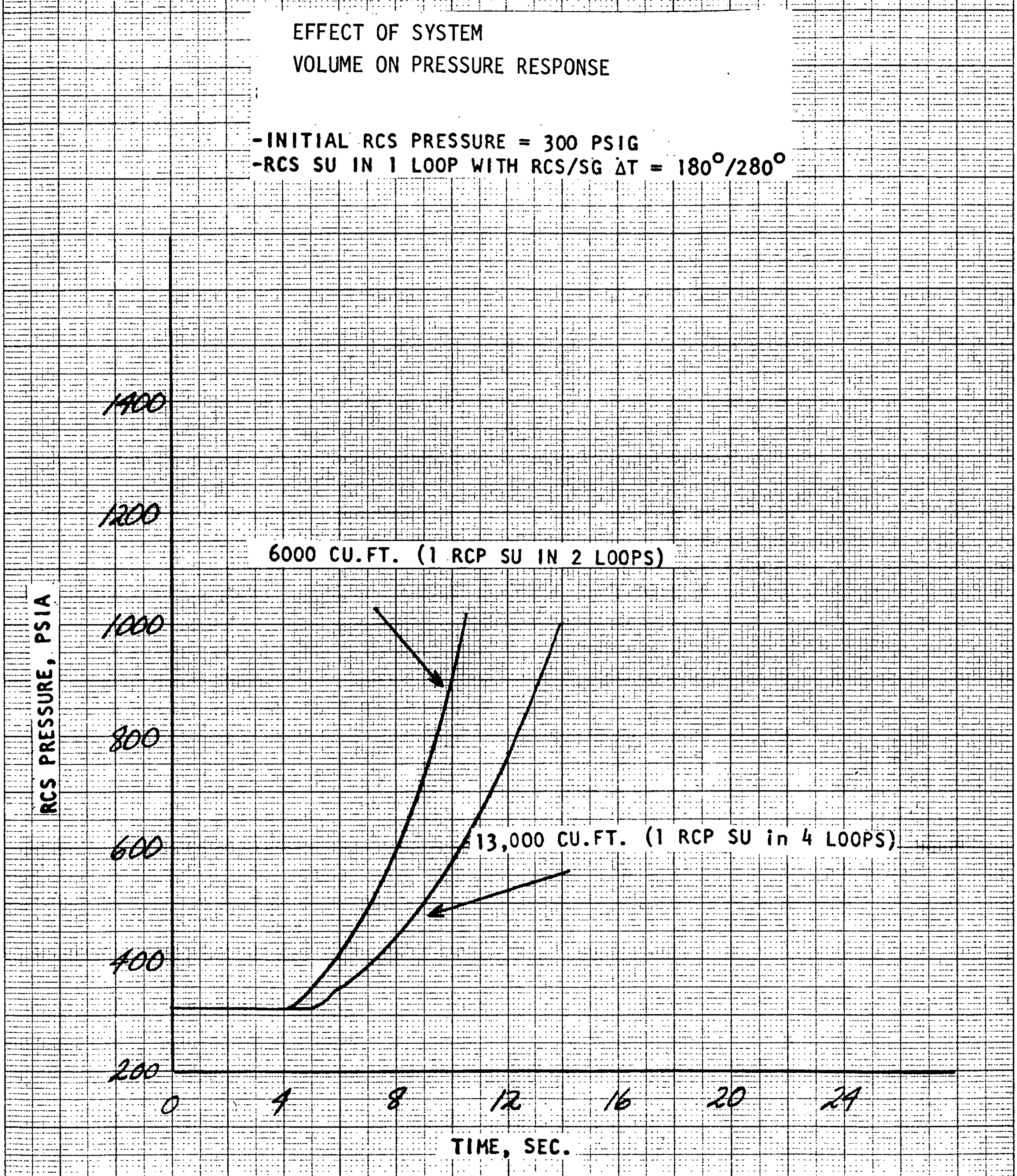
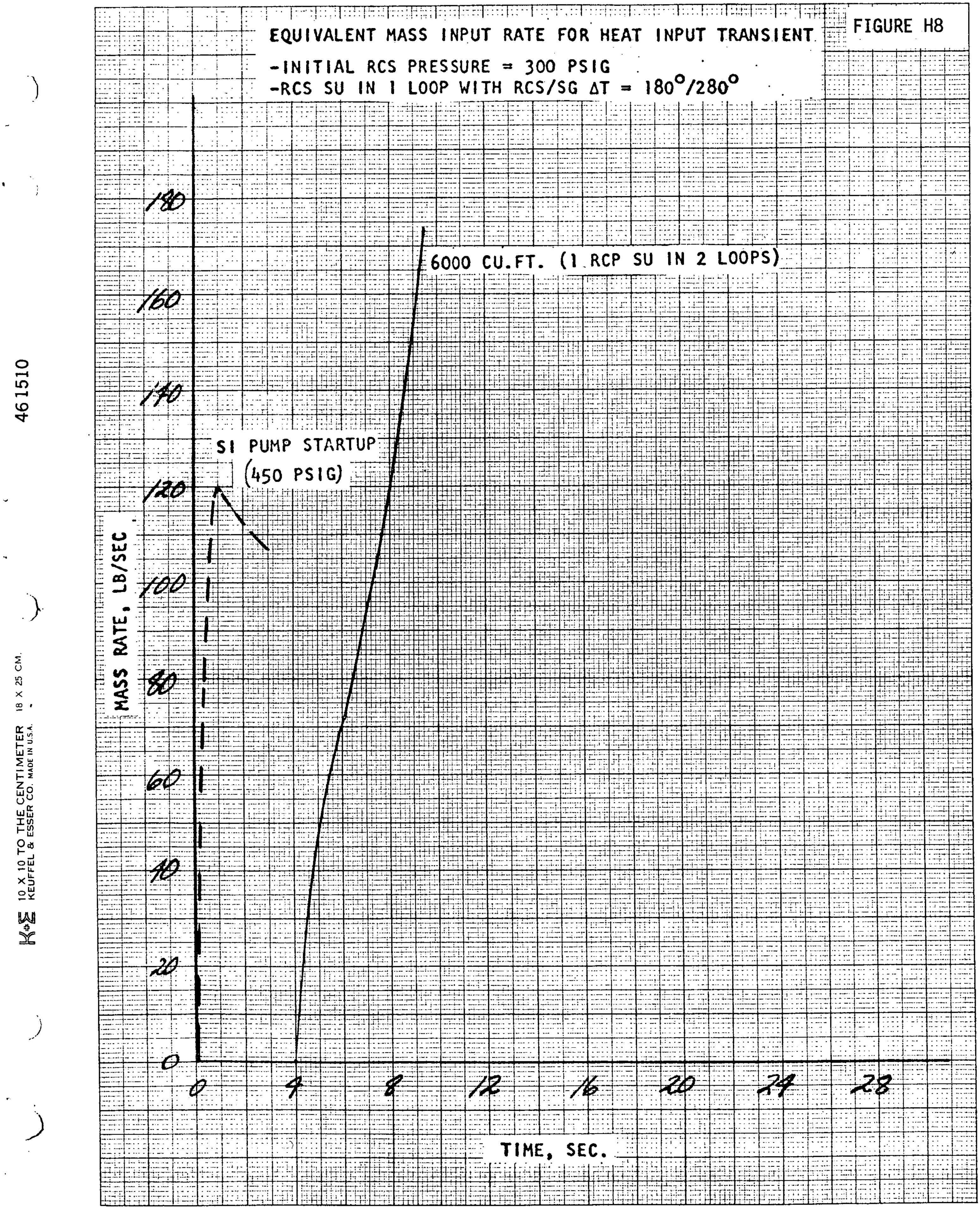

RCS TEMPERATURE, °F
320
280
240
200
160
120
80
40
0
0
40
80
120
160
200
240
P MAX - P SETPOINT, PSI
EFFECT OF RCS TEMPERATURE ON PRESSURE OVERSHOOT
-INITIAL RCS PRESSURE = 300 PSIG
-RCS VOLUME = 6000 CU.FT.
-RCP SU IN 1 LOOP
-RELIEF VALVE SETPOINT = 500 PSIG
-RCS/SG ΔT = 50°F

FIGURE H7



EFFECT OF SYSTEM
VOLUME ON PRESSURE RESPONSE
-INITIAL RCS PRESSURE = 300 PSIG
-RCS SU IN 1 LOOP WITH RCS/SG ΔT = 180°/280°
6000 CU.FT. (1 RCP SU IN 2 LOOPS)
13,000 CU.FT. (1 RCP SU in 4 LOOPS)
RCS PRESSURE, PSIA
1400
1200
1000
800
600
400
200
0
4
8
12
16
20
24
TIME, SEC.

FIGURE H8



EQUIVALENT MASS INPUT RATE FOR HEAT INPUT TRANSIENT
-INITIAL RCS PRESSURE = 300 PSIG
-RCS SU IN 1 LOOP WITH RCS/SG ΔT = 180°/280°
6000 CU.FT. (1 RCP SU IN 2 LOOPS)
SI PUMP STARTUP
(450 PSIG)
MASS RATE, LB/SEC
180
160
140
120
100
80
60
40
20
0
0
4
8
12
16
20
24
28
TIME, SEC.
10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.
461510

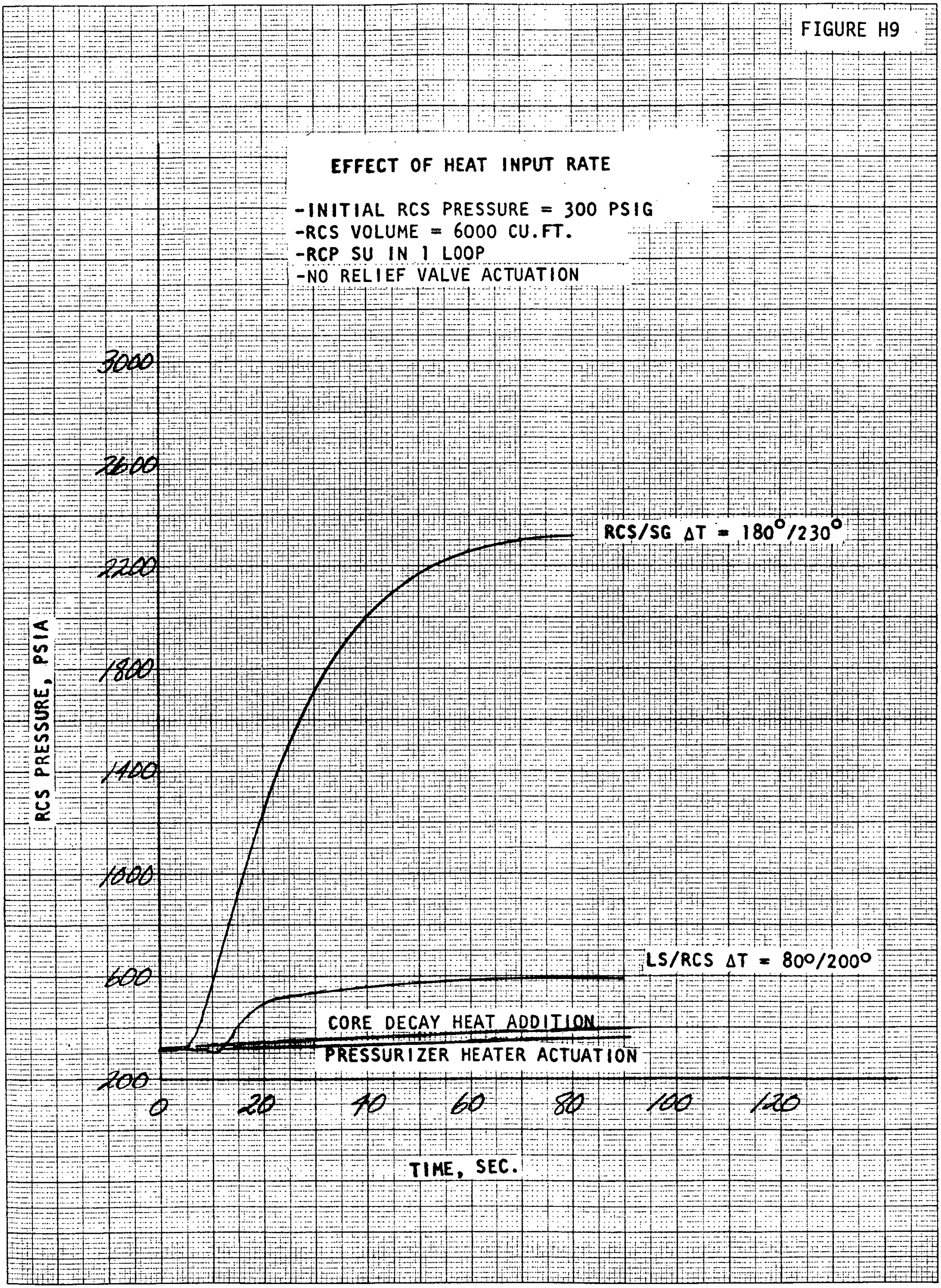
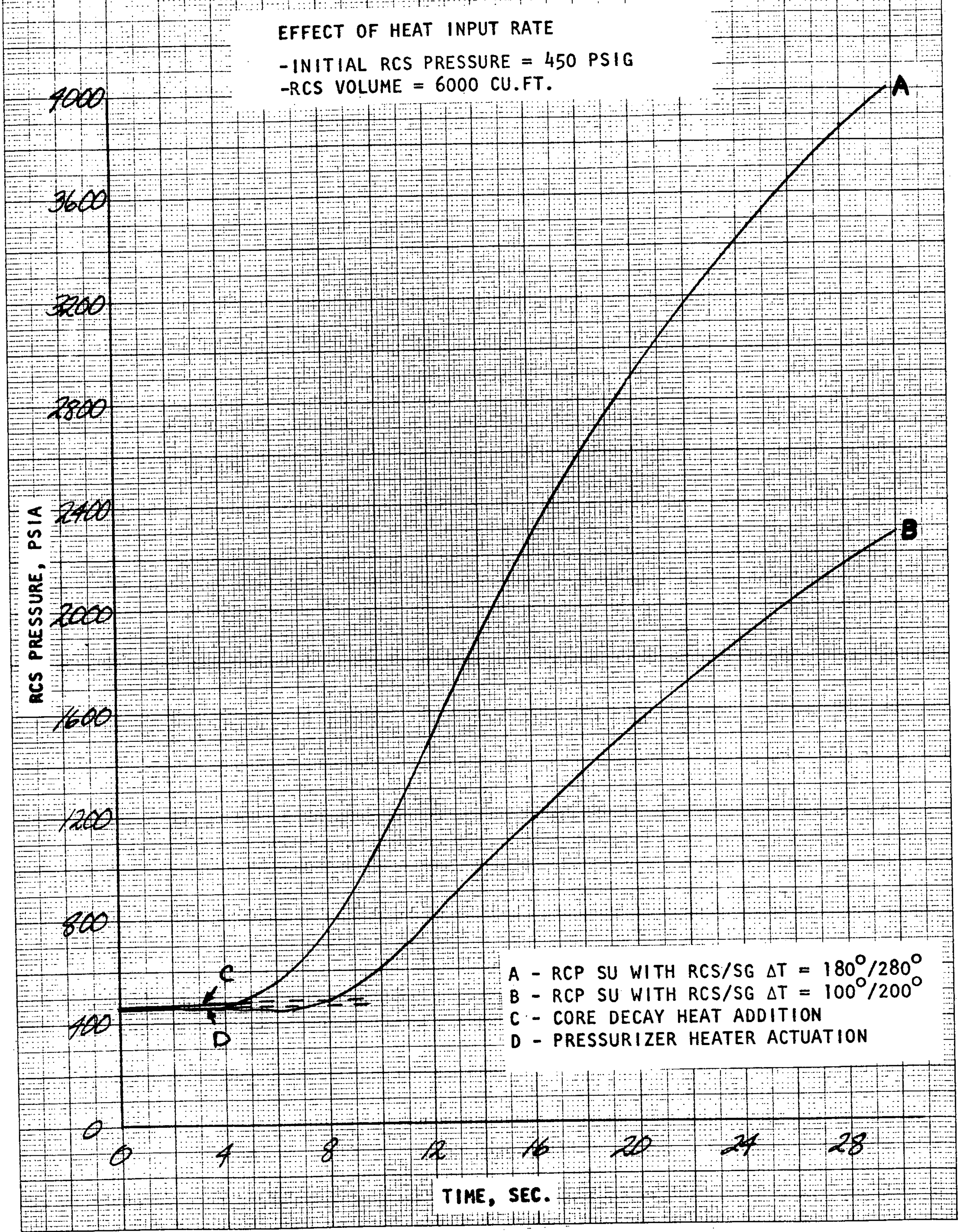


FIGURE H9
EFFECT OF HEAT INPUT RATE
-INITIAL RCS PRESSURE = 300 PSIG
-RCS VOLUME = 6000 CU.FT.
-RCP SU IN 1 LOOP
-NO RELIEF VALVE ACTUATION
RCS PRESSURE, PSIA
3000
2600
2200
1800
1400
1000
600
200
RCS/SG ΔT = 180°/230°
LS/RCS ΔT = 80°/200°
CORE DECAY HEAT ADDITION
PRESSURIZER HEATER ACTUATION
0
20
40
60
80
100
120
TIME, SEC.

FIGURE H10



10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

461510

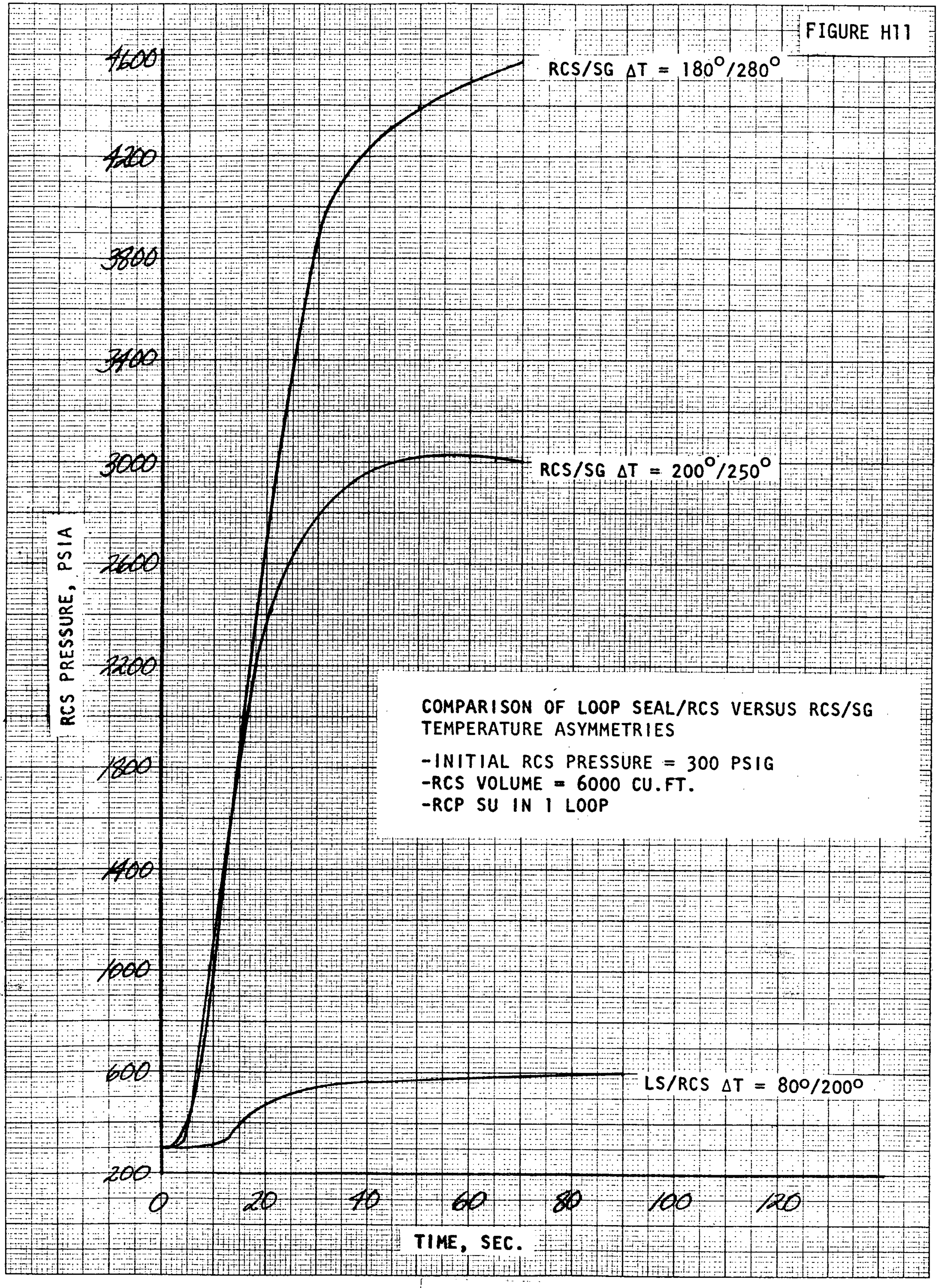


FIGURE H11
RCS/SG ΔT = 180°/280°
RCS/SG ΔT = 200°/250°
LS/RCS ΔT = 80°/200°
COMPARISON OF LOOP SEAL/RCS VERSUS RCS/SG TEMPERATURE ASYMMETRIES
-INITIAL RCS PRESSURE = 300 PSIG
-RCS VOLUME = 6000 CU.FT.
-RCP SU IN 1 LOOP
RCS PRESSURE, PSIA
4600
4200
3800
3400
3000
2600
2200
1800
1400
1000
600
200
0
20
40
60
80
100
120
TIME, SEC.

461510

10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

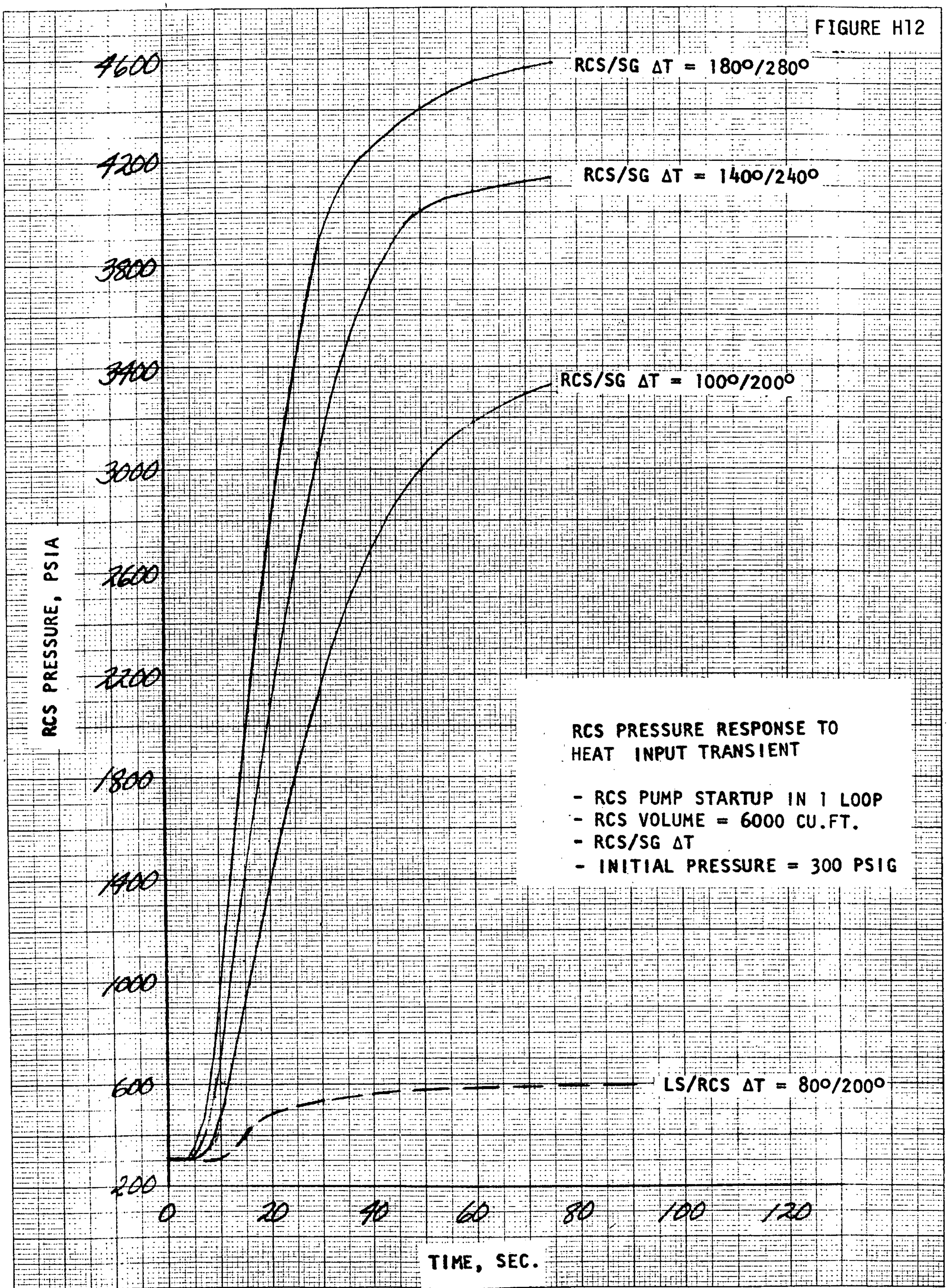


FIGURE H12

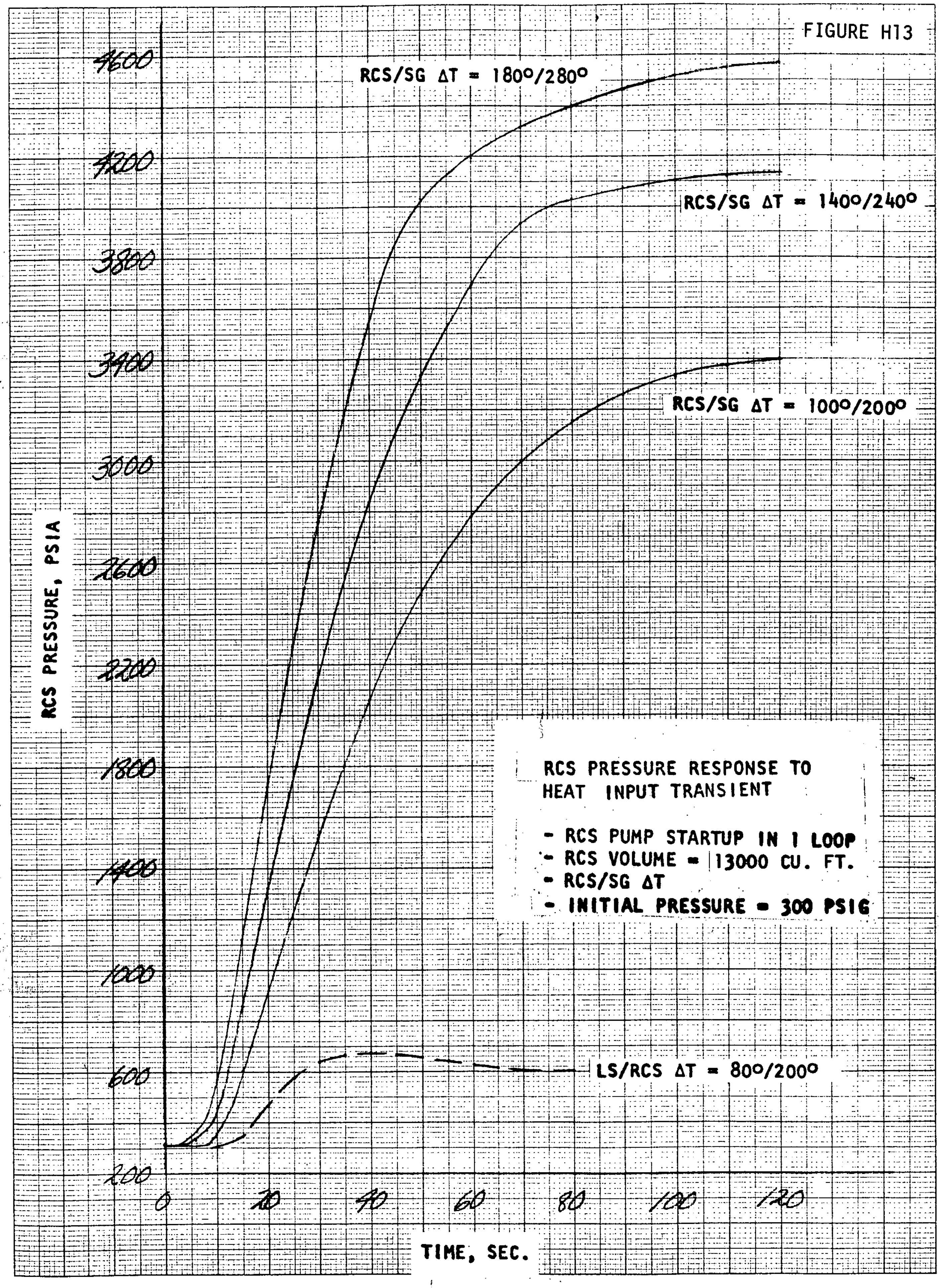
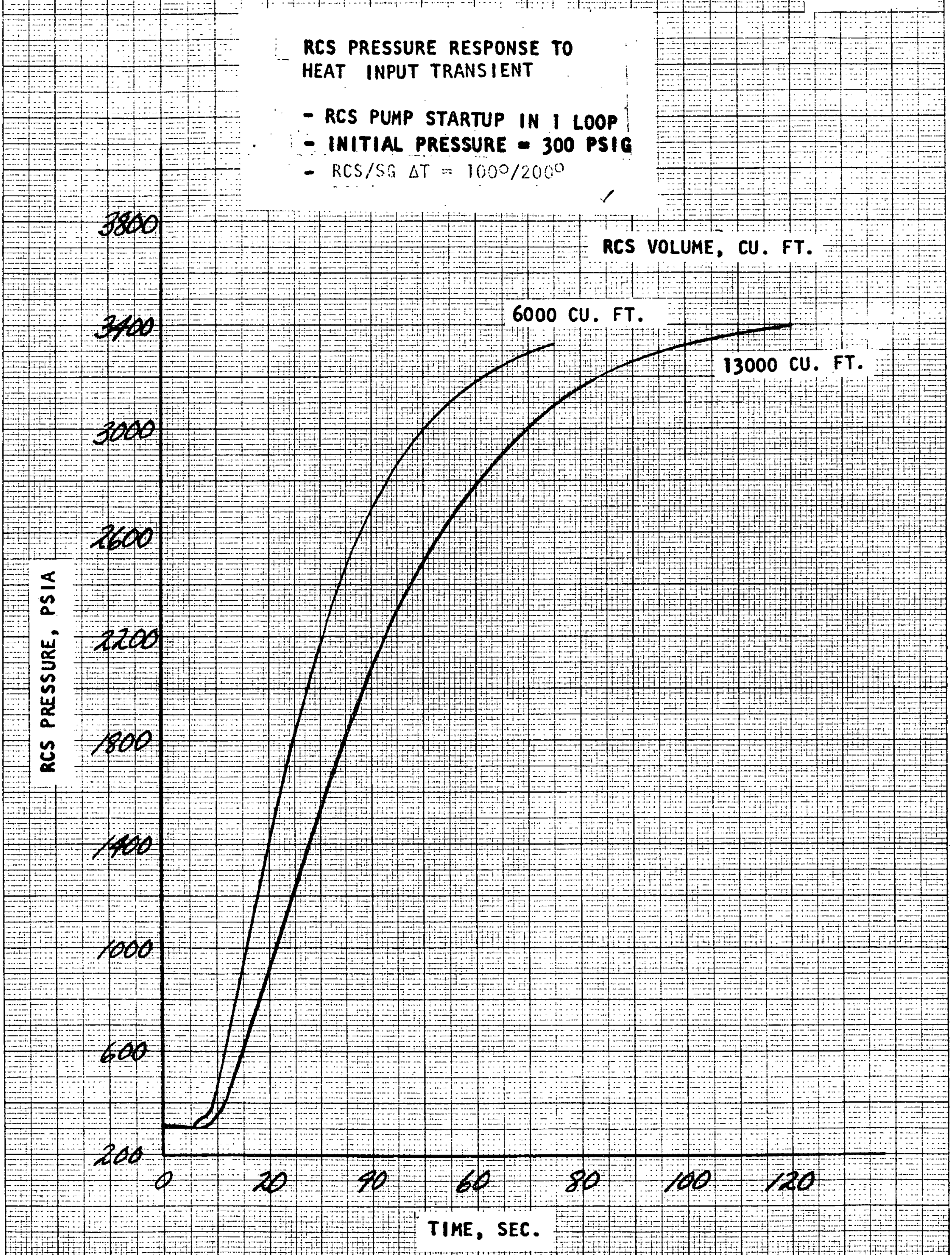


FIGURE H13
RCS/SG ΔT = 180°/280°
RCS/SG ΔT = 140°/240°
RCS/SG ΔT = 100°/200°
LS/RCS ΔT = 80°/200°
RCS PRESSURE, PSIA
4600
4200
3800
3400
3000
2600
2200
1800
1400
1000
600
200
0
20
40
60
80
100
120
TIME, SEC.
RCS PRESSURE RESPONSE TO
HEAT INPUT TRANSIENT
- RCS PUMP STARTUP IN 1 LOOP
- RCS VOLUME = 13000 CU. FT.
- RCS/SG ΔT
- INITIAL PRESSURE = 300 PSIG

FIGURE H14



461510

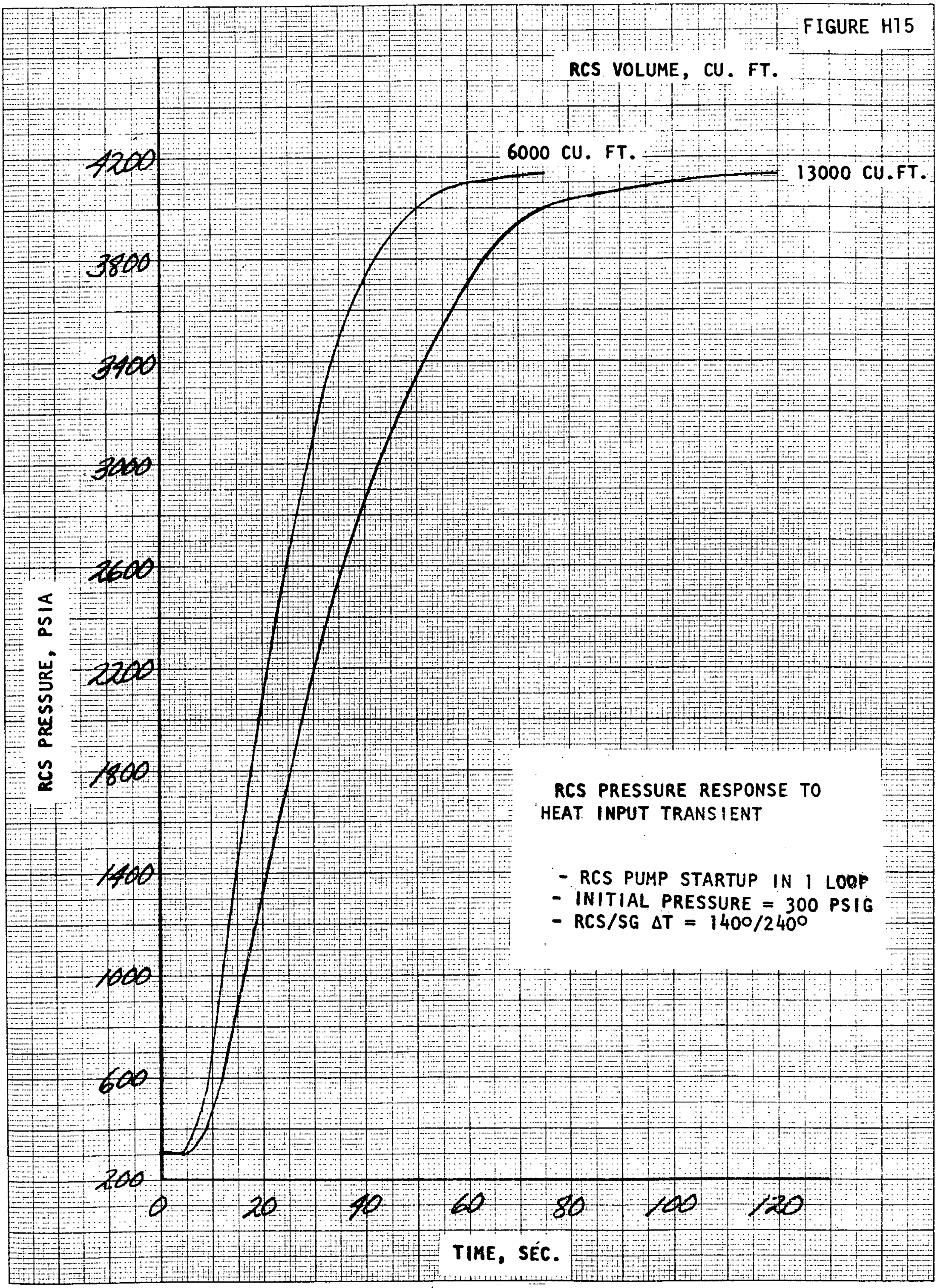


FIGURE H15
RCS VOLUME, CU. FT.
6000 CU. FT.
13000 CU.FT.
RCS PRESSURE, PSIA
4200
3800
3400
3000
2600
2200
1800
1400
1000
600
200
0
20
40
60
80
100
120
TIME, SEC.
RCS PRESSURE RESPONSE TO
HEAT INPUT TRANSIENT
- RCS PUMP STARTUP IN 1 LOOP
- INITIAL PRESSURE = 300 PSIG
- RCS/SG ΔT = 140°/240°

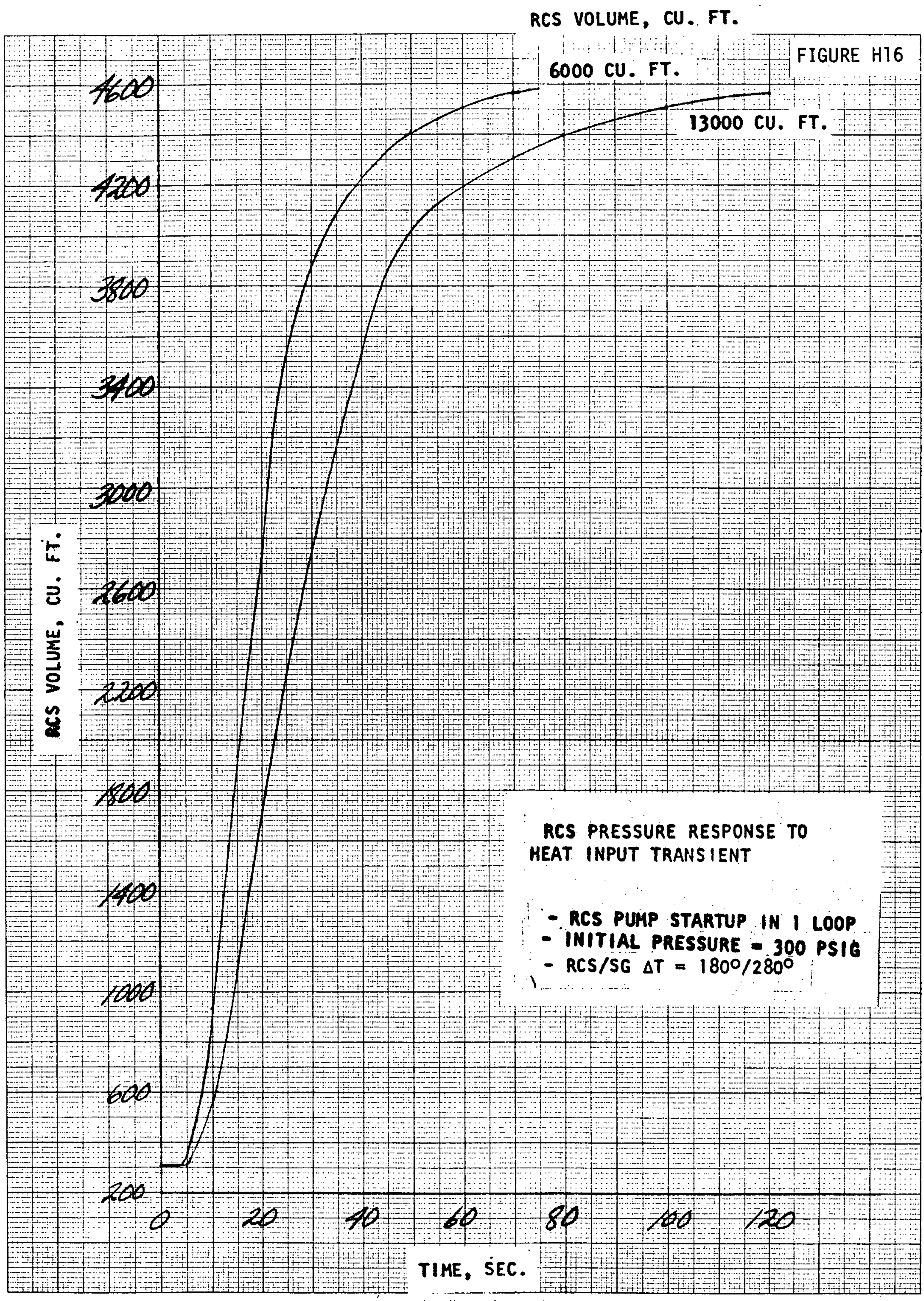
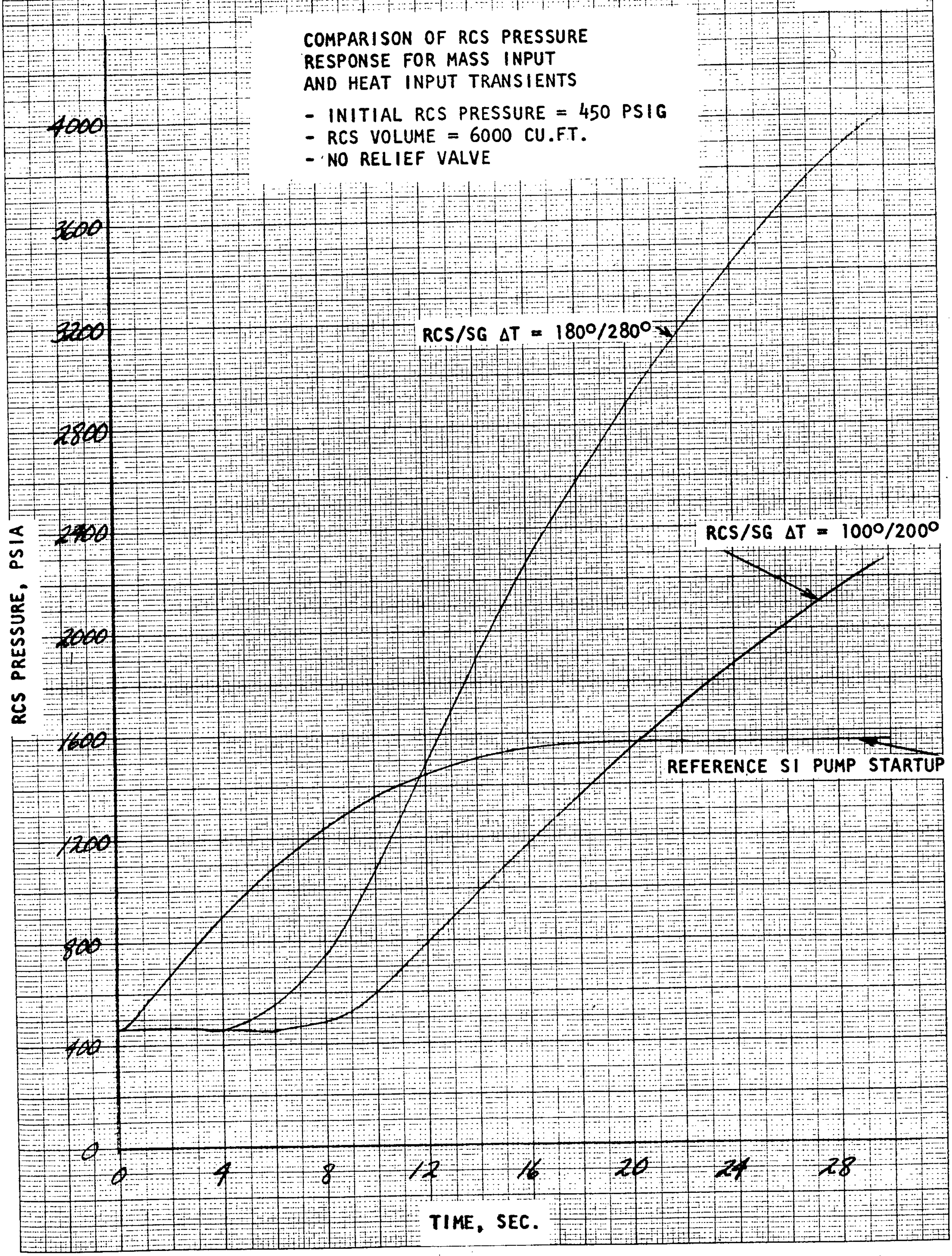


FIGURE H16
RCS VOLUME, CU. FT.
6000 CU. FT.
13000 CU. FT.
RCS VOLUME, CU. FT.
4600
4200
3800
3400
3000
2600
2200
1800
1400
1000
600
200
0
20
40
60
80
100
120
TIME, SEC.
RCS PRESSURE RESPONSE TO HEAT INPUT TRANSIENT
- RCS PUMP STARTUP IN 1 LOOP
- INITIAL PRESSURE = 300 PSIG
- RCS/SG ΔT = 180°/280°

FIGURE H17


COMPARISON OF RCS PRESSURE
RESPONSE FOR MASS INPUT
AND HEAT INPUT TRANSIENTS
- INITIAL RCS PRESSURE = 450 PSIG
- RCS VOLUME = 6000 CU.FT.
- NO RELIEF VALVE
RCS/SG ΔT = 180°/280°
RCS/SG ΔT = 100°/200°
REFERENCE SI PUMP STARTUP
RCS PRESSURE, PSIA
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
0
4
8
12
16
20
24
28
TIME, SEC.

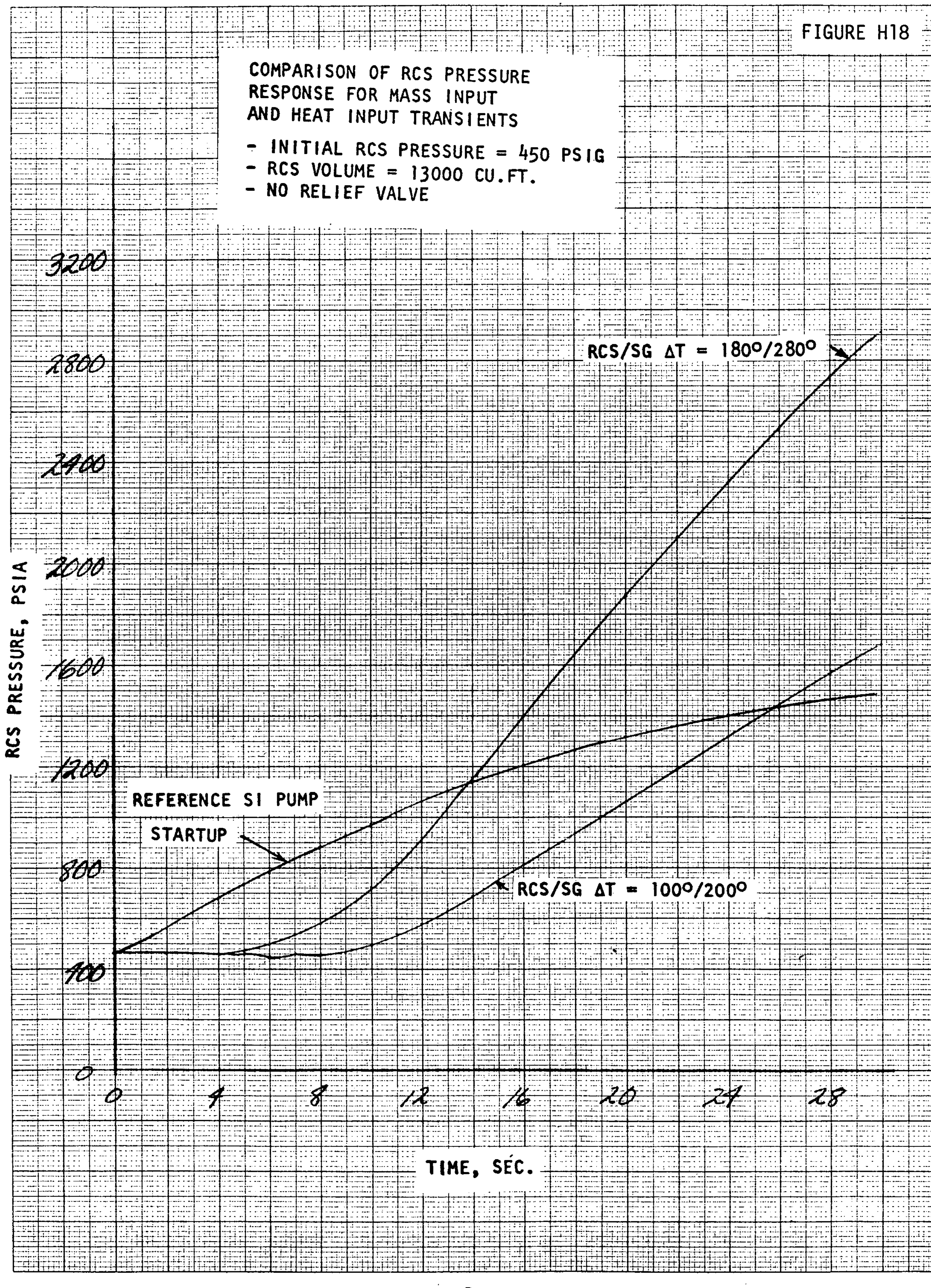


FIGURE H18
COMPARISON OF RCS PRESSURE RESPONSE FOR MASS INPUT AND HEAT INPUT TRANSIENTS
- INITIAL RCS PRESSURE = 450 PSIG
- RCS VOLUME = 13000 CU.FT.
- NO RELIEF VALVE
RCS/SG ΔT = 180°/280°
REFERENCE SI PUMP STARTUP
RCS/SG ΔT = 100°/200°
RCS PRESSURE, PSIA
TIME, SEC.
3200
2800
2400
2000
1600
1200
800
400
0
0
4
8
12
16
20
24
28

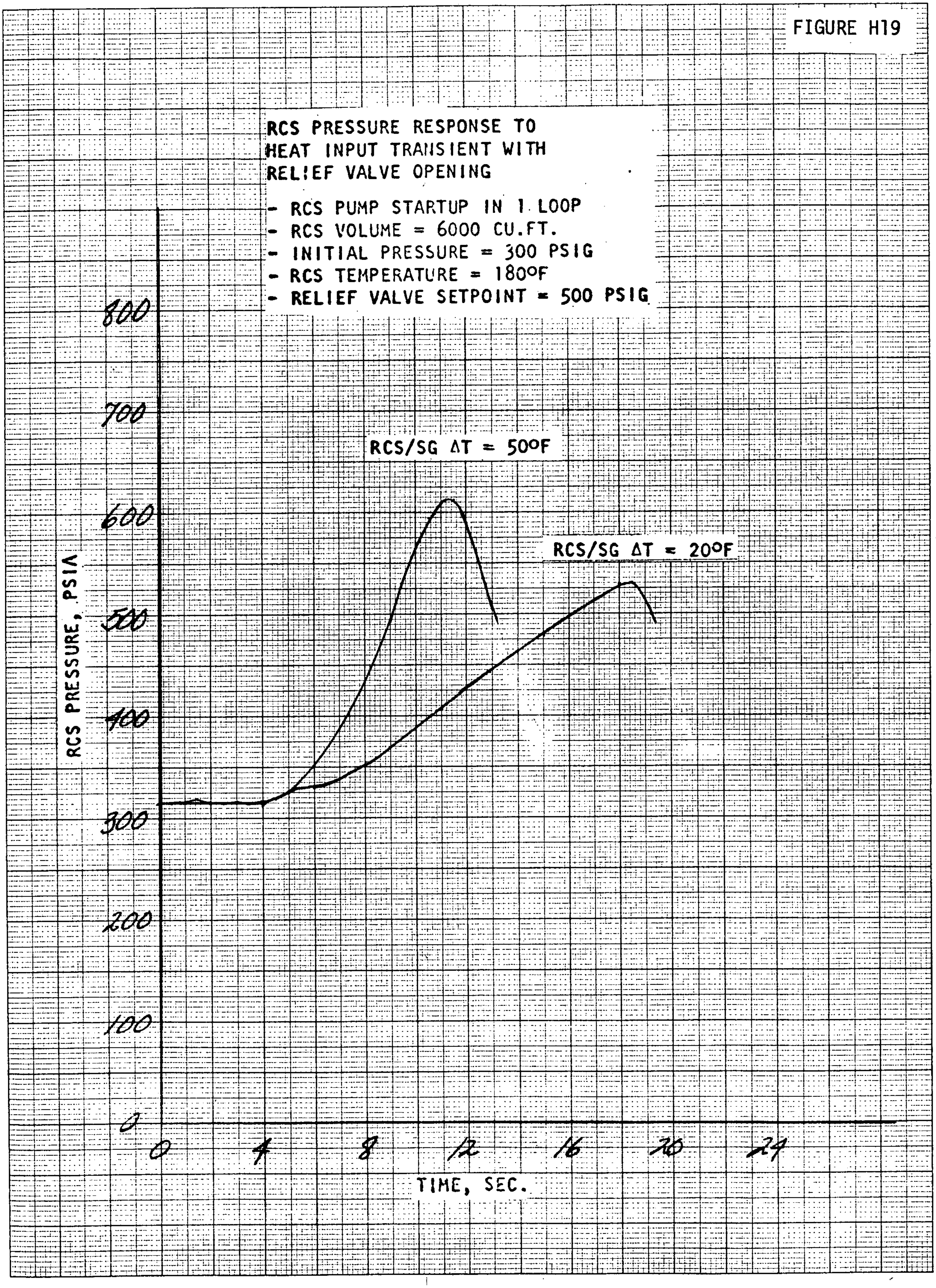


FIGURE H19
RCS PRESSURE RESPONSE TO
HEAT INPUT TRANSIENT WITH
RELIEF VALVE OPENING
- RCS PUMP STARTUP IN 1 LOOP
- RCS VOLUME = 6000 CU.FT.
- INITIAL PRESSURE = 300 PSIG
- RCS TEMPERATURE = 180°F
- RELIEF VALVE SETPOINT = 500 PSIG
RCS/SG ΔT = 50°F
RCS/SG ΔT = 20°F
RCS PRESSURE, PSIA
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
TIME, SEC.

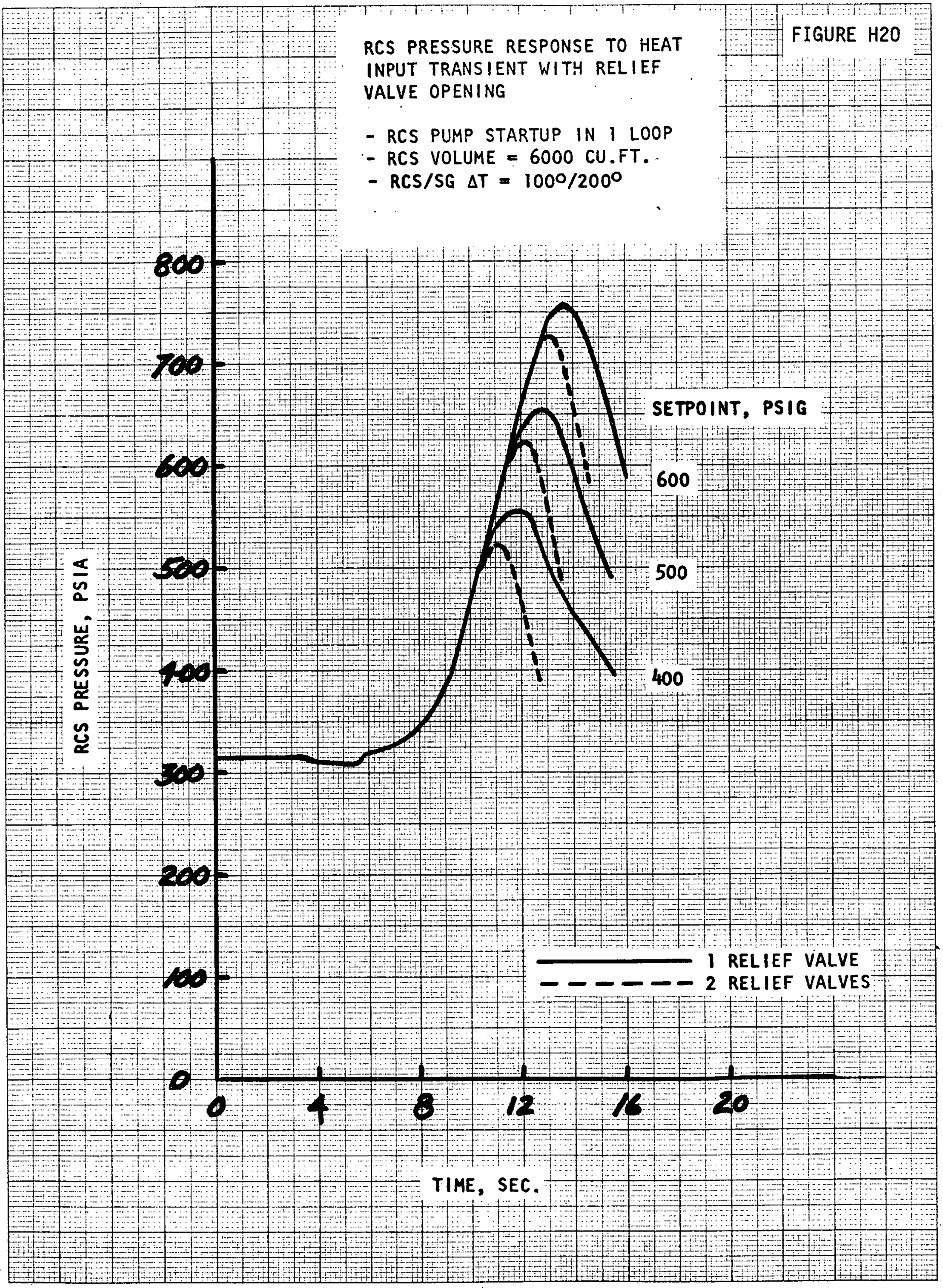


FIGURE H20

RCS PRESSURE RESPONSE TO HEAT INPUT TRANSIENT WITH RELIEF VALVE OPENING

- RCS PUMP STARTUP IN 1 LOOP
- RCS VOLUME = 6000 CU.FT.
- RCS/SG ΔT = 100°/200°

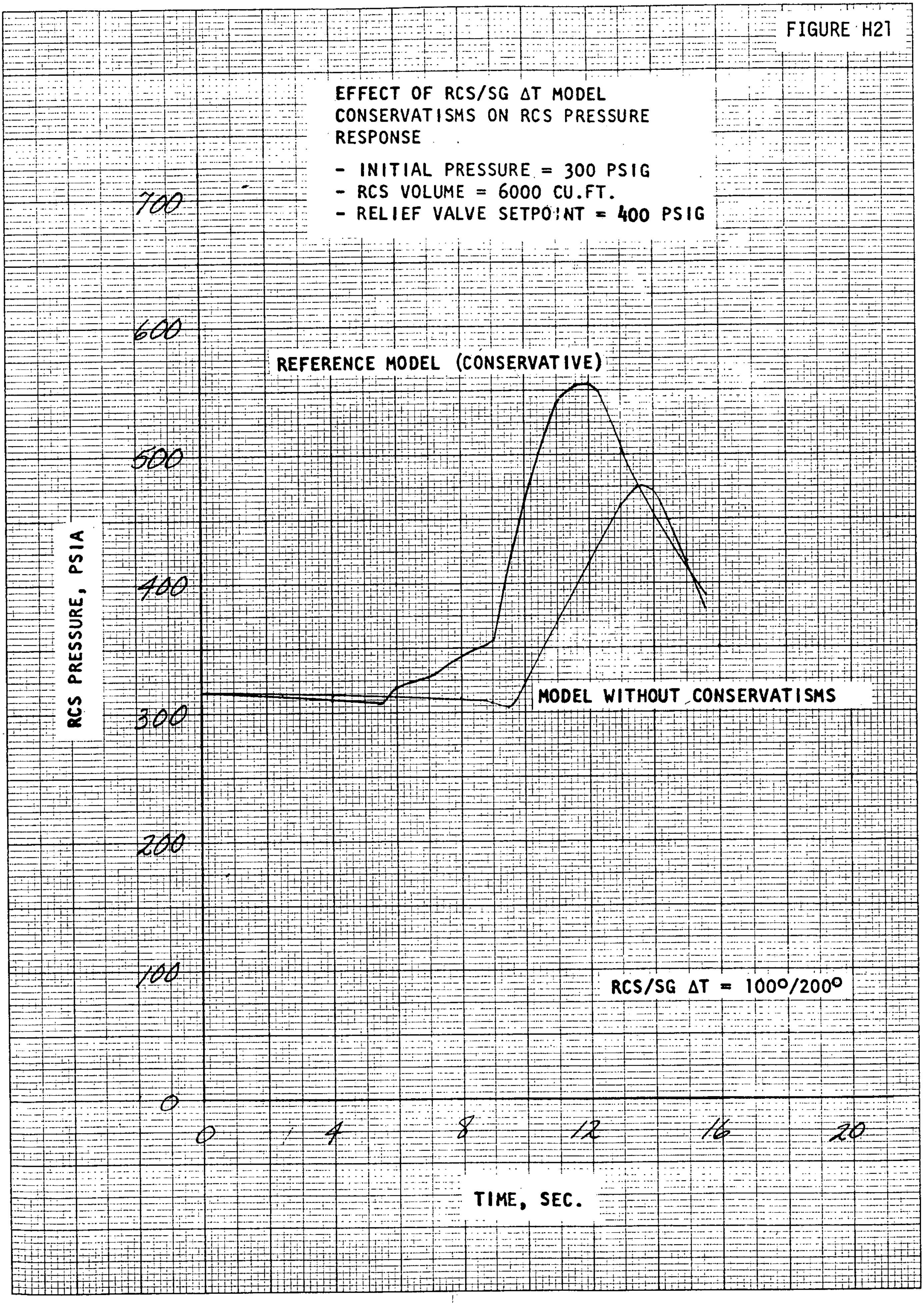


FIGURE H21
EFFECT OF RCS/SG ΔT MODEL CONSERVATISMS ON RCS PRESSURE RESPONSE
- INITIAL PRESSURE = 300 PSIG
- RCS VOLUME = 6000 CU.FT.
- RELIEF VALVE SETPOINT = 400 PSIG
REFERENCE MODEL (CONSERVATIVE)
MODEL WITHOUT CONSERVATISMS
RCS/SG ΔT = 100°/200°
RCS PRESSURE, PSIA
700
600
500
400
300
200
100
0
0
4
8
12
16
20
TIME, SEC.

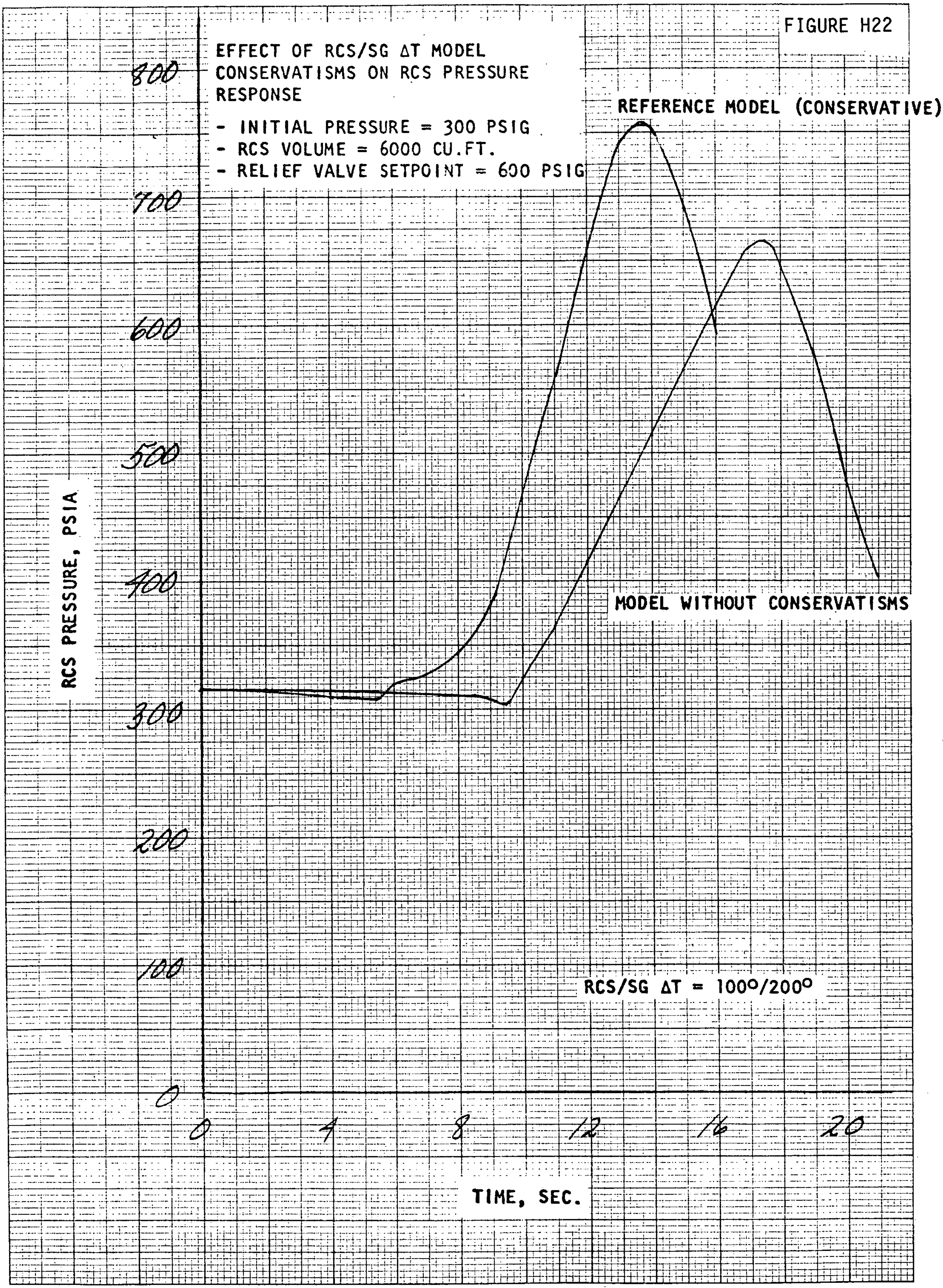


FIGURE H22
EFFECT OF RCS/SG ΔT MODEL CONSERVATISMS ON RCS PRESSURE RESPONSE
- INITIAL PRESSURE = 300 PSIG
- RCS VOLUME = 6000 CU.FT.
- RELIEF VALVE SETPOINT = 600 PSIG
REFERENCE MODEL (CONSERVATIVE)
MODEL WITHOUT CONSERVATISMS
RCS/SG ΔT = 100°/200°
RCS PRESSURE, PSIA
TIME, SEC.
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
46 1320
10 X 10 TO ½ INCH 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE H23

RCS PRESSURE RESPONSE TO HEAT INPUT TRANSIENT WITH RELIEF VALVE OPENING

- RCS PUMP STARTUP IN 1 LOOP
- RCS VOLUME = 6000 CU.FT.
- RCS/SG ΔT = 140°/240°

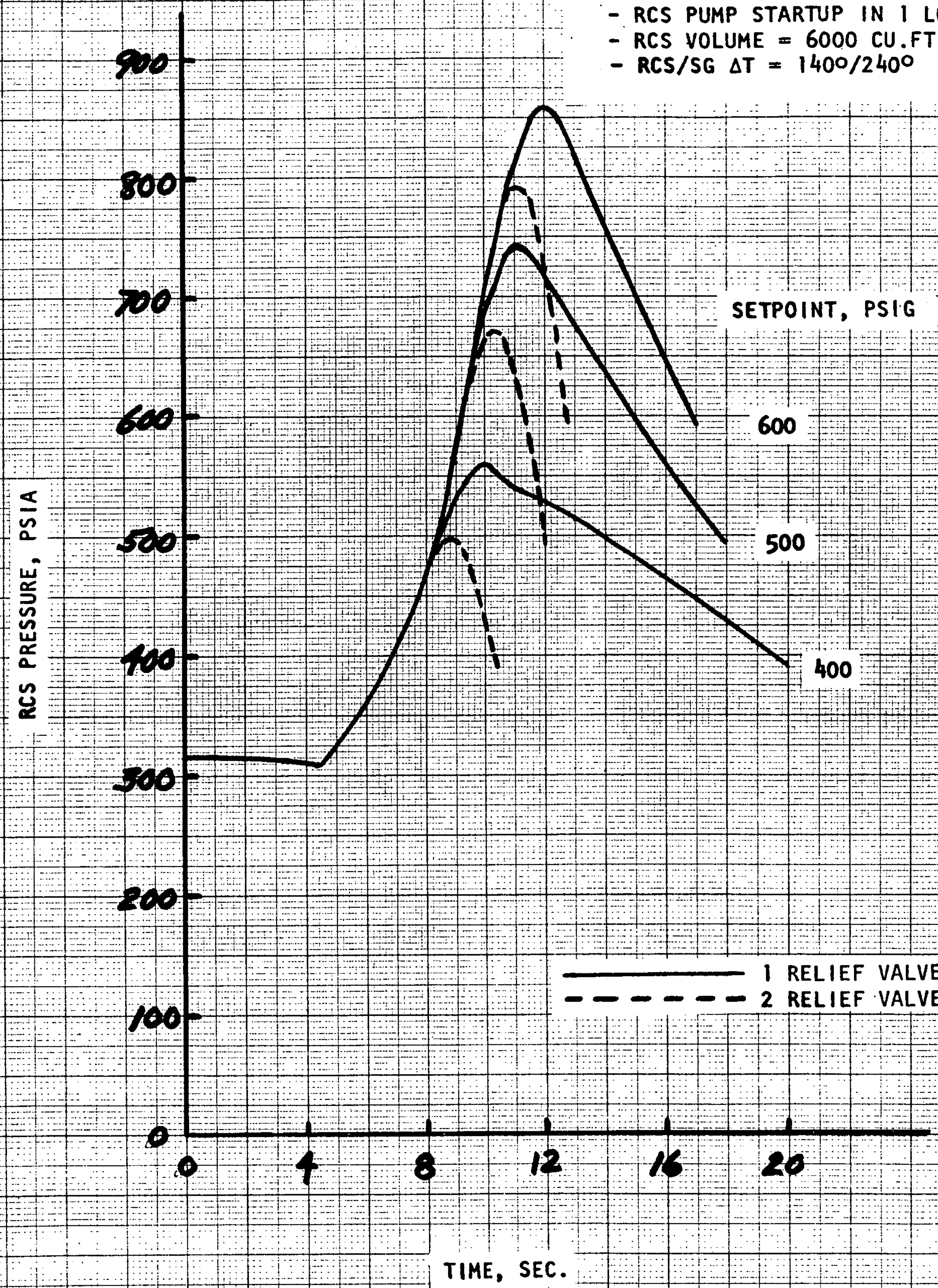


FIGURE H24

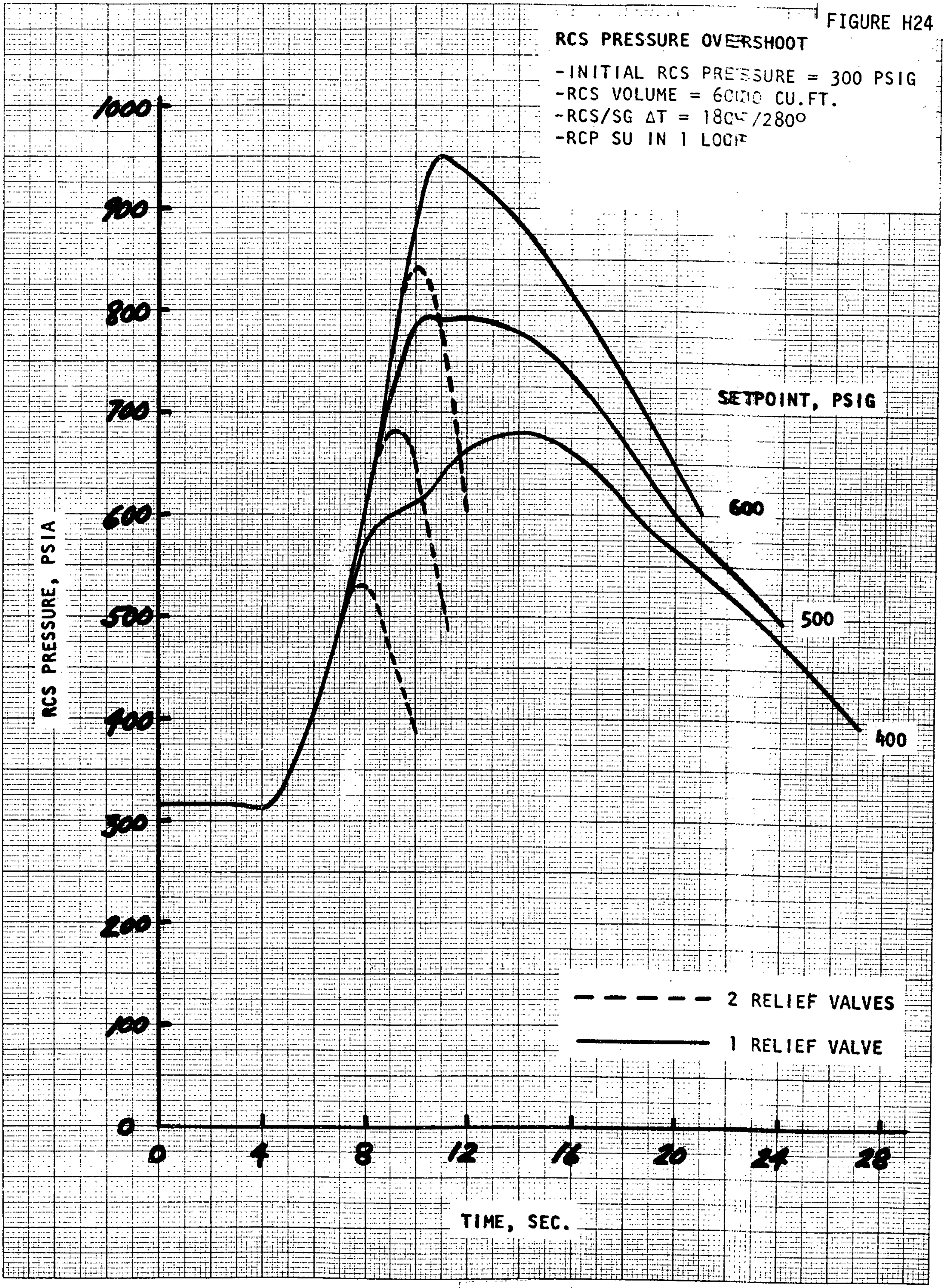

RCS PRESSURE OVERSHOOT
-INITIAL RCS PRESSURE = 300 PSIG
-RCS VOLUME = 6000 CU.FT.
-RCS/SG ΔT = 180°/280°
-RCP SU IN 1 LOOP
RCS PRESSURE, PSIA
1000
900
800
700
600
500
400
300
200
100
0
TIME, SEC.
0
4
8
12
16
20
24
28
SETPOINT, PSIG
600
500
400
2 RELIEF VALVES
1 RELIEF VALVE

FIGURE H25

PRESSURE RESPONSE FOR 1 RELIEF VALVE CYCLE

-INITIAL RCS PRESSURE = 300 PSIG
-RCS VOLUME = 6000 CU.FT.
-RCP SU IN 1 LOOP WITH RCS/SG ΔT = 100°F
-RELIEF VALVE SETPOINT = 600 PSIG

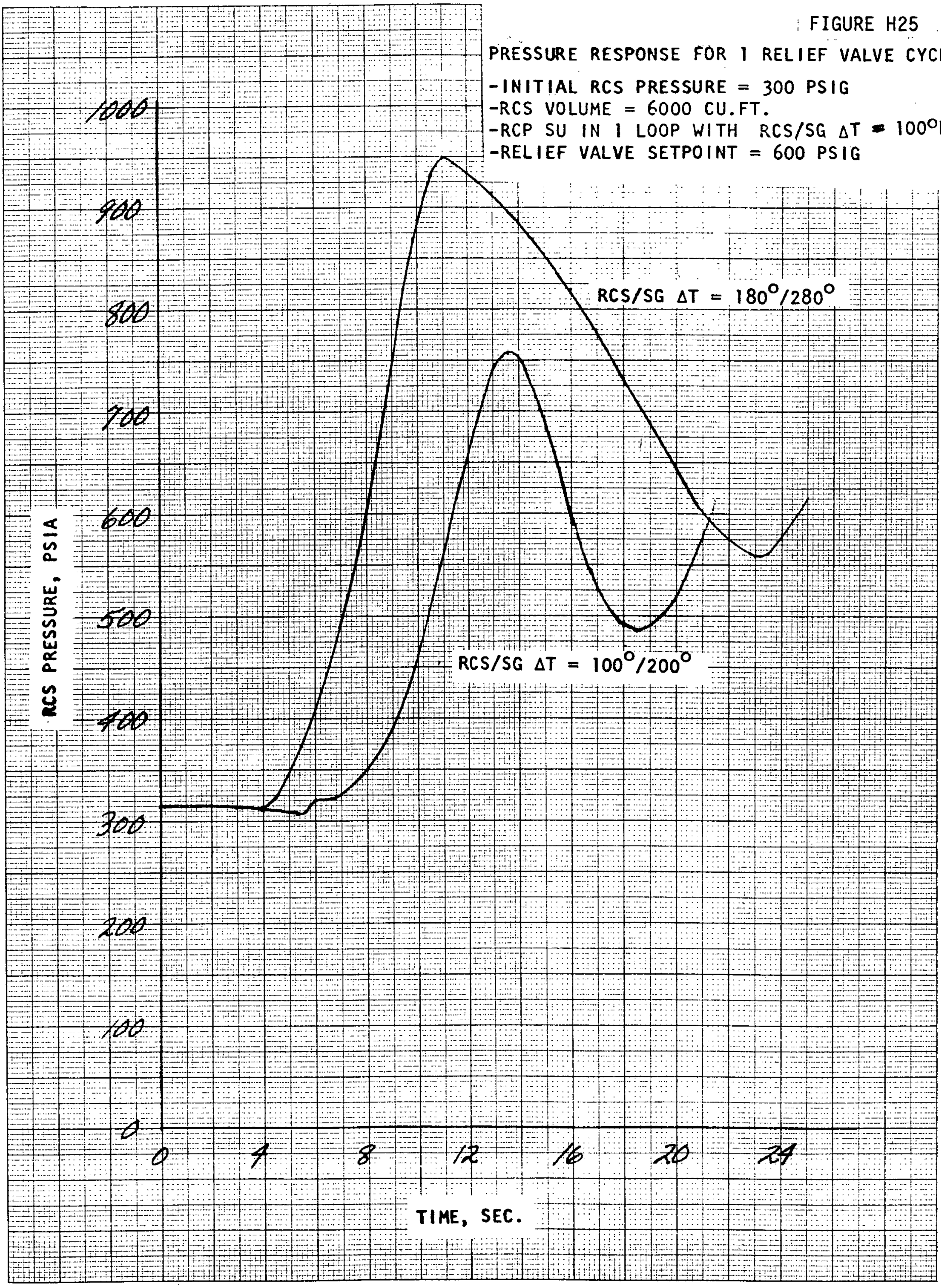
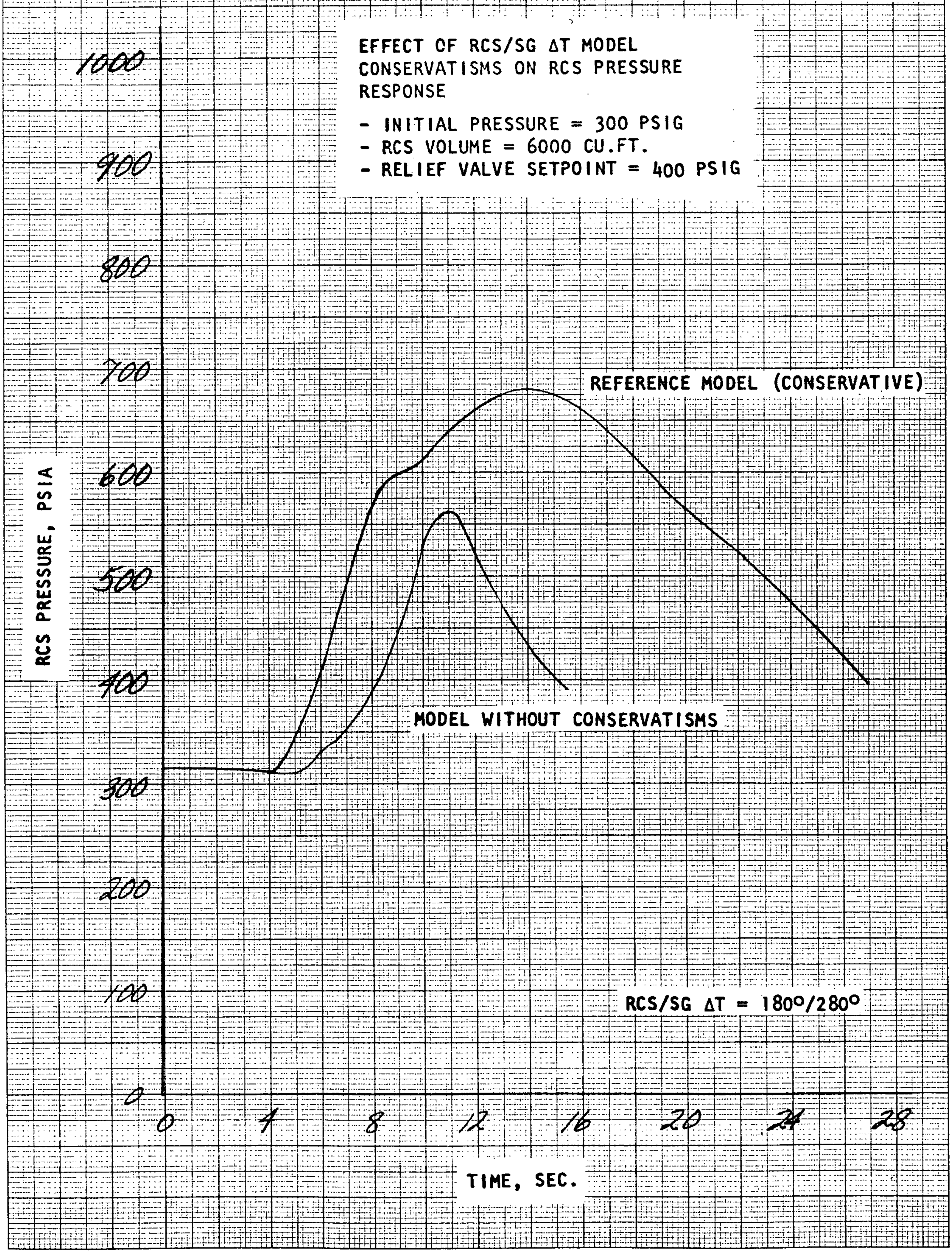


FIGURE H26


EFFECT OF RCS/SG ΔT MODEL CONSERVATISMS ON RCS PRESSURE RESPONSE
- INITIAL PRESSURE = 300 PSIG
- RCS VOLUME = 6000 CU.FT.
- RELIEF VALVE SETPOINT = 400 PSIG
REFERENCE MODEL (CONSERVATIVE)
MODEL WITHOUT CONSERVATISMS
RCS/SG ΔT = 180°/280°
RCS PRESSURE, PSIA
TIME, SEC.
1000
900
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
28

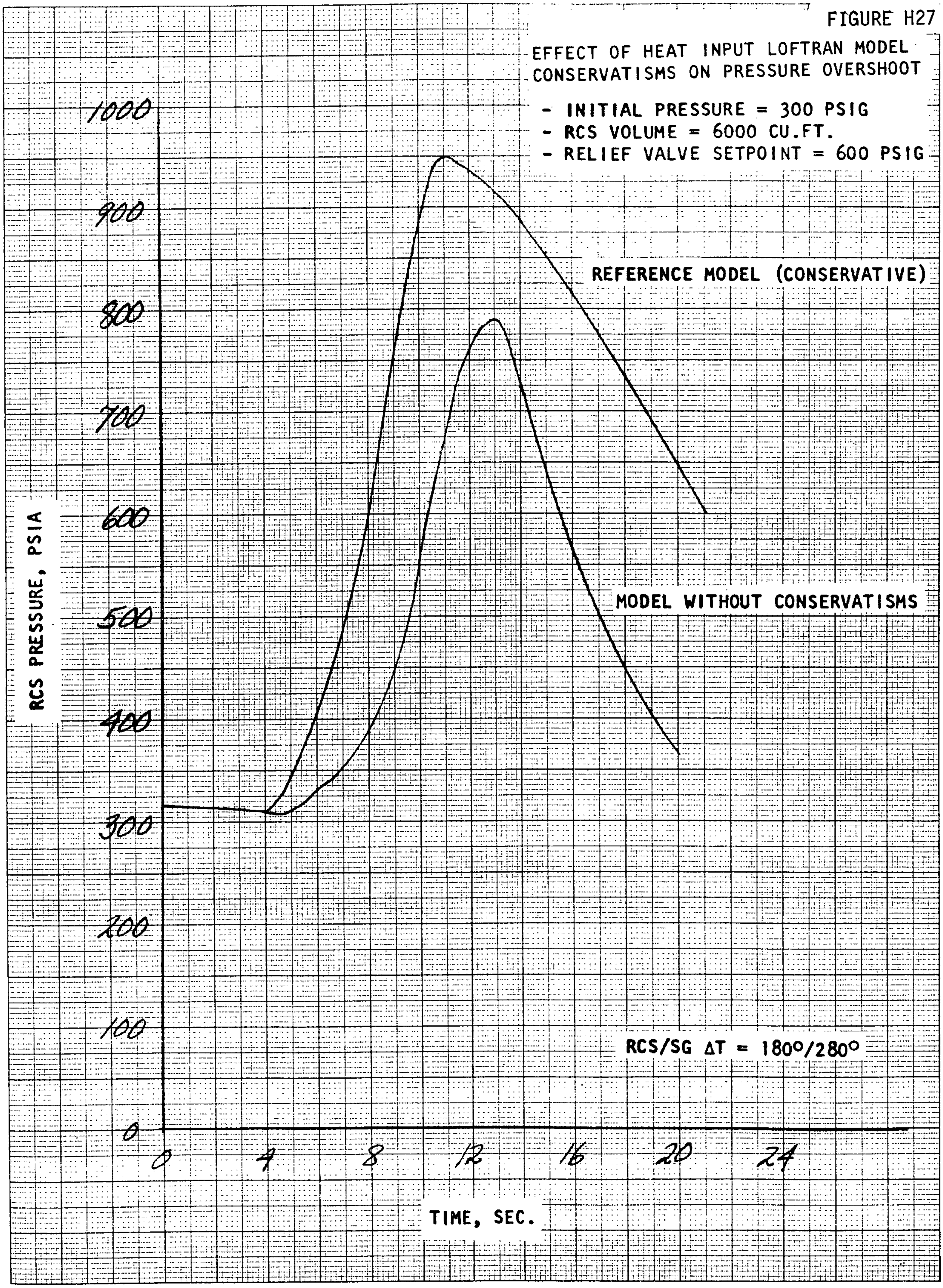


FIGURE H27
EFFECT OF HEAT INPUT LOFTRAN MODEL CONSERVATISMS ON PRESSURE OVERSHOOT
- INITIAL PRESSURE = 300 PSIG
- RCS VOLUME = 6000 CU.FT.
- RELIEF VALVE SETPOINT = 600 PSIG
REFERENCE MODEL (CONSERVATIVE)
MODEL WITHOUT CONSERVATISMS
RCS/SG ΔT = 180°/280°
RCS PRESSURE, PSIA
TIME, SEC.
1000
900
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24

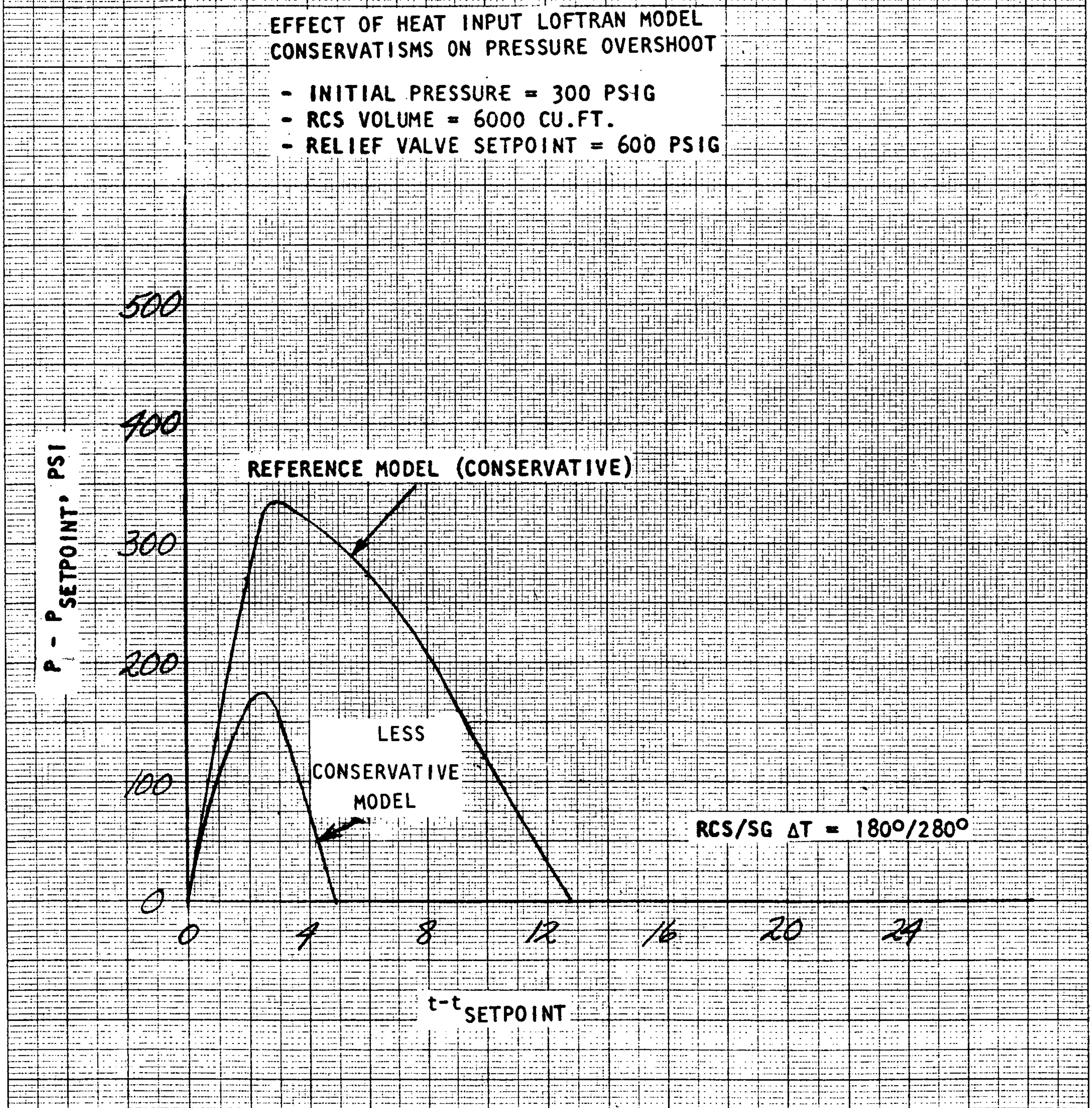

EFFECT OF HEAT INPUT LOFTRAN MODEL
CONSERVATISMS ON PRESSURE OVERSHOOT
- INITIAL PRESSURE = 300 PSIG
- RCS VOLUME = 6000 CU.FT.
- RELIEF VALVE SETPOINT = 600 PSIG
P - P SETPOINT, PSI
500
400
300
200
100
0
REFERENCE MODEL (CONSERVATIVE)
LESS
CONSERVATIVE
MODEL
RCS/SG ΔT = 180°/280°
0
4
8
12
16
20
24
t-t SETPOINT

FIGURE H29

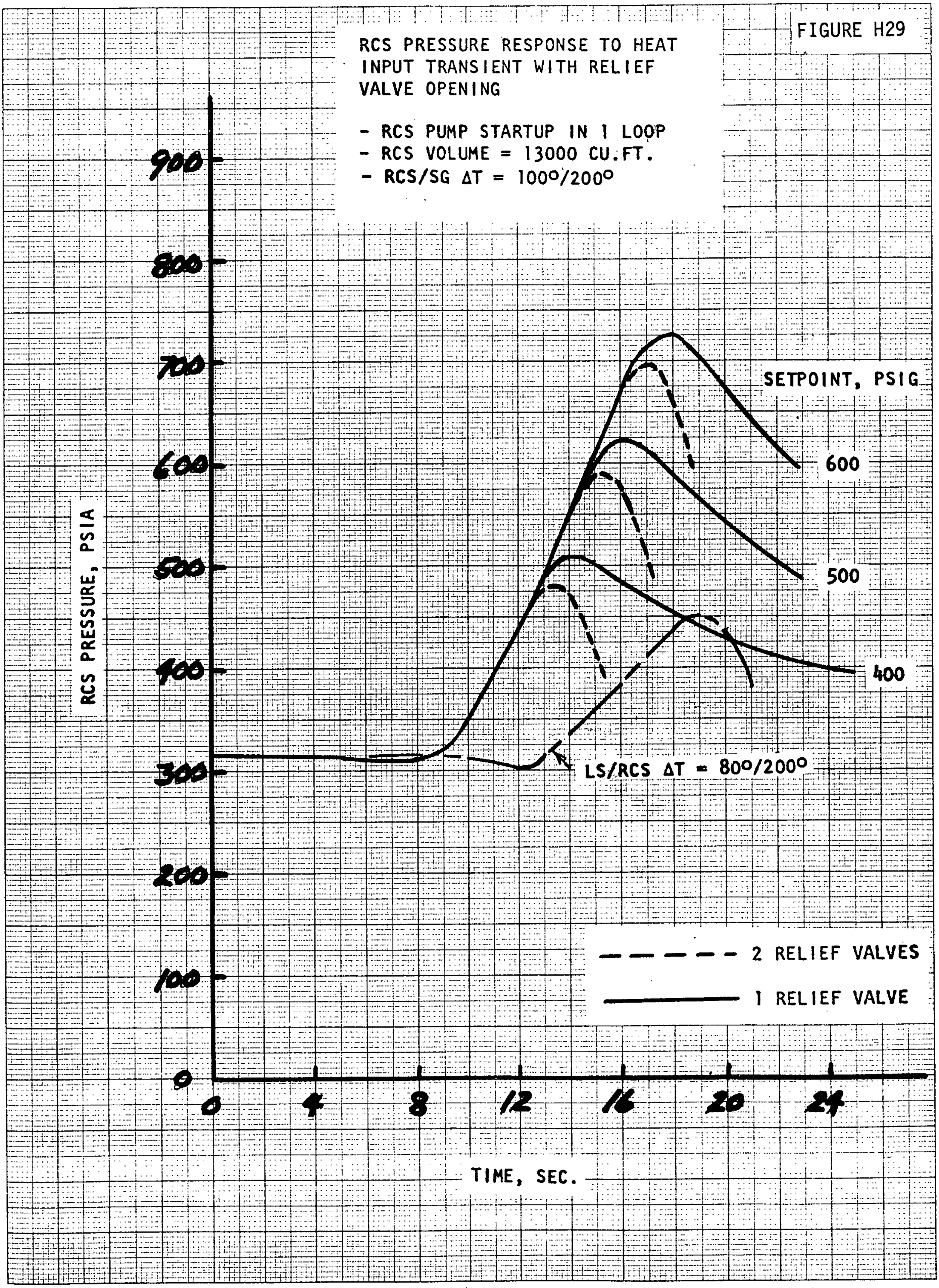
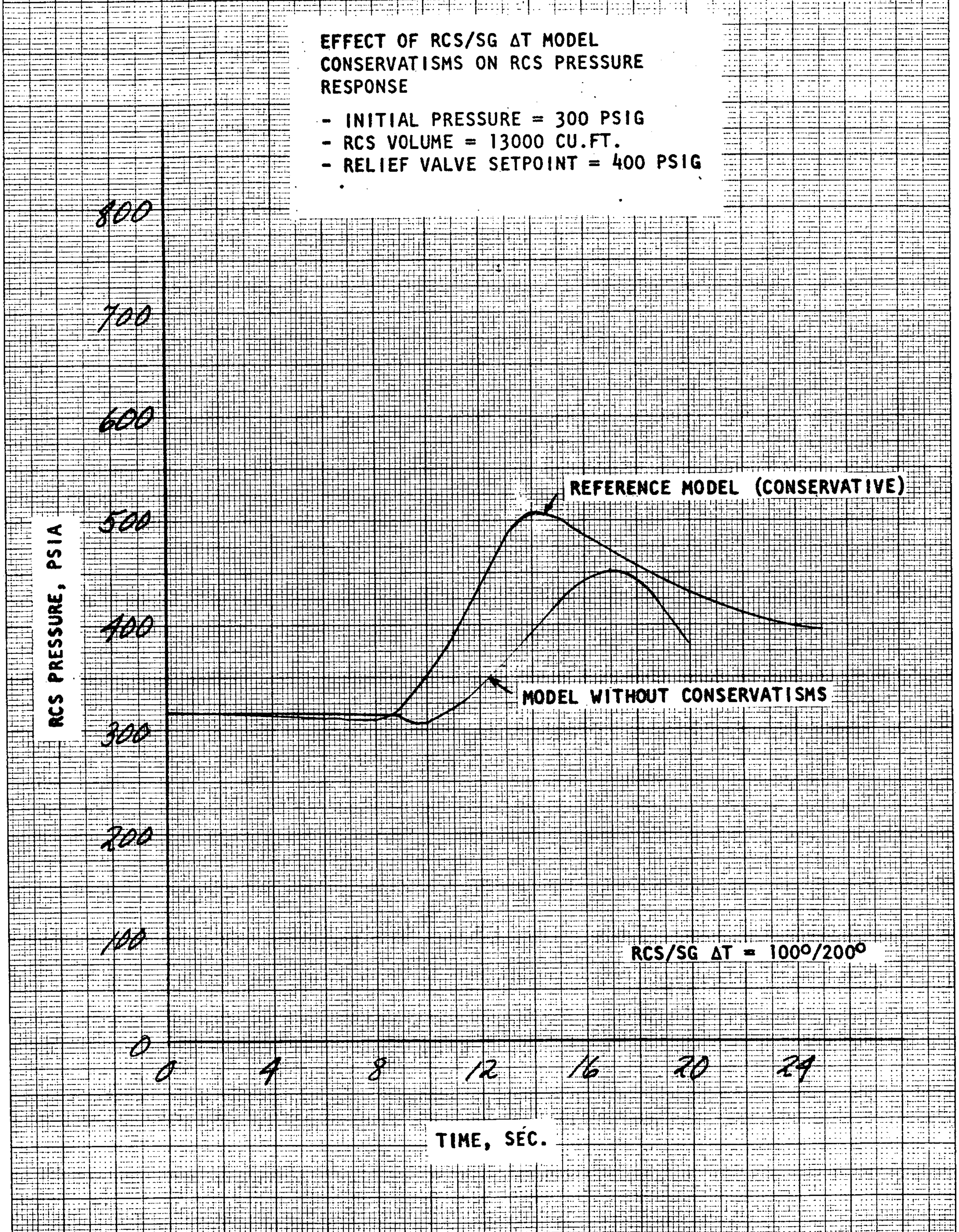

RCS PRESSURE RESPONSE TO HEAT INPUT TRANSIENT WITH RELIEF VALVE OPENING
- RCS PUMP STARTUP IN 1 LOOP
- RCS VOLUME = 13000 CU.FT.
- RCS/SG ΔT = 100°/200°
900
800
700
600
500
400
300
200
100
0
RCS PRESSURE, PSIA
SETPOINT, PSIG
600
500
400
LS/RCS ΔT = 80°/200°
2 RELIEF VALVES
1 RELIEF VALVE
0
4
8
12
16
20
24
TIME, SEC.

FIGURE H30


EFFECT OF RCS/SG ΔT MODEL CONSERVATISMS ON RCS PRESSURE RESPONSE
- INITIAL PRESSURE = 300 PSIG
- RCS VOLUME = 13000 CU.FT.
- RELIEF VALVE SETPOINT = 400 PSIG
800
700
600
500
400
300
200
100
0
RCS PRESSURE, PSIA
REFERENCE MODEL (CONSERVATIVE)
MODEL WITHOUT CONSERVATISMS
RCS/SG ΔT = 100°/200°
0
4
8
12
16
20
24
TIME, SEC.

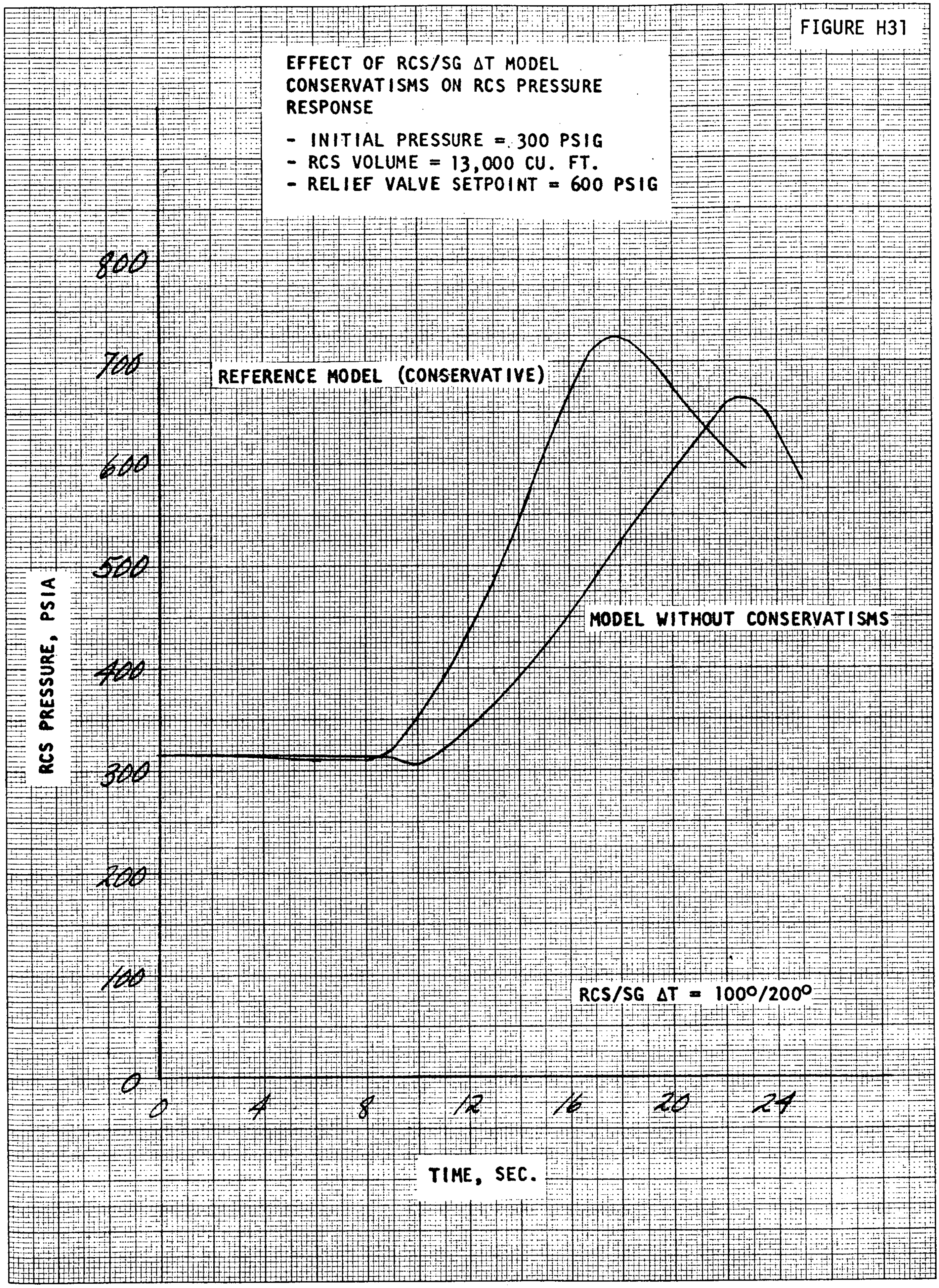


FIGURE H31
EFFECT OF RCS/SG ΔT MODEL CONSERVATISMS ON RCS PRESSURE RESPONSE
- INITIAL PRESSURE = 300 PSIG
- RCS VOLUME = 13,000 CU. FT.
- RELIEF VALVE SETPOINT = 600 PSIG
REFERENCE MODEL (CONSERVATIVE)
MODEL WITHOUT CONSERVATISMS
RCS/SG ΔT = 100°/200°
RCS PRESSURE, PSIA
TIME, SEC.
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24

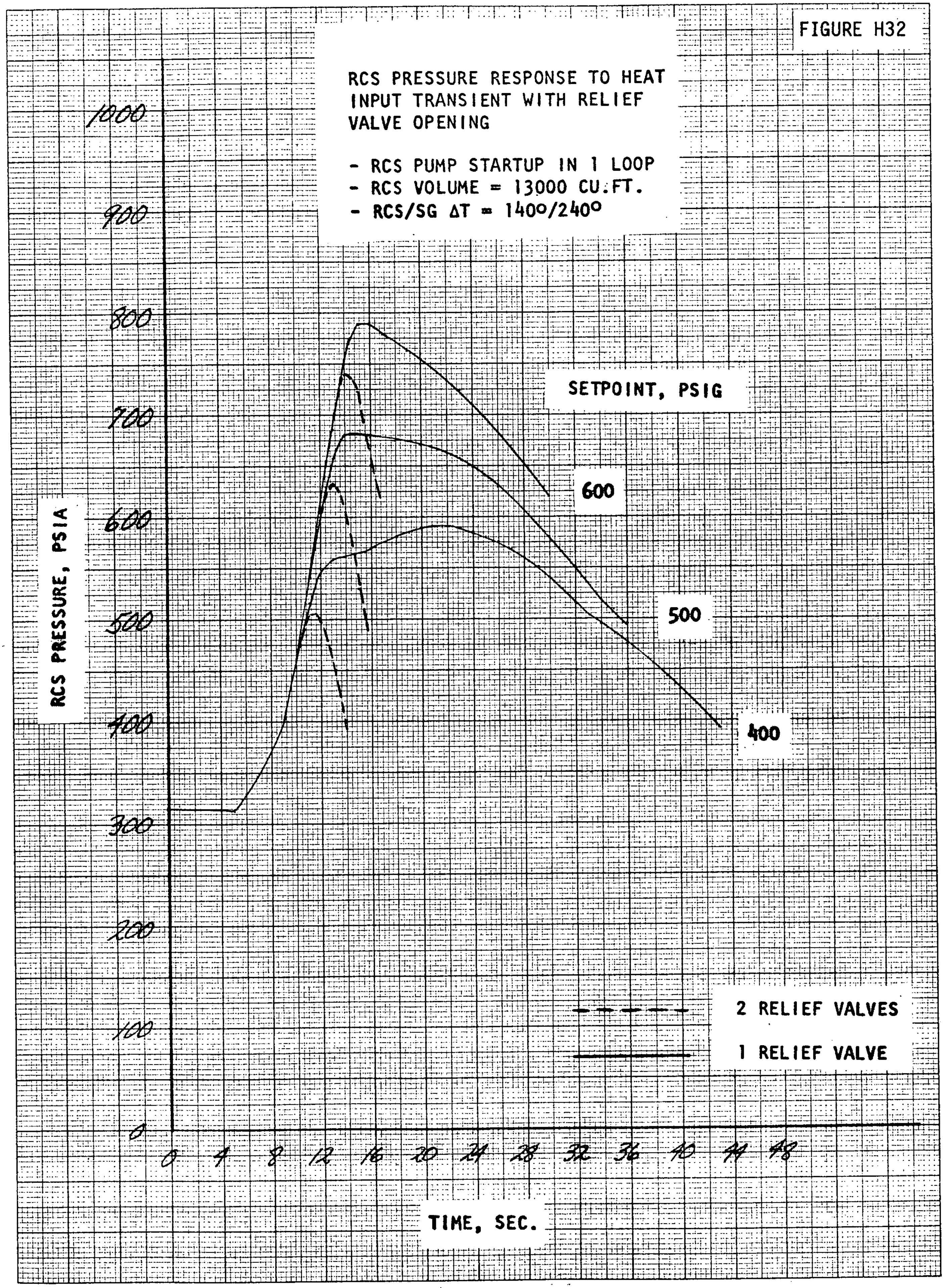
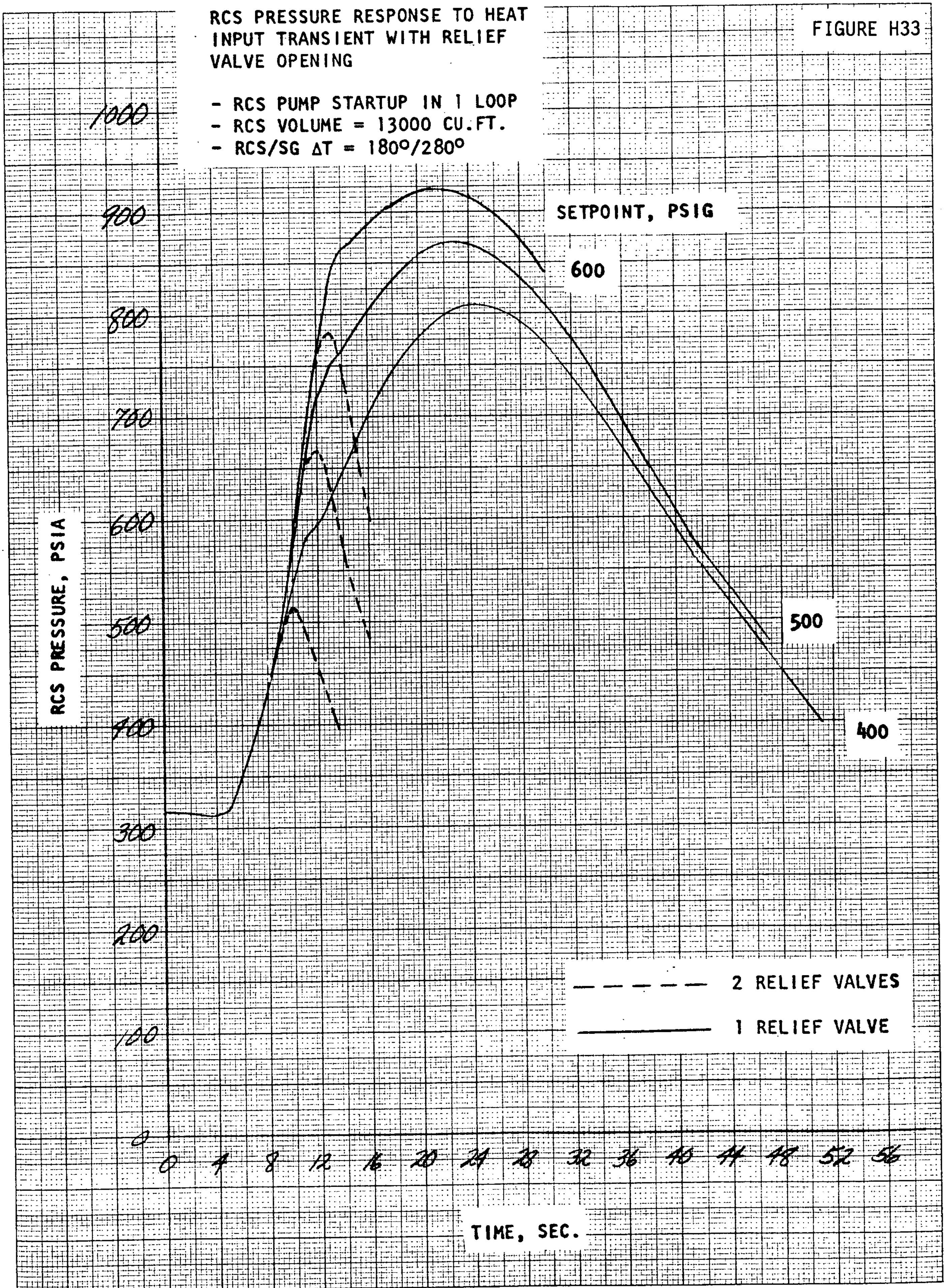


FIGURE H32
RCS PRESSURE RESPONSE TO HEAT INPUT TRANSIENT WITH RELIEF VALVE OPENING
- RCS PUMP STARTUP IN 1 LOOP
- RCS VOLUME = 13000 CU.FT.
- RCS/SG ΔT = 140°/240°
SETPOINT, PSIG
600
500
400
RCS PRESSURE, PSIA
1000
900
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
28
32
36
40
44
48
TIME, SEC.
2 RELIEF VALVES
1 RELIEF VALVE
461510
10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.


RCS PRESSURE RESPONSE TO HEAT INPUT TRANSIENT WITH RELIEF VALVE OPENING
- RCS PUMP STARTUP IN 1 LOOP
- RCS VOLUME = 13000 CU.FT.
- RCS/SG ΔT = 180°/280°
FIGURE H33
SETPOINT, PSIG
600
500
400
RCS PRESSURE, PSIA
1000
900
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
TIME, SEC.
2 RELIEF VALVES
1 RELIEF VALVE

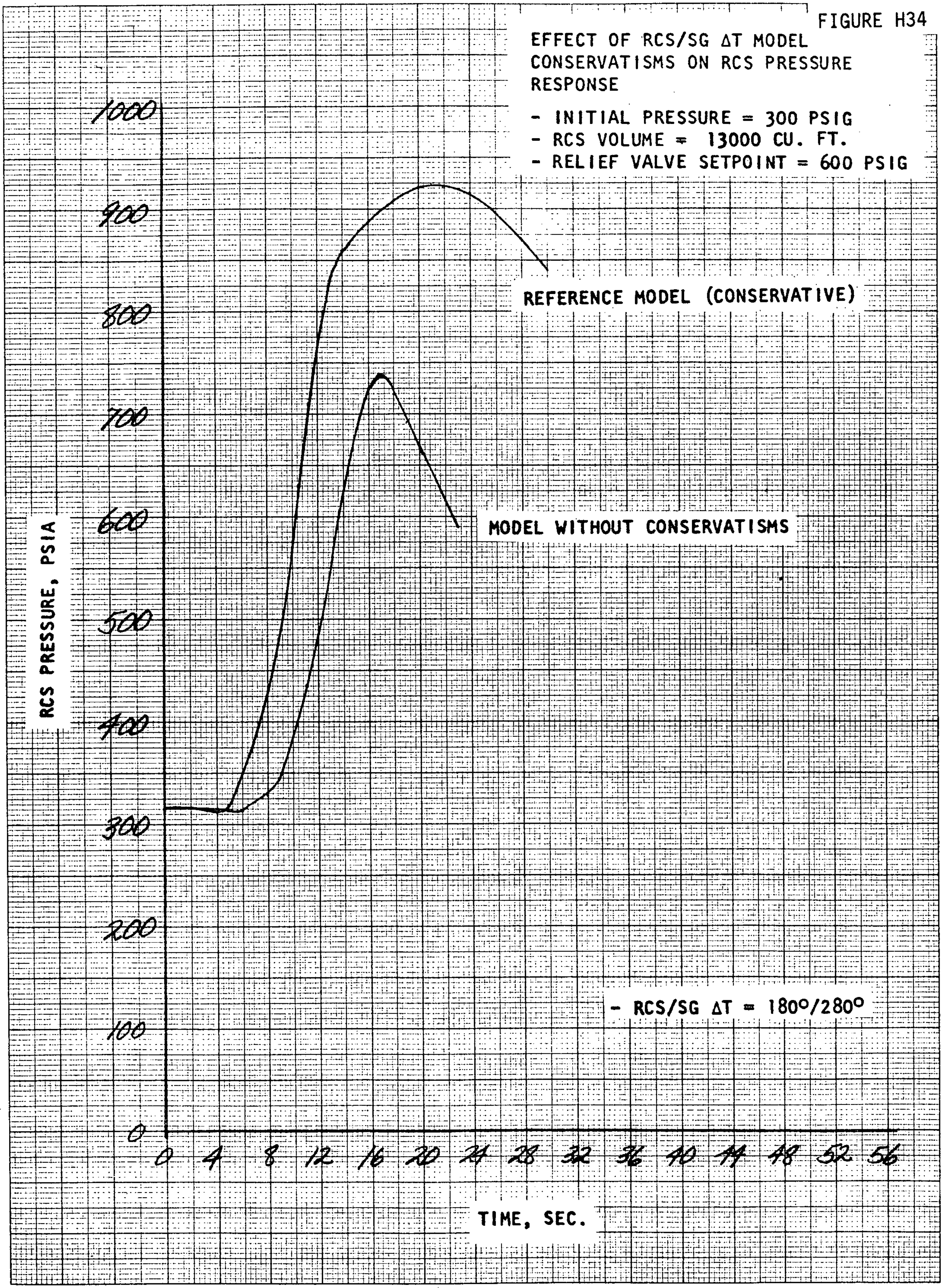


FIGURE H34
EFFECT OF RCS/SG ΔT MODEL CONSERVATISMS ON RCS PRESSURE RESPONSE
- INITIAL PRESSURE = 300 PSIG
- RCS VOLUME = 13000 CU. FT.
- RELIEF VALVE SETPOINT = 600 PSIG
REFERENCE MODEL (CONSERVATIVE)
MODEL WITHOUT CONSERVATISMS
- RCS/SG ΔT = 180°/280°
RCS PRESSURE, PSIA
1000
900
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
TIME, SEC.
461510
10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

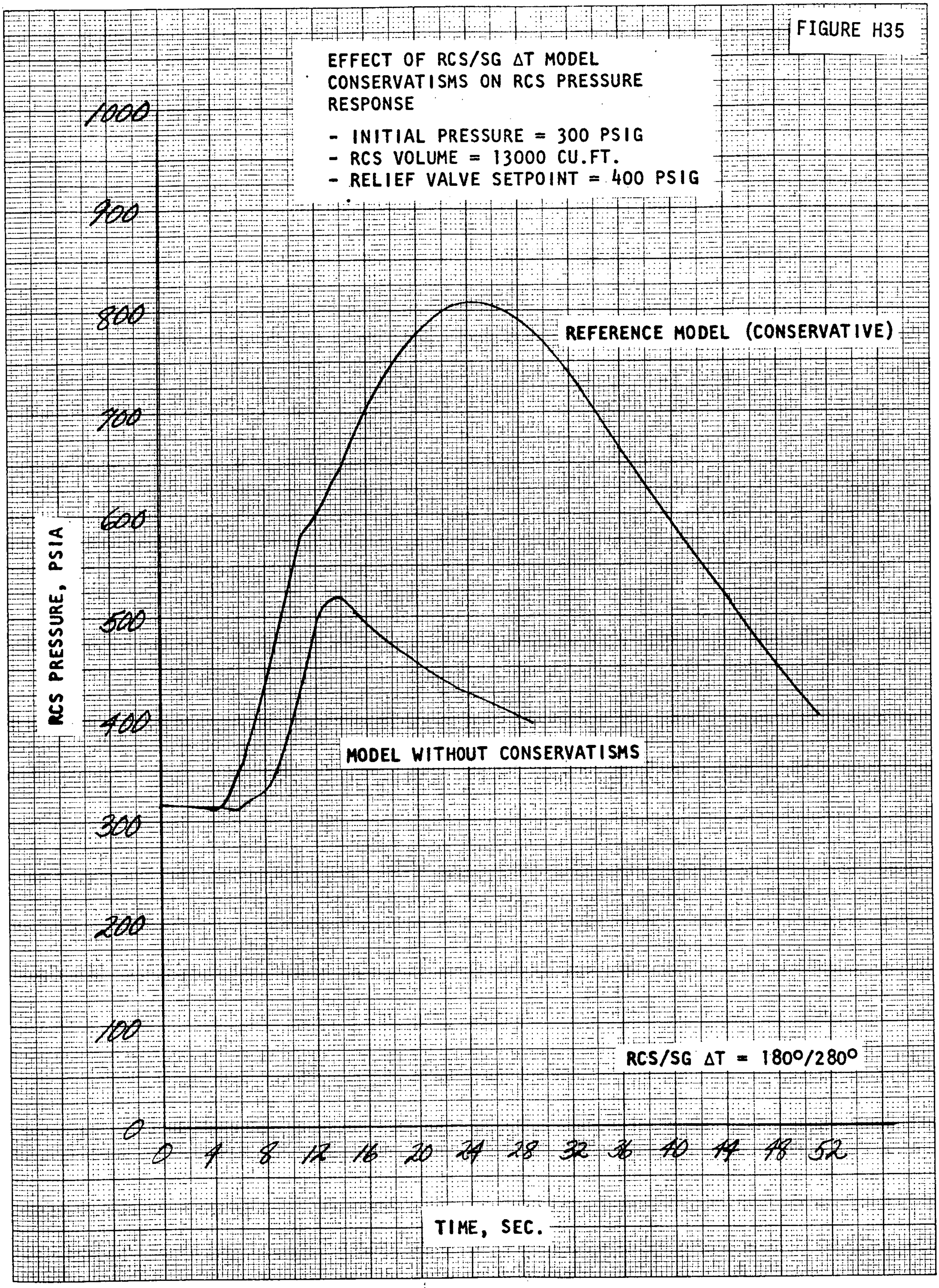
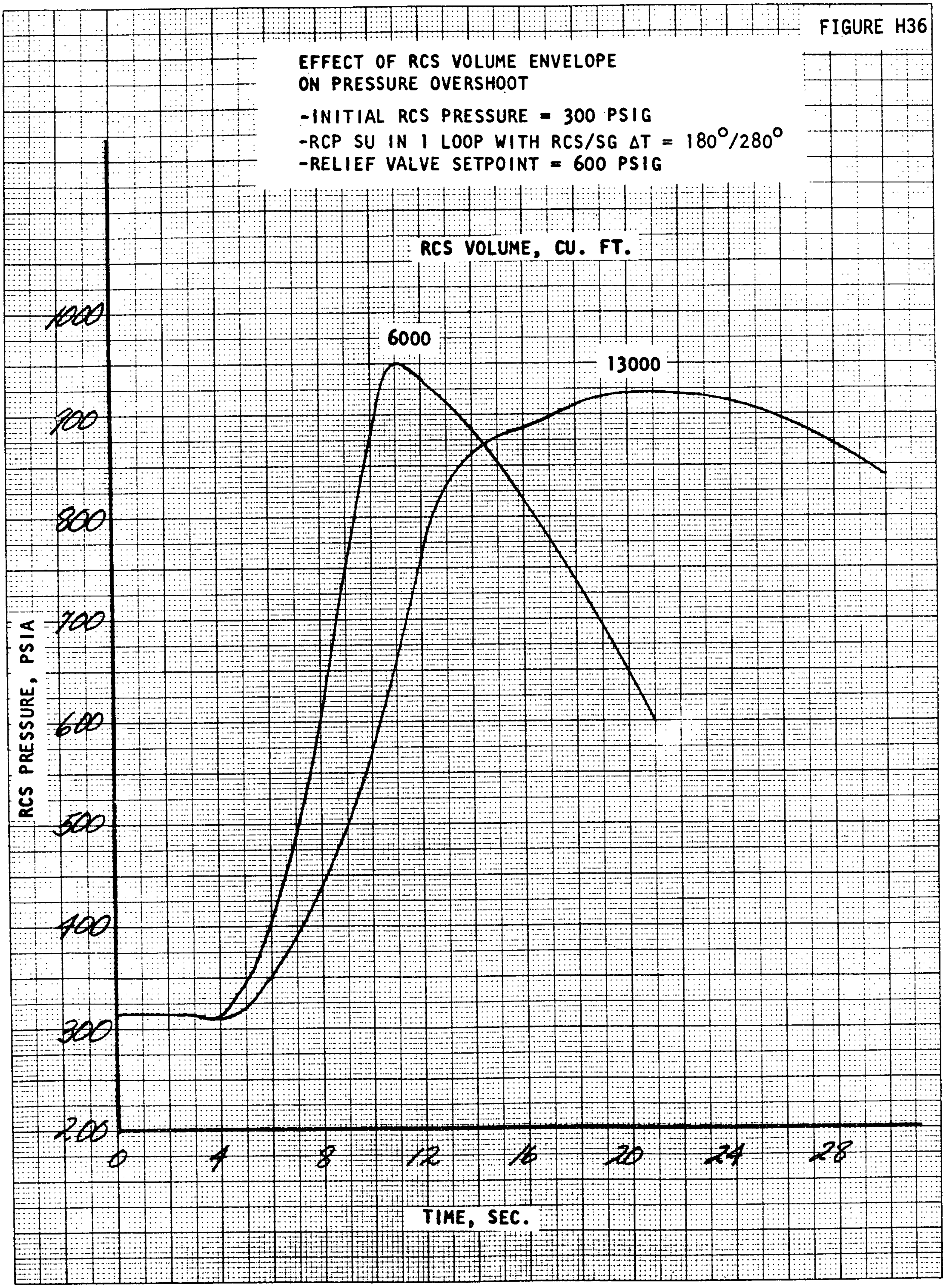


FIGURE H35
EFFECT OF RCS/SG ΔT MODEL CONSERVATISMS ON RCS PRESSURE RESPONSE
- INITIAL PRESSURE = 300 PSIG
- RCS VOLUME = 13000 CU.FT.
- RELIEF VALVE SETPOINT = 400 PSIG
REFERENCE MODEL (CONSERVATIVE)
MODEL WITHOUT CONSERVATISMS
RCS/SG ΔT = 180°/280°
RCS PRESSURE, PSIA
1000
900
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
28
32
36
40
44
48
52
TIME, SEC.



461510

K&E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A.

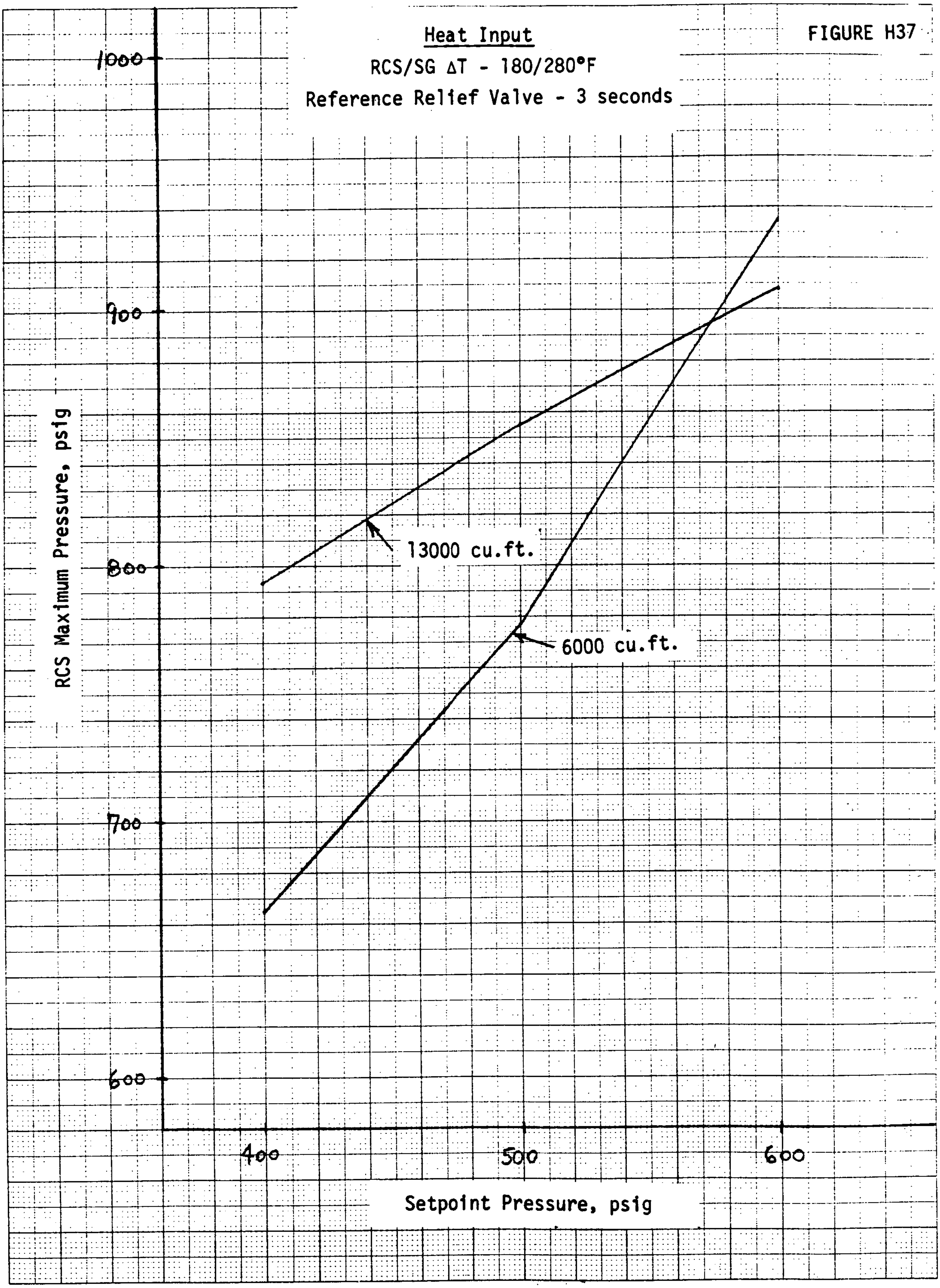


FIGURE H37
Heat Input
RCS/SG ΔT - 180/280°F
Reference Relief Valve - 3 seconds
1000
900
800
700
600
RCS Maximum Pressure, psig
13000 cu.ft.
6000 cu.ft.
400
500
600
Setpoint Pressure, psig

APPENDIX C

TABLE 1

INCIDENTS OF PRESSURE

TRANSIENTS BEYOND TECH. SPEC. LIMITS

	INCIDENT (Date)	CAUSE DESCRIPTION	PRESSURE TRANSIENT FROM (PSIG)	TO	TECH SPEC LIMIT (PSIG)	TIME TO REACH PEAK PRESSURE (minutes)
1.	Beaver Valley Unit No. 1 (2/24/76)	Operator error in transferring electrical buses caused instrument spike isolating letdown from RHR System	400	1000	440 (130 F)*	Note 1
2.	Indian Point Unit No. 2 (2/16/72)	Unknown	420	670	500 (140 F)*	2
3.	Indian Point Unit No. 2 (2/17/72)	Operator isolated letdown without verifying availability of letdown thru RHR system	420	650	500 (180 F)*	2
4.	Indian Point Unit No. 2 (3/8/72)	Reactor coolant pump starting swept cold water thru hot steam generator-pressure increase due to thermal expansion	400	640	500 (115 F)*	1
5.	Indian Point Unit No. 2 (4/6/72)	Operator inadvertently isolated letdown	420	680	500 (170 F)*	2
6.	Indian Point Unit No. 2 (5/18/73)	Closure of certain air operator valves in reactor coolant letdown system caused by freezing of moisture in air supply line.	440	575	500 (130 F)*	Note 1

	INCIDENT (Date)	CAUSE DESCRIPTION	PRESSURE TRANSIENT FROM (PSIG) to		TECH SPEC LIMIT (PSIG)	TIME TO REACH PEAK PRESSURE (min.)
7.	Indian Point Unit 2 (1/23/74)	Starting of a single reactor coolant pump caused pressure surge. A nitrogen blanket in the pressurizer to act as a surge volume had been established; however, the amount of nitrogen added to the pressurizer was insufficient.	425	525	500 (190 F)*	Note 1
8.	Indian Point Unit No. 2 (2/22/74)	An inadvertent safety injection signal was generated which, by design, caused the accumulator discharge stop valves to open.	150	560	500 (115 F)*	Note 1
9.	Oconee Nuclear Station Unit 2 (11/15/73)	During Zero Power Physics testing, test procedure instructions directed operating personnel to increase reactor coolant pressure to approximately 1860 psig violating the limits.	800	1860	1600 (300 F)*	30
10.	Palisades (9/1/74)	A procedure "CAUTION" statement was not rigorously adhered to while performing a primary coolant system leak test	---	960	Requires 160 F to pressurize above 885 (150 F)*	---

	INCIDENT (Date)	CAUSE DESCRIPTION	PRESSURE TRANSIENT FROM (PSIG)	TO	TECH SPEC LIMIT (PSIG)	TIME TO REACH PEAK PRESSURE (min.)
11.	Point Beach Unit No. 2 (12/10/74)	Following repair, a safety injection pump was lined up for a test run. However, safety injection pump discharge was not isolated from injecting into the reactor coolant system. Pressure transient caused by starting of SI pump.	345	1400	615 (850) (170 F)*	30 Seconds
12.	Point Beach Unit No. 2 (2/28/76)	Operational reasons required the RHR system to be isolated from the reactor coolant system. Reduced letdown resulted in pressure increase	400	830	615 (168 F)*	Note 1
13.	Prairie Island Unit No. 1 (10/31/73)	Reactor coolant pump starting swept cold water thru hot steam generator-pressure increase due to thermal expansion	420	1100	720 (132 F)*	Note 1
14.	Prairie Island Unit No. 1 (1/16/74)	While conducting Safeguards Logic Train A monthly surveillance test, a SI signal was initiated when a step which puts Train A in TEST was inadvertently missed. The SI signal opened No. 11 accumulator outlet isolation valve. RHR System isolation occurred as designed at 600 psig.	395	840	610 (90 F)*	Note 1

INCIDENT (Date)	CAUSE DESCRIPTION	PRESSURE TRANSIENT FROM (psig) TO		TECH SPEC LIMIT (Psig)	Time to Reach Peak Pressure (min.)
15. Prairie Island Unit No. 2 (11/27/74)	A test signal injected into the letdown controller instrument loop caused a letdown control valve to go closed. This isolated the letdown path. RHR System automatically isolated.	Note 1	900	800 (155 F)*	Note 1
16. St. Lucie Unit No. 1 (8/12/75)	Letdown isolation valve failed closed when I&C personnel removed cover from sealing relay associated with letdown isolation valve. When relay cover was removed, broken wires on relay became disconnected causing letdown valve to close.	210	600 (660)	520 (105 F)*	Note 1
17. Surry Unit No. 1 (1/28/73)	During process of filling and venting the RCS, "A" accumulator motor operated discharge isolation valve was opened to sweep any air trapped in accumulator discharge line into RCS. The opening of the valve caused the accumulator to cause the increase in RCS pressure.	450	590	500 (80 F)*	1
18. Trojan (7/22/75)	The RHR suction valve from the RCS was closed by an unknown person (i.e., this isolated letdown) while the positive displacement charging pump was operating.	400	3326	520 (between 100 and 105 F)*	10 to 12

INCIDENT (Date)	CAUSE DESCRIPTION	PRESSURE TRANSIENT FROM (Psig)	TO	TECH SPEC LIMIT (Psig)	Time to Reach Peak Pressure ~~(min.)~~
19. Turkey Point Unit No. 3 (12/3/74)	In preparation for starting a reactor coolant pump, the operator placed the letdown control valve in automatic in order to increase reactor coolant pressure. At 465 psig the RHR system loop suction isolation valve automatically closed isolating letdown.	50	800	510 (105 F)*	Note 1
20. Zion Unit No. 1 (6/13/73)	Charging pump 1A, with suction from RWST, was started to increase reactor system pressure. Normal pressure control of continuous charging and letdown was not being used since VCT was unavailable Operator was distracted by a telephone call and left the area of the pump control switch. Unattended pump continued to pressurize system. RHR suction relief valve failed to lift and RHR system later isolated automatically at 600 psig.	110	1290	460 (105 F)*	Note 1
21. Zion Unit No. 1 (6/3/75)	Operator failed to stop the centrifugal charging pump when he secured the RHR system to replace the RHR suction relief valve. When the RHR system was secured, letdown was also secured.	100	1100	480 (115 F)*	10

INCIDENT (date)	CAUSE DESCRIPTION	PRESSURE TRANSIENT FROM (Psig)	TO	TECH SPEC LIMIT (Psig)	Time to Reach Peak Pressure (min.)
22. Zion Unit No. 2 (9/18/75)	Station personnel were performing a RHR valve interlock test in which the RHR System is automatically isolated from the reactor coolant system. When the applied test signal reached the set-point, the RHR isolation valves closed removing the letdown path.	95	1300	450 (88 F)*	15
23. Ginna	The NSSS vendor has indicated that this plant has had an overpressure incident. Further investigation is in progress.				
24. Point Beach Units 1 & 2					
25. Surry Unit No. 1					
26. D. C. Cook Unit No. 1	See item # 26 on next page				
27. Peach Bottom Unit No. 2 (3/6/74)	Following a main steam line isolation test, portions of the reactor vessel shell temperatures decayed to 125 F while reactor pressure remained at approximately 400 psig.	---	400	250 (125 F)*	
28. Beaver Valley Unit No. 1 (3/5/76)	Instrument Technician tripped wrong B/S during MSP, then OPS placed inverter in service with output breaker open, deenergizing #1 vital bus, causing SIS which isolated letdown	400	1150	440 (150 F)*	Note 1

INCIDENT (date)	CAUSE DESCRIPTION	PRESSURE TRANSIENT FROM (Psig)	TO	TECH SPEC LIMIT (Psig)	TIME TO REACH PEAK PRESSURE (min.)
26. D.C. Cook Unit No. 1 (4/14/76)	During RPS testing, inadvertent letdown isolation was initiated.	Note 1	1040	470 (110 F)*	Note 1
29. St. Lucie Unit No. 1 (6/17/76)	With Shutdown Cooling System secured, a reactor coolant pump was started and RCS temperature rose to 140°F - reason unknown as of 6/22/76	300 approx.	820	520 (90 - 100°F)	1

NOTE 1 - The available abnormal occurrence report does not provide this information.

* - Temperature of reactor vessel during transient

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