GENERIC REPORT

OVERPRESSURE PROTECTION FOR OPERATING CE NSSS

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Prepared by

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for

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ABSTRACT

A generic study concerning overpressure protection during low temperature operation for operating Combustion Engineering Nuclear Steam Supply Systems has been completed.

Results of analytical modeling indicates long term means of protection will require both administrative/procedural controls as well as hardware modifications to current system design.

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1.0 INTRODUCTION

A number of PWR overpressurization incidents during low temperature modes of operation have occured in which the 10CFR50 Appendix G pressure limitations have been exceeded. The incidents resulted from inadvertent mass/energy inputs such as letdown isolation, safety injection pump starts, charging pump starts, or reactor coolant pump starts. Unchecked, these mass/energy contributions may result in pressure transients of varying degrees of rapidity.

The purpose of this investigation is to analyze these overpressurization initiating events and design features that are germaine to all CE operating NSSS and provide generic recommendations for positive preventive action. Analytical models are developed to identify the design base event(s) using postulated worse case initial conditions. Inherent in the CE NSSS design are mechanisms and procedural controls which may be used to prevent or mitigate the consequences of an incident. Models depicting these protection capabilities are also incorporated within the design base model to indicate whether these capabilities alone are sufficient. Finally, conceptual design fixes, including applicable design criteria, are addressed in addition to estimated implementation schedules.

2.0 DESIGN CRITERIA

The basic criteria to be applied in determining the adequacy of overpressure protection is that no single equipment failure or operator error shall exceed the operating curve limitations (Ref. 1). In addition to the initiating mechanism and actions that logically follow, common mode failures, operator action time, IEEE and seismic criteria are also considered.

Minimum pressure - temperature (MPT) curves for the 2 to 10 year period of full power operation plant lifetime are used to limit maximum allowable pressure. This limitation provides a reasonable conservatism for current plant operation. The nil-ductility transition temperature (NDTT), upon which the MPT curves are based, decreases with additional radiation exposure. Since metallurgical experience with NDTT is limited, the MPT curves are formulated with gross conservatism. Thus, the 10 to 40 year limitations are considered excessively restrictive as a design criteria. The ongoing capsule-surveillance program which is analyzing irradiated specimens will indicate the merit of MPT curve conservatisms and the choice of 2 to 10 year curve limitations in future analyses.

3.0 SYSTEM DESCRIPTIONS

Contributions of either mass or energy into a closed solid liquid system will result in pressurization of the system. In the case of CE NSSS reactor coolant system overpressurization may be initiated by components within the RCS, shutdown cooling (SDC) system isolation, inadvertant actuation of the safety injection (SI) system, or insufficient letdown in the volume control system. Descriptions of these systems and the possible overpressurization components follow.

3.1 REACTOR COOLANT SYSTEM

As shown in Figure 1, the CE reactor coolant system consists of four reactor coolant pumps operating in two loops with one steam generator in each loop. A pressurizer is attached to the hot leg as is the shutdown cooling suction nozzle(s). Safety injection nozzles are located on each of the reactor coolant pump discharge legs. One letdown and one charging line are located on the respective suction and discharge sides of a coolant pump. Reactor coolant system components which serve as possible overpressurizing inputs are 1) pressurizer heaters, 2) reactor core decay heat, 3) reactor coolant pumps, and 4) steam generators.

In this investigation energy input by pressurizer heaters, conservatively assumes all heaters in operation. For the generic 2560 Mwt class plant full heater input is 1500 KW. Pressurizer to cold leg ΔT limitations are $200^{\circ}F$ to $400^{\circ}F$ for operating CE plants.

When considered, decay heat is a maximum within the temperature ranges of interest (i.e. $\leq 300^{o}F$) when the RCS enters the shutdown cooling mode, a minimum of 3½ hours after shutdown. Conservative estimates of decay heat rates at initiation of shutdown cooling, after attaining refueling water temperatures (30 hours, minimum), and after one week are 1.0, 0.6, and 0.3 percent, respectively.

Reactor coolant pump heat is conservatively considered the thermal equivalent of the pump power rating. When a reactor coolant pump is started while the steam generators are hot (i.e. secondary inventories are at higher temperatures than the reactor vessel coolant), a secondary to primary temperature differential is created and thus heat transfer to the RCS. This heat input will result in a severe overpressurization of a solid system. This transient would be terminated at 2500 psia by ASME Code Class 1 safety valves.

3.2 SHUTDOWN COOLING SYSTEM

The shutdown cooling (SDC) system removes residual and decay heat from the reactor following reactor shutdown and maintains a suitable temperature for refueling and maintenance operations. It is designed to cool the RCS from $300^{o}F$ to the $130^{o}F$ refueling mode temperature. Low pressure safety inject pumps are used to provide coolant flow during SDC operation; containment spray pumps are available as back-up. Primary coolant circulates from the SDC nozzles, through the pumps, through the shutdown cooling heat exchangers, to the low pressure safety injection header, and enters the RCS through safety injection nozzles located on each cold leg.

Maximum SDC suction operating pressure is limited by a pressure interlock to approximately 300 psia. The LPSI or containment spray pumps are used for SDC.

Overpressurization considerations involve inadvertant isolation of the SDC System. An isolation terminates core decay heat removal capabilities. The resulting heat input would cause pressurization in a solid liquid reactor coolant system.

3.3 SAFETY INJECTION SYSTEM

The safety injection system (SI) is designed to supply emergency boration and core cooling in the unlikely event of a loss-of-coolant incident. During normal operating conditions safety injection is initiated by a safety injection actuation signal (SIAS) either when the pressurizer pressure drops below 1600 psia or when containment pressure rises above 4 psig. When depressurizing the RCS, the SIAS is de-activated before pressure decreases below 1600 psia. Should a spurious SI signal occur below 1600 psia, system components which may be activated include two high pressure safety injection (HPSI) pumps, two low-pressure safety injection (LPSI) pumps, three charging pumps and four pressurized safety injection tanks.

Table 1 summarizes the pertinent design parameters for these components.

Each component may be activated separately or as a group. Both HPSI and LPSI pump suctions are aligned to the refueling water tank during safety injection. Delivery curves for these pumps

are shown in Figure 2. The LPSI pumps are also used to supply coolant flow during SDC operation. The SI tanks are passive components which discharge borated water to the RCS whenever system pressure drops below the tank operating pressure and the tanks are not isolated. The charging pumps are reciprocating pumps which supply the RCS with concentrated boric acid solution through the charging line. When ECCS testing can be performed with the RCS either depressurized and open (read off) or above the MPT limiting temperature, inadvertent overpressurization is no longer a concern.

3.4 VOLUME CONTROL SYSTEMS

During normal operations the chemical and volume control system (CVCS) automatically adjusts RCS water volume using a signal from the level instrumentation located on the pressurizer. A pressurizer level control program regulates the letdown flow by adjusting the letdown control valve so that the reactor coolant pump bleedoff plus letdown flow matches the input from the operating charging pump.

During solid RCS conditions the pressurizer level control program fully opens the letdown control valve. Primary system pressure is regulated by adjusting letdown backpressure control valves to balance the charging pump delivery. Isolation of the letdown system will result in pressurization of a solid RCS due to input of the charging pump(s). Data concerning these pumps are given in Table 1.

4.0 OVERPRESSURIZATION CONTRIBUTIONS

Inadvertent operation or isolation of the systems described in the previous sections result in solid RCS pressurizations of varying degrees. Not all mass/energy inputs lead to pressurization above the operating limits dictated by the MPT curves. Those that do not overpressurize CE systems are described below and will not be considered in the detailed analyses discussions later in the report.

1. LPSI pump input; since shut-off heads (approx. 180 psi, see Figure 2b) are below the most restrictive MPT limits, these pumps are not considered as overpressurizing components.

2. SI tank discharge; the maximum design pressure for these tanks is 250 psig, below the minimum allowable pressure limit.

3. Containment spray pumps; these are only used as a backup to LPSI pumps during low pressure operations of the SDC system.

All other previously described inputs are considered contributions to overpressurization; these are tabulated in Table 2. Results of the transient analyses are compared in Figure 3 which clearly shows the more severe cases.

5.0 ANALYSIS

Initiating events applicable to CE plants are analyzed on an individual basis to compare their relative contribution towards overpressurization. Design parameters used to typify generic systems correspond to 2560 Mwt Class plants. Values for these parameters are given in Table 1; and initial conditions for each incident are listed in Table 3. Equations used for the analyses are listed in Appendix B.

The results of Figure 3 show the worse case transients as a RCP start with hot steam generators. In addition to this heat input, pressurizer heaters may be operable at the time of the inadvertent RCP start. Also, one-percent decay heat is possible since SDC is isolated by interlocks above 300 psia. This clearly is the worse combination of inputs and is therefore used as the design basis.

Models used to develop the Figure 3 transients are described in the succeeding section. Also modeled are the relief valve discharge capacities for liquid flow at both normal (2400 psia) and low (415 psia) set pressures.

Models used to depict RCS pressure transients are based on continuity and energy conservation principles. When mass or energy transport from a rigid system is less than the input, the system

is insufficiently protected for overpressurization. In order to protect against excessive transients, the system must be capable of either relieving excess mass and/or energy inventory, or expanding at the system boundaries.

Only solid liquid systems are considered in the analysis. Expansion of the RCS boundaries simulates a "soft" RCS, analagous to having a pressurizer steam space. During certain transients a sufficient steam volume may be procedurally available to absorb any mass addition or liquid expansion. However, the more severe transients involve excessive amounts of mass additions. A steam space only serves to delay the pressure rise until the volume is filled, creating a solid system and rapid acceleration in pressure. In addition, a sufficient steam volume may not be possible to maintain during certain periods of operations.

5.1 MASS ADDITION MODELS

Solid system mass addition models are based on the conservation of mass and energy principles. The following assumptions apply.

1. RCS boundaries are rigid and do not expand under the magnitudes of pressure and temperature encountered.

2. Pressures increase isothermally.

3. Mass addition rates are as specified by the pertinent pump delivery curves (e.g. Figures 2a and 2b).

4. Pump starts are instantaneous step functions (actually, HPSI pumps accelerate to full speed within 4 to 8 seconds).

5. Letdown isolations are instantaneous step functions.

The analyses involve time incremented computations of specific volume changes as a function of mass input. System pressures are found as time dependent functions of specific volume and total system enthalpy. Initial conditions for each model and generic RCS design parameters are tabulated in Table 3 and Table 4, respectively.

The following events require mass addition models to simulate the transients depicted in Figure 3.

1. Single HPSI pump start

2. Spurious SI actuation

3. Charging/letdown imbalance

Besides the mass addition induced pressure excursions, pressurizer heater and/or decay heat inputs may simultaneously occur as a result of normal operating conditions when the initiating event commences. The resulting pressure transients are assumed additive.

5.2 ENERGY ADDITION MODELS

Energy addition models are based on energy conservation with constant system mass. Applicable conservative assumptions are as follows.

1. RCS boundaries are rigid; metal masses do not act as heat sinks.

2. Specific volume remains constant with time.

3. Heat inputs are maximized; i.e. 100°F secondary-primary ΔT's, one-percent decay heat, and full power pressurizer heaters.

4. RCP starts are instantaneous step functions (RCPs attain full speed, linearly, in approx. 10 seconds).

The analyses involve time incremented RCS pressure computations as time varient functions of total system energy content with constant specific volume. The following events require an energy addition model to simulate the corresponding transients of Figure 3. Initial conditions for each model and generic RCS design parameters are tabulated in Table 3 and Table 4, respectively.

1. RCP start with hot steam generators.

2. SDC Isolation

3. Pressurizer Heater Actuation

5.3 RELIEF VALVE MODELS

Discharge capabilities of relief valves are modeled to indicate their effect upon overpressurization. Using the Bernoulli equation and continuity principles, the liquid discharge rate is modeled as an orifice discharge. Since the overpressure protection occurs

during liquid conditions, discharge coefficients are used conservatively as 0.60, assuming liquid flow. Valve discharge capabilities are pressure dependent relative to the rated capacity at the valve set point; i.e. as RCS pressure increases the valve discharge increases as function of the square-root ratio to the set pressure.

6.0 DESIGN BASE INCIDENT

The most severe pressure transients are shown in Figure 3 as 1) a RCP start with hot steam generators, and 2) a spurious SI signal which includes two HPSI pumps and three charging pumps (as discussed in Section 4.0, LPSI pumps and SI tanks are not considered). For the design base incident, both SI trains are assumed administratively isolated below 200°F. A requirement of sufficient pressurizer steam volume for temperatures above 200°F is assumed before activating the first HPSI pump; the second pump is assumed administratevely isolated below 260°F. In view of these assumptions, the transient resulting from the RCP start when the system is water solid is considered the design base. These assumptions are discussed later as conceptual administrative fixes.

6.1 INITIAL CONDITIONS

Worse case design base initial conditions are 300 psia RCS pressure, saturated temperature in the pressurizer, heaters at full power, and a one-percent decay heat addition rate. Results using these inputs are shown in Figure 4. Also shown in the transient model is the effect of the power operated relief valves (PORV's) when they open at the current set pressure of 2400 psia. Once these valves open, the transient is quickly terminated. The valve discharge coefficient was conservatively assumed as 0.60 since PORV's have not, to date, been rated for liquid service. ASME Code Class 1 safety valves protect the RCS at 2500 psia.

6.2 DESIGN BASE INCIDENT MODEL DESCRIPTION

The design base analysis simulates a closed water solid RCS with time varient heat addition from each steam generator; core decay and pressurizer heater input is considered on a bulk basis to the system. Steam generator heat input is a function of 1) the transient secondary water and metal mass heat content located within the downcomer section of the generator, 2) the transient average tube primary temperature, and 3) the volume flow rates through each generator.

Overall heat transfer coefficients are considered flow dependent; hence, different coefficients for each steam generator. The convective coefficients outside the generator tubes are calculated as in Reference 2 for a batch cooling model. Coefficients are calculated assuming initial steam generator and tube flow conditions and are assumed constant with time. A detailed tabulation of initial conditions and system parameters is shown in Table 5.

6.3 LOW PORV SET POINTS

Shown in Figure 5 are the resulting transients when PORVs are incorporated within the design base model, set at 400 psig. The valve models assume discharge areas of 1.29 in^2 per valve, discharge coefficients of 0.60, back pressures of 50 psig, and maximized pressurizer temperatures of 420^{o}F (saturated temperature a transient initial pressure of 300 psig). Valve relieving capacity is pressure

dependent; i.e. as RCS pressure increases, the discharge rate also increases (as discussed in Section 5.3) A comparison of Figure 5 results with minimum allowable pressures (from 2 to 10 year MPT curves, Figure 6) indicates sufficient protection is provided with two valves for cold leg temperatures above 160°F.

7.0 CONCEPTUAL SOLUTIONS AND RECOMMENDATIONS

Discussions concerning possible solutions are categorized below.

7.1 SHORT TERM MEASURES

Solutions which can be implemented immediately, requiring only administrative/procedural action, are as follows. These measures are presently being pursued.

1. Procedural controls to avoid water solid conditions by maintaining a pressurizer steam space for as low a temperature as possible.
2. Administrative isolation of non-essential components which are possible overpressurization contributors (e.g. HPSI pumps, RCPs, pressurizer heaters, charging pumps).
3. Briefing of operators to increase awareness of potential problems.
4. Single set-point alarms beneath MPT limitations to alert operators of a pressure excursion.

7.2 LONG TERM MEASURES

Two possible means of physically controlling pressure transients exist: 1) release of excess system mass and energy, and 2) providing a compressible cushion by either generating a steam bubble or by adding a noncondensible (e.g. nitrogen) bubble to the system. Each of these solutions has limitations.

Liquid relief valves may be incorporated in the system design during low pressure-temperature operation. However, practical limits of a maximum obtainable relief rate exist(i.e. size, number of

valves, and back pressure flow limitations). In addition, contaminated discharges result and should be contained.

During transients for which liquid relief is impractical, a compressible pressurizer bubble is attractive. Sudden coolant expansions or inventory increases are almost instantaneously controlled with sufficient volume. Shortcomings include volume magnitudes which are needed to handle the entire transient. Non-condensible volumes should be avoided. Problems which may be encountered when gaseous pressurizer volumes are employed include 1) venting, 2) disposal, and 3) RCS chemistry effects.

Long term solutions to overpressurization must incorporate both forementioned means of protection. Specific solutions can only be realized after an analysis for each specific plant is completed. Recommended long term solutions are discussed in the following sections.

7.2.1 ADMINISTRATIVE CONTROLS

Recommended long term administrative/procedural controls are as follows:

1) HPSI pumps should be isolated below 200°F (indicated cold leg temperature).

2) Before electrically activating the first HPSI pump, a minimum steam volume is necessary to absorb mass input resulting from spurious SI actuation. The second HPSI pump should be activated above 260°F. This temperature assures MPT limits above pump shut-off head.

Technical Specifications are satisfied since both HPSI pumps need not be operable below 300^{o}F.

3. Reactor coolant pump operation may be administratively controlled for pressures below 300 psia and when a steam space does not exist in the pressurizer. Pump sweeps of solid systems may be necessary; protection for this case is discussed in Section 7.2.2.

4. A minimum steam volume (approx. 300 ft^3) is recommended before operating RCP's. This volume will absorb the liquid expansion should RCP/steam generator heat input be added to the primary coolant during heat-up.

5. Administratively ensure that the ΔT between the steam generators shell side and RCS is minimuzed.

7.2.2 HARDWARE MODIFICATIONS

Measures requiring physical modifications to the RCS include the installation of dual set-point relief valves to provide protection. Both mechanical (spring-loaded) and power operated relief valves (PORV's) are available. Each type of valve has limitations.

Spring-loaded relief valves are certified (American Petroleum Institute) for liquid service. However, the valves are not presently of seismic class. Also, spring-loaded valve set-points are not variable.

Power operated relief valves (PORVs) have not to date been certified for liquid service conditions. These valves are seismically rated, and may have variable set-points. A test program to qualify PORV operability and performance furing liquid service will be conducted.

Included in the design of current CE operating plants are PORVs set at 2400 psia. If qualified for liquid service they could be used for overpressure protection with low pressure set-points. The design base model analysis (Section 6.3) indicates the current PORVs will provide sufficient protection. Use of these, or equivalent low set-point valves would provide the protection against a possible RCP sweep overpressurization.

If current PORVs were used an additional auxiliary controller for low set-points would be required.

The following operations would be necessary to provide the RCS with overpressure protection when utilizing current PORV's. A suggested low set-point pressure is 400 psia. g

1. For plant cooldown from hot standby, an overpressure protection alarm occurs at a pressurizer pressure of 400 psia to alert the operator that PORV's need to be reset to their low set-point and unisolated, respectively. Prior to solid water plant operation when pressurizer pressure is approximately 350 psia the PORV's are reset and unisolated.

2. For plant startup from cold shutdown to hot standby, at a pressurizer pressure of approximately 350 psia, and with a bubble formed, the PORV's are isolated and reset to the normal value of 2400 psia. Once reset the valve may be unisolated.

Were a pressure transient to develop, the following events would take place to prevent the reactor vessel from exceeding design MPT limits.

1. An overpressurization alarm at a suggested pressure of 350 psia warns the operator of a pressure surge and an imminent relief valve opening at 415 psia pressurizer pressure.

2. PORV's open at approximately 415 psia, providing the plant with total overpressure protection. When the transient is reduced to PORV blowdown pressure the valves close.

7.2.3 ADDITIONAL CONSIDERATIONS

Disposal of discharged primary coolant is a major factor to consider in the overall solution. The advantage of administratively controlled electrical isolation and steam volume cushion solution is the minimization of primary coolant discharge from the RCS boundaries. In cases where coolant discharges cannot be avoided (e.g. after the steam volume is filled, or when RCS is swept by RCP when solid), the following precautionary measures should be considered.

1. Avoid excessive discharge piping backpressure build-up which may restrict discharge rate and possibly eliminate the use of existing relief valves.

2. Contain the discharge or direct it to a confined disposal site (eg. the containment sump). Alternate vessels other than the pressurizer quench tank should be considered since this tank was not designed to handle massive or prolonged discharges. Reaction

forces on the discharge piping should also be considered for liquid/two-phase discharges.

Locations which may be considered for placement of liquid relieving valves should not involve a hydrostatic test of the RCS, i.e. relief valve(s) should be added on the "outside" of an isolation valve so the connection may be hydro-tested while isolated from the RCS.

Space limitations may effect placement of relief or isolation valves on present pressurizer PORV lines. Additional locations for consideration are on isolable letdown lines and the RCS drain system. Installation of permanent pressure-temperature records would also be beneficial in determining the severity of future events.

8.0 DESIGN CRITERIA FOR ESTABLISHING LONG TERM SOLUTION

The design considerations listed here in will be evaluated for each plant specific long term overpressurization solution design and procedure. Specific designs will specify the applicability of each or combinations of the following:

1. Operator Action - Credit for operator action will not be taken until 10 minutes after the overpressurization initiating event. Earlier corrective action can be assumed if an alarm, dedicated for this service, is provided as part of the design. Set-points for the alarm(s) indicated for this service will be determined by the design and hardware used to mitigate overpressurization. Since most initiating events result in overpressurization in less than one minute, insufficient time exists for the operator to prevent overpressurization once initiated.

2. Single Failure- The design basis for any proposed design, either set-points or hardware, shall be such that a single failure will not precipitate a LOCA when the system is in a passive, non-operational mode. Testability will be incorporated into the design logic to verify that hardware, dedicated to prevent overpressurization, is operable. Guidelines will include testing function of position indication of valves and actuation systems to insure valve operability.

3. Common Mode Failure - Common mode failure will be considered for any design dedicated to prevent overpressurization. Common mode failure will be considered such that the single failure that precipitated the initiating overpressurization event will

not disable the overpressure protection design. Typical events could be loss of off-site power or loss of instrument air supply.

4. IEEE Criteria - The electrical design will consider single failure as stated in (2) above. Isolation criteria consistent with IEEE279 will be used to preclude the possibility of a LOCA during plant operation at power. Since a single failure causes the initiating event only, a second failure will not be part of the central design logic. However, electrical separation will be considered, when required, to satisfy common mode failure criteria discussed in (3) above.

5. Seismic Category - Consistant with the fundamental design objective of preventing another potential LOCA pathway, isolation of dedicated hardware will meet seismic Category I criteria when it forms part of the Reactor Coolant System pressure boundary. Equipment specifically designed to prevent overpressurization will not be designed to Seismic Category I. Examples of such equipment are mechanical or power operated relief valves. Seismic requirements will be addressed during common mode failure considerations such as a seismic event precipitating a loss of off-site power or instrument air supply.

9.0 IMPLEMENTATION

A detailed implementation program will be provided with each operating plant specific report. The objective of this part of the report is to define in general what the critical path items are that comply with recommendations made here in as follows.

9.1 PROCEDURE MODIFICATIONS

Changes to procedures are readily implemented subsequent to completion and approval of operating plant specific analysis. Many procedure changes are presently being made as part of the operating plant interim measures. It is expected that the approved procedure changes would be available to operating units within 2 to 3 months of plant specific analysis approval.

9.2 QUALIFICATION TEST PROGRAM

Should this pathway be pursued as a result of specific analysis, the program must demonstrate that existing and/or required hardware will:

1. Operate within the thermal hydraulic conditions analyzed.
2. Satisfactorily pass the liquid or 2-phase mixture as analyzed.

An investigation regarding the feasibility of such a program to be conducted by Combustion Engineering or a capable independent testing laboratory has begun. A program objective is completion prior to June 1, 1977.

9.3 HARDWARE PROCUREMENT

Any system modifications must be done as a two part schedule; part one being procurement and part two installation. Should additional

hardware be required, availability subsequent to completion of operating plant specific analysis is in general as follows:

HARDWARE	AVAILABILITY
Recorders and Alarms	6 months
Motor Operators (2 1/2")	18 months min.
Air Operators (2 1/2")	18 months min.
Air Accumulators (non seismic)	18 months min.
Air Accumulators (seismic N_2)	Presently being qualified. Unknown availability
Piping (2 1/2")	12 months min.
Electrical Hardware	6 months
Instrumentation Indicators	6 months
Transmitter (Class 1)	24 months
Transmitter (Non Class 1)	9 months
Power Operated Relief Valves	15 - 18 months
Mechanical Relief Valves	15 - 18 months
Isolation Valves	18 months min.

Installation schedules will be developed after plant specific analyses are completed.

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10.0 CONCLUSIONS

Based on the analyses, results, and recommendations discussed in the preceeding sections, the following conclusions are presented.

1. In view of their conservative origin, coupled with the ongoing irradiated material surveilance program, pressure limits corresponding to the 2 to 10 year full power operating MPT curves are used as the basis for exceeding operating limits.

2. The most severe transient which may occur during a water solid condition is the RCP start/hot steam generator/decay heat/pressurizer heater input model. This case is the design basis for protection.

3. Pressurizer heater actuations, charging/letdown imbalances, and SDC are considered minor incidents contributing to overpressurization. Design base protection means are sufficient to control these events.

4. Administrative isolation of HPSI pumps below 200°F eliminates a spurious SI actuation from consideration below 200°F.

5. The most positive protection against overpressurization is considered the maintenance of a pressurizer steam volume to as low a temperature as possible.

6. Electrical isolation of non-essential components is also a viable means of protection, especially at low temperatures where pressure limits are lowest. Both HPSI pumps

should be isolated below 200°F (indicated average temperature). Above 200°F, a minimum pressurizer steam volume (size dependent upon specific plant analysis) is recommended. The second HPSI pump should not be activated below 260°F.

7. Relief valves should be incorporated into system designs to provide protection during conditions conducive to overpressurization (i.e. low temperature, water solid system). These valves may be either mechanical or qualified power operated relief valves, depending on the desired operability.

8. If power operated relief valves are desired, operability and performance qualifying tests for liquid service are necessary.

9. Based upon a conservative model for liquid discharge capability PORVs used in operating CE plants will provide sufficient protection for cold leg temperatures above 160°F when set at a low set point of 400 psig. Based on this generic indication, a minimum temperature for operation of RCPs during water solid conditions would be required.

10. Relief valve discharge piping must be considered for flow limiting backpressure build-up.

11. Availability of hardware typically ranges from 6 to 18 months minimum.

12. Administrative measures can be taken to insure that the ΔT between the steam generator shell side and RCS is minimized.

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REFERENCES

1 NRC Letter, Docket No. 50-336, to Utilities dated August 11, 1976

2 Kern, D.Q. Process Heat Transfer, McGraw-Hill Book Co., New York, 1960

3 Kreith, F. Heat Transfer, International Textbook Co., Scranton, Pa., 1969

4 2560 MWT Class Plant Technical Specification

5 2560 MWT Class Plant Operating Procedures:

OP-1, Rev. 2 (B G & E)

OP-5, Rev. 2 (B G & E)

2201, Rev. 3 (NEU)

APPENDIX A

FIGURES AND TABLES

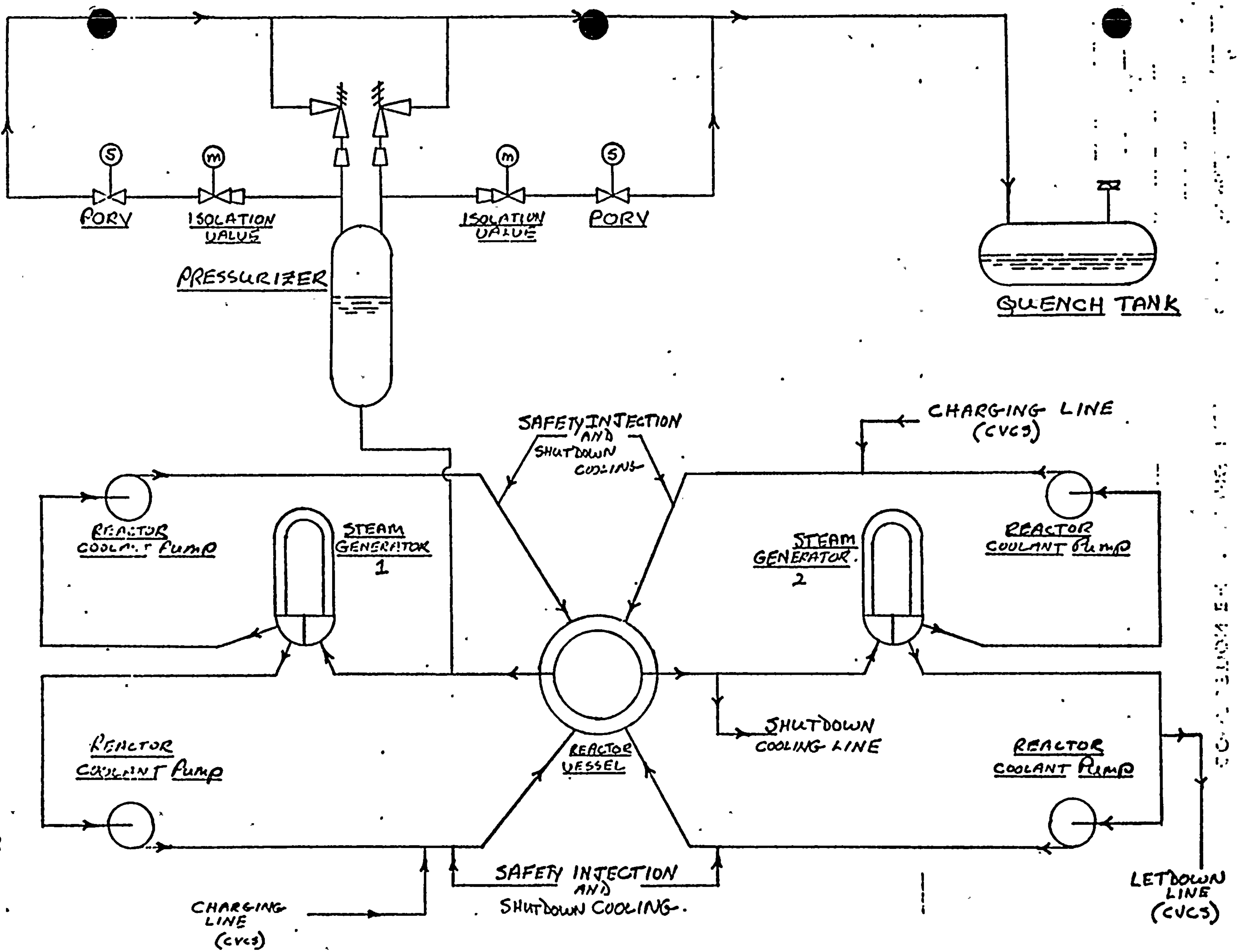


FIGURE 1 • REACTOR COOLANT SYSTEM

FIGURE 2A: TYPICAL TWO PUMP HPSI DELIVERY CURVE

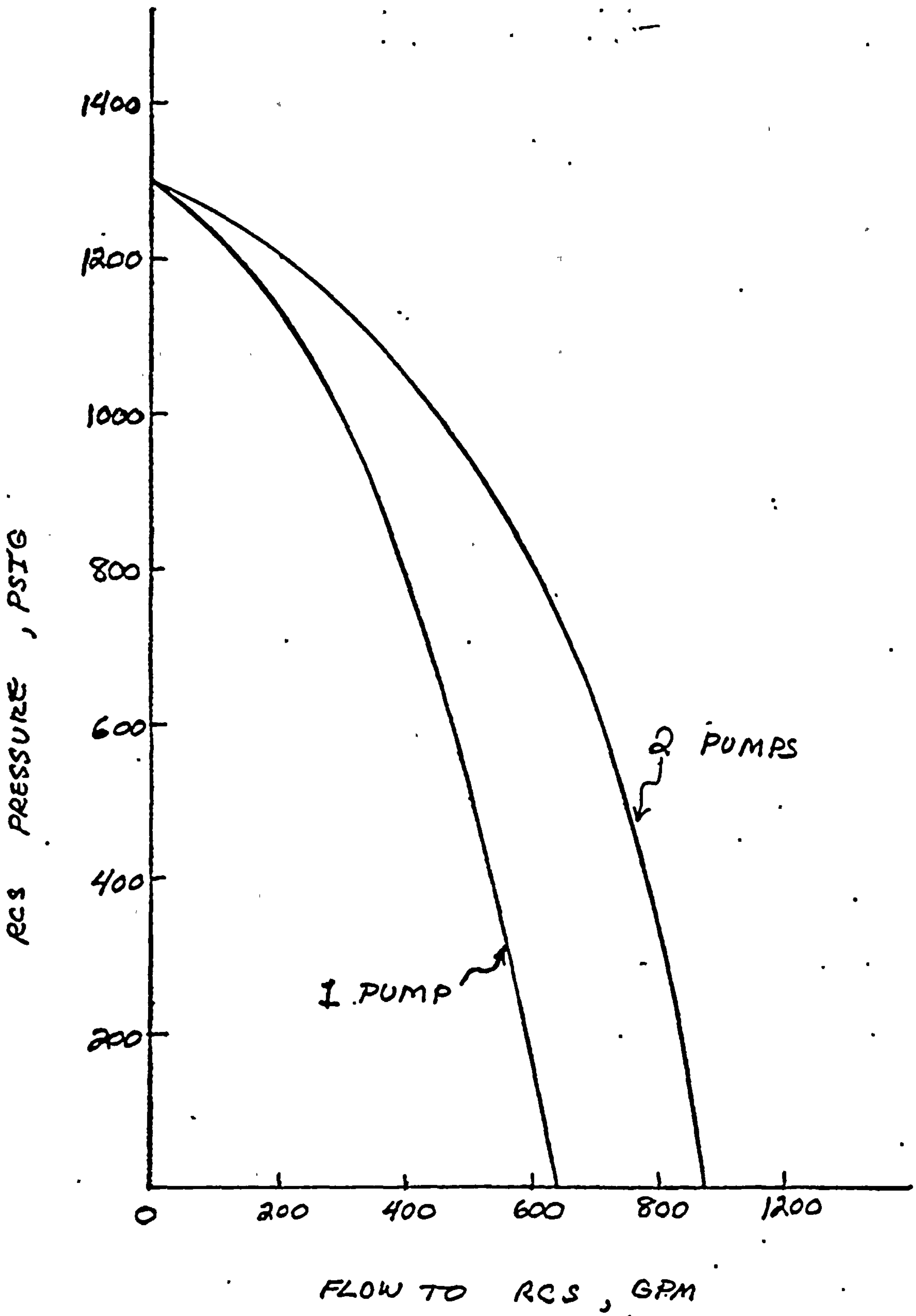


FIGURE 2B: TYPICAL LPSI TWO PUMP DELIVERY CURVE

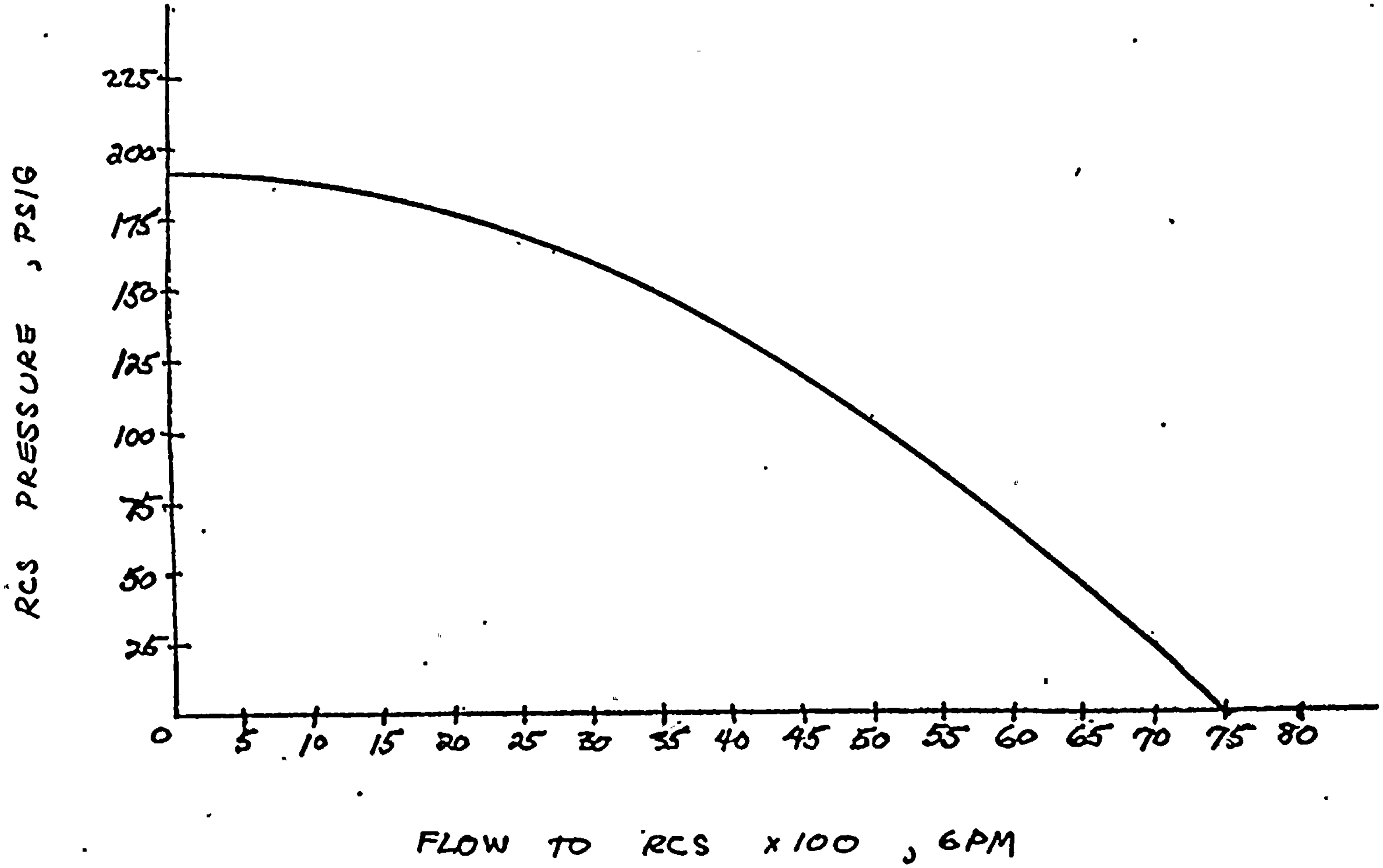
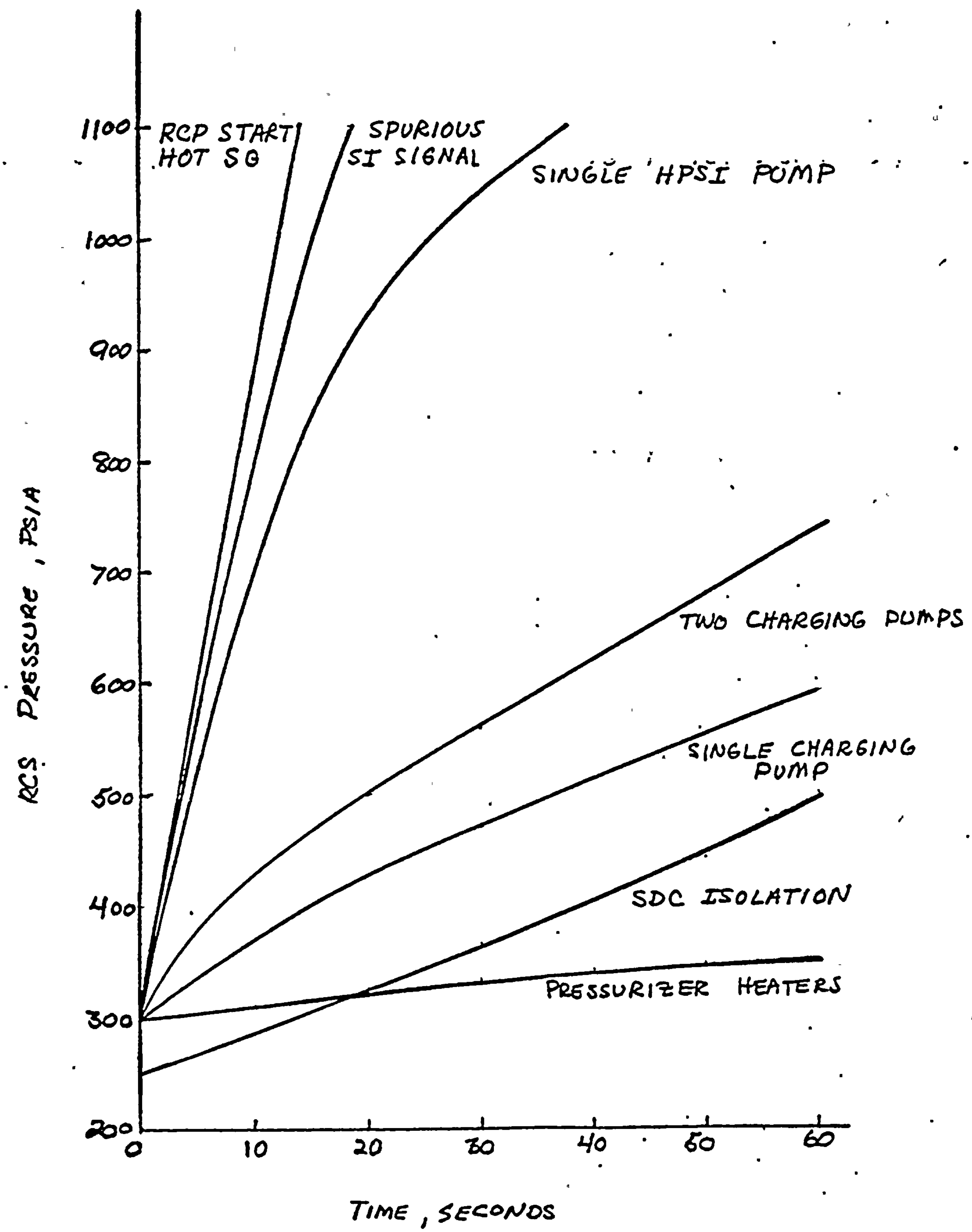


FIGURE 3: OVERPRESSURIZATION TRANSIENTS



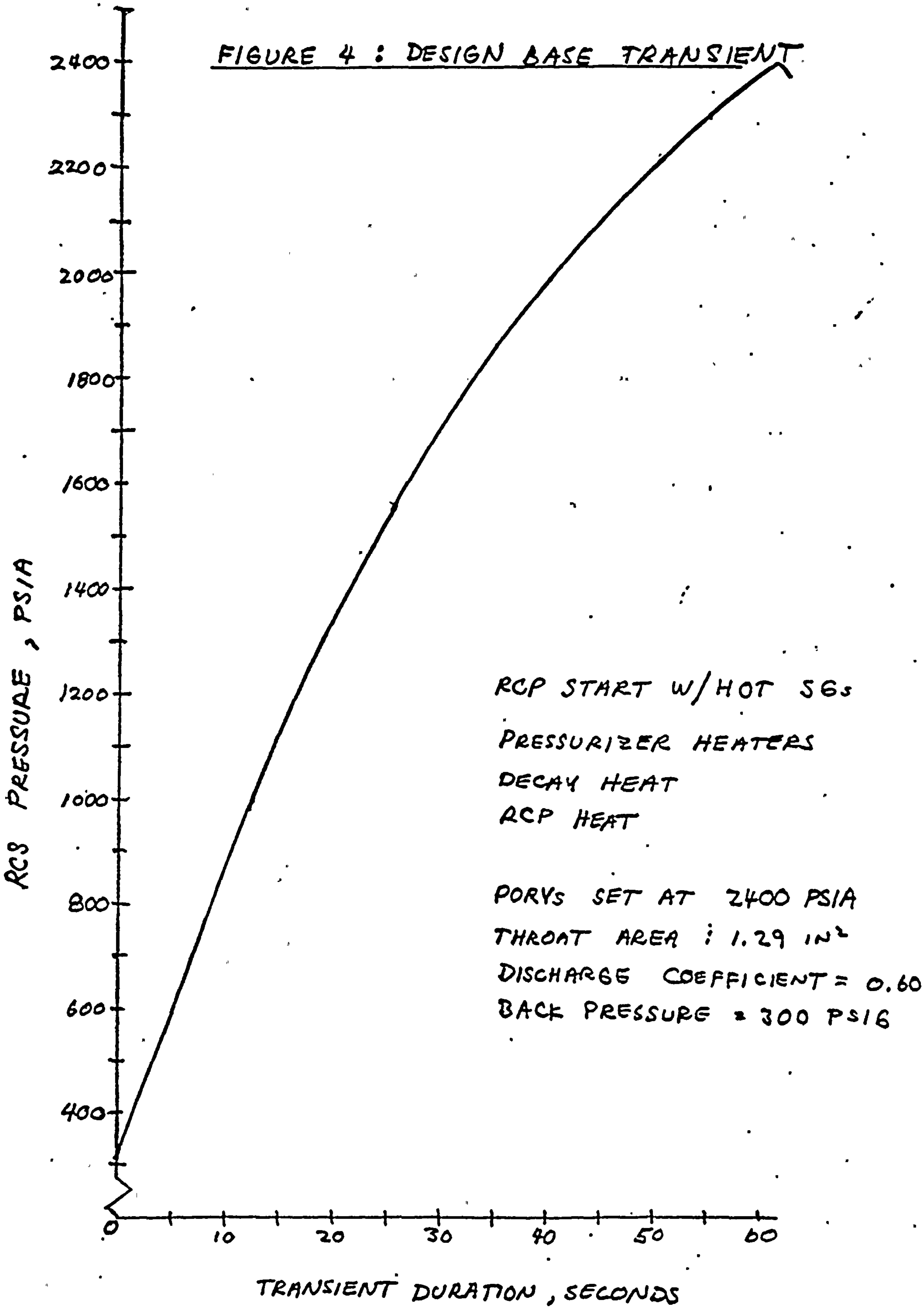


FIGURE 4 : DESIGN BASE TRANSIENT
RCS PRESSURE, PSIA
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
0
10
20
30
40
50
60
TRANSIENT DURATION, SECONDS
RCP START W/HOT SGs
PRESSURIZER HEATERS
DECAY HEAT
RCP HEAT
PORVs SET AT 2400 PSIA
THROAT AREA : 1.29 IN²
DISCHARGE COEFFICIENT = 0.60
BACK PRESSURE = 300 PSIG

FIGURE 5: DESIGN BASE MODEL
LOW VALVE SETPOINT AT 400 PSIG

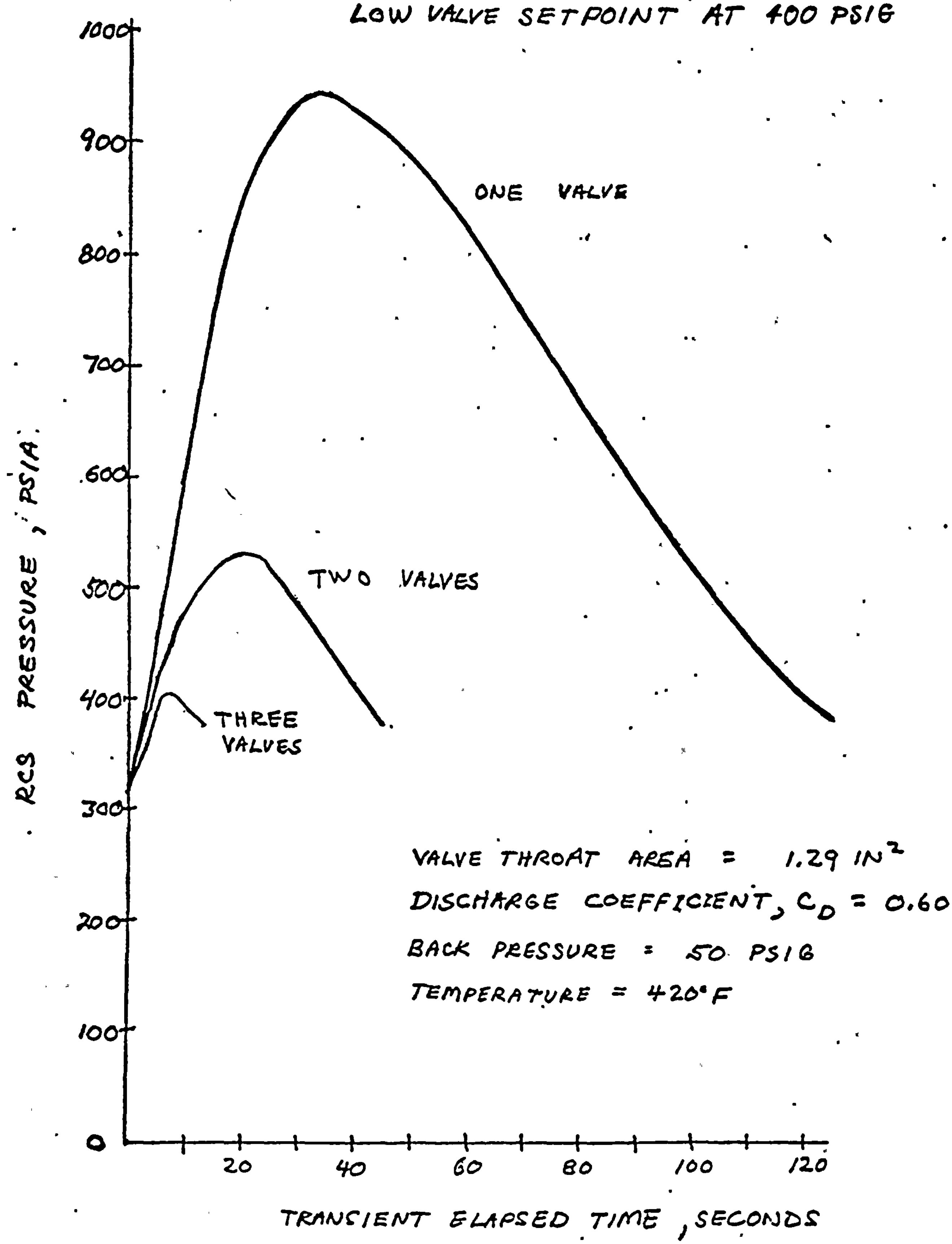
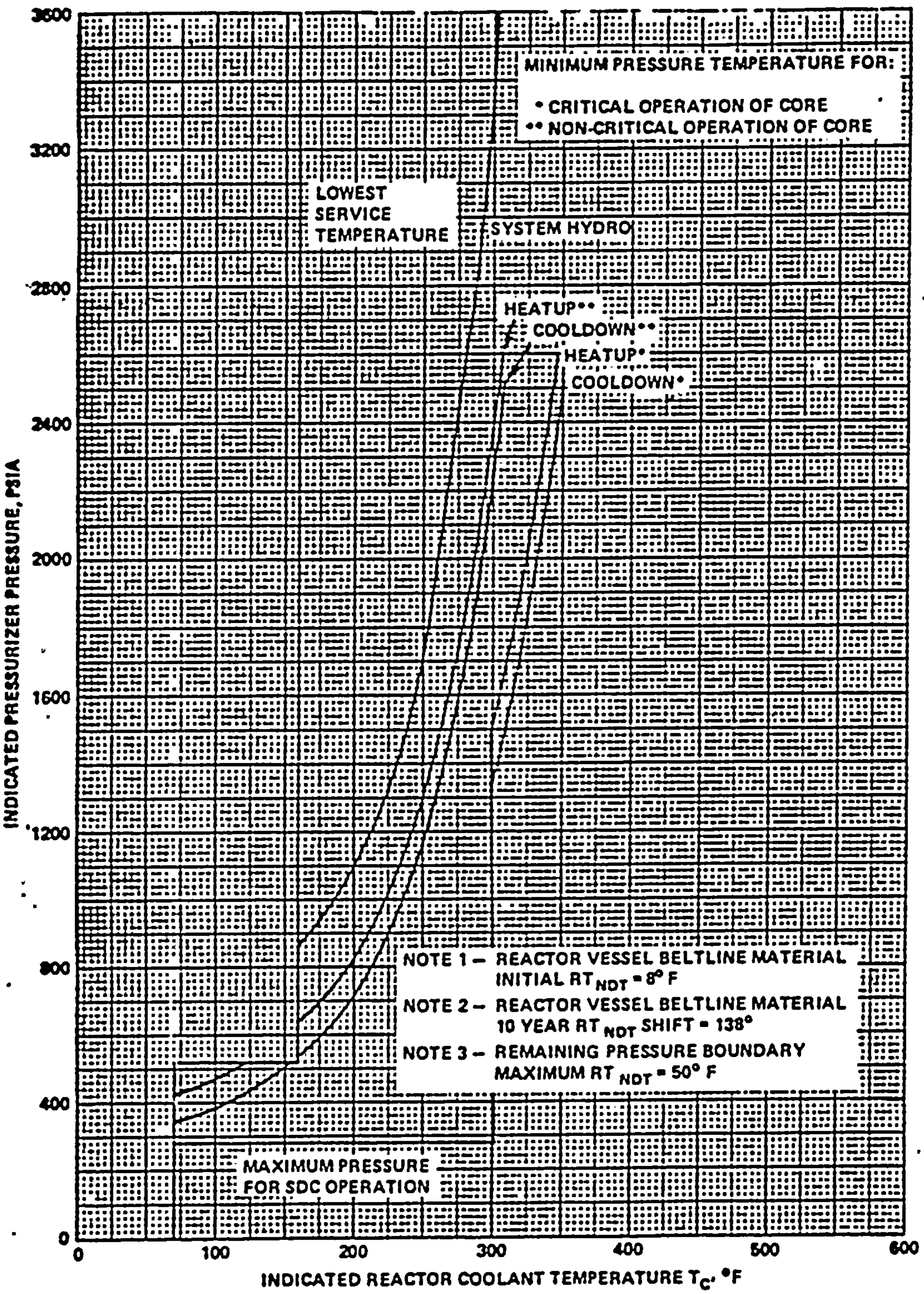


FIGURE 6



Reactor Coolant System Pressure Temperature Limitations
for 2 to 10 Years of Full Operation

TABLE 1: Component Data Summary

Pump Data

	Type	Design Pressure	Capacity	Shut-Off Head
HPSI	Seven Stage Horizontal Centrifugal	1750 psig	See Fig. 2a	2930 ft. (1270 psia @ 60°F)
LPSI	Single Stage Horizontal Centrifugal	500 psig	See Fig. 2b	420 ft. (180 psia @ 60°F)
Charging Pump	Positive Displacement	2735 psig	44 gpm	3010 psig
Containment Spray Pumps	Single State Horizontal Centrifugal	500 psig	same as LPSI	460 ft. (215 psia @ 60°F)

SI Tank Data

Total Volume	2000 ft.^{3}
Water Volume	1113 (min) ft.^{3}
Design Pressure	250 psig
Operating Pressure	200 psig

TABLE 2

Initiating Events Considered Applicable to Operating CE Plants

1. Pressurizer Heater Actuation
2. Shutdown Cooling Isolation
3. Charging/Letdown Imbalance
4. HPSI Pump Start
5. Spurious SI Signal
6. RCP Start with Hot Steam Generators

TABLE 3: Initial Conditions

Event*	Pressure	Temperature	Mass/Energy Input
Pressurizer Heater Actuation	Prcs = 300 psia	T_{ave} = 160°F	1500 KW
SDC Isolation	Prcs = 250 psia	T_c = 200°F	25.6 Mwt (Decay Heat)
Charging/Letdown Imbalance	Prcs = 300 psia	T_{ave} = 160°F	44 gpm/pump One and Two Pump Inputs
HPSI Pump Start	Prcs = 300 psia	T_{ave} = 200°F	per Fig 2a Deliver Curve
SI Actuation	Prcs = 300 psia	T_{ave} = 200°F	2HPSI Pumps 3 Charging Pumps
RCP Start w/Hot Steam Generator	Prcs = 300 psia	T_{sdc} = 100°F T_{sec} = 200°F	Steam Generator Heat Transfer

* RCS is water solid in all cases

TABLE 4: Generic RCS Parameters

Component	Number	Volume (ft^3 per component)
Reactor Vessel	1	4652
Steam Generator	2	1683
Reactor Coolant Pump	4	112
Pressurizer	1	1500
Hot Leg	2	140
Suction Leg	4	112
Discharge Leg	4	80
Surge Line	1	32

Full Power Pressurizer Heater Capacity	1500 KW
Design Core Thermal Power	2560 MW
Reactor Coolant Pump Heat	5.0 MW/pump
Reactor Coolant Pump Capacity	
One-Pump	140,000 gpm
Four-Pump	81,200 gpm

TABLE 5: Design Base Model Parameters

Event: RCP start with hot steam generators

Secondary Energy Contributions:

One-percent Decay Heat	25.6 MW
Pressurizer Heaters	1500 KW
RCP Heat	5 MW

Steam Generator Parameters:

Number	2
Type	Vertical U-Tube
Number of Tubes	8519
Tube Outside Diameter	0.750 in.
Tube Wall Thickness	0.05 in.
Heat Transfer Area	90,232 ft^2
Coolant Volume	1683 ft^3
Dry Weight	1,004,000 lb.
Flooded Weight	1,526,700 lb

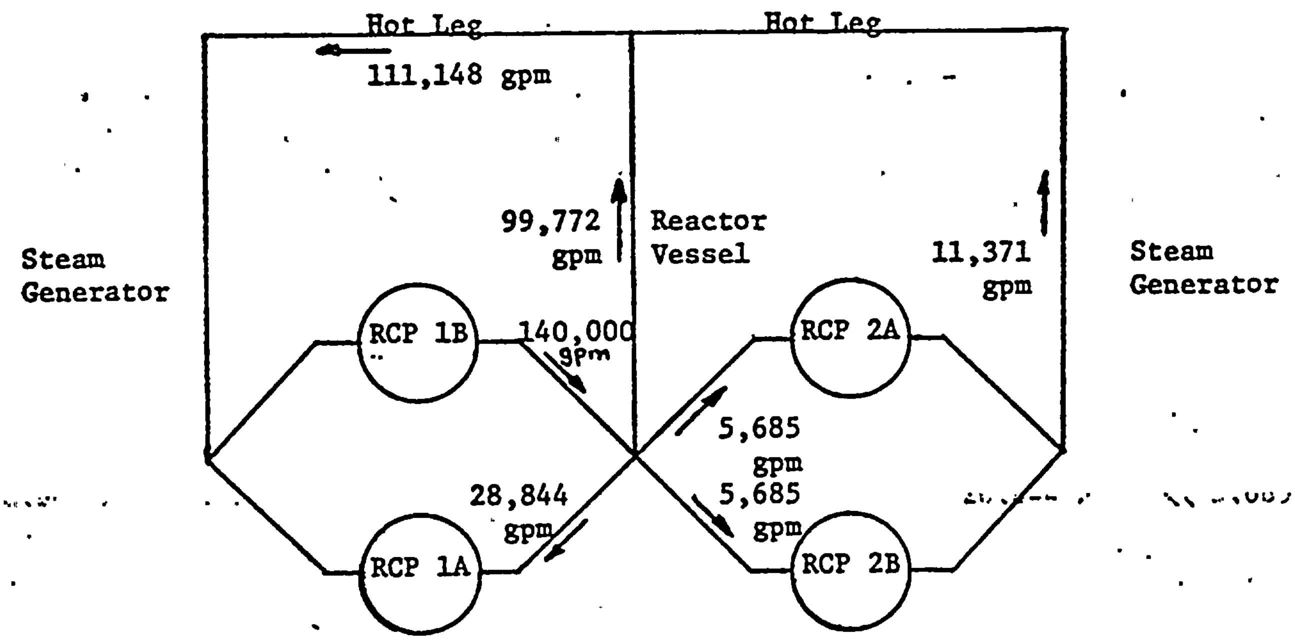
Secondary Masses Considered in Model:

Secondary metal (inside downcomer)	350,000 lb
Secondary water (inside downcomer)	150,000 lb.

(continued)

TABLE 5 (continued)

Single Pump Operation Flow-split:



Overall Heat Transfer Coefficients:

Steam Generator No. 1	264 Btu/hr ft^2 ^{o}F
Steam Generator No. 2	160 Btu/hr ft^2 ^{o}F

Calculated via methods of Ref. 2 and Ref. 3 (See AppendixB)

APPENDIX B

NOMENCLATURE

Letter Symbols

A	area, ft^2
C_D	discharge coefficient
C	specific heat
D	diameter, ft.
d	diameter, in.
HPSI	high pressures safety injection
h	heat transfer coefficient, Btu/(hr)(ft^2)(^oF)
k	thermal conductivity, Btu/(hr) (ft^2)(^oF/ft)
L	tube length, ft.
LPSI	low pressure safety injection
P	Pressure, psia
PORV	power operated relief valve
Pr	Prandtl number
Q	volume flow rate, ft^3/sec.
R	thermal resistance, (hr)(ft^2)(^oF)/Btu
Re	Reynold number
RCP	reactor coolant pump
RCS	reactor coolant system
SDC	shutdown cooling
SI	safety injection
SIAS	safety injection actuation signal

St	Stanton number
T	temperature, ^{o}F
ΔT	temperature difference, ^{o}F
U	overall heat transfer coefficient Btu/(hr)(ft^2)(^{o}F)

Greek Letters

β	coefficient of thermal expansion, $1/^{o}F$
ρ	density, lbm/ft^3
μ	viscosity, centipoises x 2.42 = lbm/(ft)(hr)

Subscripts

b	backpressure
f	evaluated at film temperature
i	inside property
p	primary
o	outside property
rcs	reactor coolant system conditions
s	secondary
set	set-pressure condition
t	throat property

APPENDIX B

Relief Valve Flow Rates:

$$Q = Q_r \sqrt{\frac{P_{rcs} - P_b}{P_{set} - P_b/\rho}}$$

$$Q_r = C_D A_t \sqrt{P_{set} - P_b/\rho}$$

Overall Coefficients of Heat Transfer:

$$U_o = \frac{1}{1/h_o + R_o = R_k + R_i \, (A_o/A_i) + (A_o/A_i)(1/h_i)}$$ (Reference 3)

$$h_o = 116 \left[\frac{k_f{}^3 \rho_f{}^2 C_f \, \beta \, \frac{\Delta T}{d_o}}{\mu_f} \right]^{0.25}$$ (Reference 2)

for R_e 120,000

$$h_i = \left[S_t \, (\mu_s/\mu_p)^n \, f(R_e, P_r) \right] = (k_p/D) \left[R_e, P_r \right]_p (\mu_p/\mu_s)^n$$ (Reference 3)

n = 0.36 for liquid heating

for R_e 120,000, R_e 10,000

$$h_i = 0.023 \, (3600 \, V^{0.8}) \, D^{0.2} k \, (\mu/\rho)^{-0.8}$$ (Reference 3)

R_o =

R_o = 0.001 hr ft^2 °F/Btu

R_i = 0.001 hr ft^2 °F/Btu (Reference 3)

$$R_k = \frac{1}{k/L}$$