50-255

PALISADES PLANT OVERPRESSURIZATION
ANALYSES

dtd 6/24/77 CN #771820204

— NOTICE —

THE ATTACHED FILES ARE OFFICIAL RECORDS OF THE DIVISION OF DOCUMENT CONTROL. THEY HAVE BEEN CHARGED TO YOU FOR A LIMITED TIME PERIOD AND MUST BE RETURNED TO THE RECORDS FACILITY BRANCH 016. PLEASE DO NOT SEND DOCUMENTS CHARGED OUT THROUGH THE MAIL. REMOVAL OF ANY PAGE(S) FROM DOCUMENT FOR REPRODUCTION MUST BE REFERRED TO FILE PERSONNEL.

DEADLINE RETURN DATE

Docket # 50-255
Control #
Date 6/24/77 of Document

RECORDS FACILITY BRANCH

PALISADES PLANT OVERPRESSURIZATION ANALYSES

Prepared by

ENERGY INCORPORATED

JUNE 1977

For

CONSUMERS POWER COMPANY

NOTICE

This report was prepared by Energy Incorporated as an account of work sponsored by Consumers Power Company. Neither Consumers Power Company, nor Energy Incorporated, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, nor assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, nor represents that its use would not infringe privately owned rights.

ABSTRACT

Analyses concerning overpressurization incidents and overpressurization protection during low fluid temperature and water solid operation for the Palisades Plant operated by the Consumers Power Company has been completed.

Results of the analyses indicate that overpressurization protection of the Palisades Plant is possible with the combination of both system modification and appropriate administrative/procedural controls. The results also indicate that one power operated relief valve (PORV) set at a relief pressure of 400 psig has sufficient capacity to provide overpressurization protection for the Palisades Plant.

TABLE OF CONTENTS

TABLE OF CONTENTS (Contd)

LIST OF FIGURES

LIST OF TABLES

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 were exceeded. The incidents occurred as the result of inadvertent mass/energy inputs such as letdown isolation, safety injection pump starts, charging pump starts, or primary coolant pump starts. Unchecked, these mass/energy contributions may result in pressure transients of varying degrees of rapidity.

The purpose of the analyses reported in this document is to evaluate the overpressurization initiating events and design features that are unique to the Palisades Plant and to provide recommendations for positive action to prevent 10CFR50 Appendix G limitations from being exceeded. Analytical models are developed to identify the design base event using postulated worse case initial conditions. Inherent in the Palisades design are mechanisms and administrative/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 the sufficiency of these capabilities. Finally, conceptual design modifications, including applicable design criteria, are addressed in addition to estimated implementation schedules.

2.0 DESIGN CRITERIA

The basic criteria applied in determining the adequacy of overpressure protection for the Palisades Plant is that no single equipment failure or operator error shall exceed the minimum pressure - temperature (MPT) curves[1] for the 2 to 10 year period of full power operation plant lifetime. This limitation provides a reasonable conservatism for current plant operation. The nil-ductility transition temperature (NDTT), upon which the MPT curves are based, increases with additional radiation exposure. Since metallurgical experience with NDTT is limited, the MPT curves are formulated with gross conservatism. The ongoing coupon-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.

Consideration has also been given to operator action, single failure, test ability, seismic consideration, IEEE-279, and common mode failure.

2.1 Operator Action

The criteria for operator action is consistent with that agreed to at the meetings between the CE owners group and the NRC and CPCO letters to the NRC. The plant is operated in accordance with established operating procedures which are configured to be an essential part of the overall plant for protection against overpressurization. In the analysis of postulated events, once the event has occurred, operator action to mitigate its consequences is conservatively assumed not to occur for ten minutes.

The only condition related to operator action considered in the analysis of overpressurization events is that he adhere to normal operating procedures dedicated to PCS overpressure protection. Although the above criteria have been established, there is no dependence on operator action at the ten minute point to mitigate the effects of an overpressurization event. The pressurizer relief valves and the normal availability of the

Shut Down Coolant (SDC) System safety valves provide complete, redundant protection from overpressurization in all the events analyzed.

2.2 Single Failure

The single failure criterion has been applied to both initiating events and the means of mitigating the effect of these overpressurization events. Either a single equipment malfunction or a single erroneous operator control manipulation has been assumed to initiate each of the overpressurization events analyzed. Protection against overpressurization events is provided by the two pressurizer solenoid operated relief valves, each of which when activated is capable of preventing the worst case event from producing results which exceed MPT limits. The SDC System safety valves provide additional relief capacity whenever normal operating procedures require the SDC System to be open to the PCS. Every means practicable has been employed to provide the margin of protection afforded by the single failure criterion in both preventing an event initiation and limiting the effects of an event once initiated.

2.3 Testability

Each pressurizer solenoid operated relief valve can be isolated from the pressurizer by means of an upstream isolation valve. Once isolated, the solenoid operated pilot actuator can be tested for operability prior to plant cooldown. Normal operating procedures will be modified to require this test prior to plant cooldown for each refueling shutdown.

2.4 Seismic Considerations

The pressurizer relief and SDC System safety valves have been designed to meet the requirements of Seismic conditions to which the plant was licensed.

2.5 IEEE-279

Since the pressure control and alarm instrumentation and electric equipment associated with reactor vessel overpressurization protection are not designated as components of a "protection system" as defined by IEEE-279, the requirements of this document will not be all inclusively applied. Separation, redundancy, testing criteria and design for post-LOCA environment are examples of provisions of IEEE-279 not adhered to by this equipment. Additional instrumentation and electrical equipment, where required by proposed design changes, will be specified to meet requirements of the original plant design to which it was licensed to operated.

2.6 Common Mode Failure

There is no single failure of a component or system or single event that has been identified in our analysis as capable of both causing an over-pressurization event and defeating the protection afforded against such events.

3.0 SYSTEM DESCRIPTION

3.1 Primary Coolant System (PCS)

Essentially the functions of the primary coolant system are to transfer heat from the reactor core to the steam generator where the heat is used to produce steam for use in a turbine generator and to serve as a primary barrier to the release of fission products from the reactor core to the environs. The Primary Coolant System Piping and Instrumentation Diagram is detailed on Figure 3.1. The PCS temperatures are measured with temperature elements TE 0111A and TE 0121 B and recorded on wide range recorders TR 0115 and TR 0125, respectively. A more complete and definitive outline of the system is described in Palisades Plant Primary Coolant System Functional Description No. M-10 and a copy is available from CPCO on request.

3.2 Safety Injection System (SIS)

Functionally, the safety injection system is designed to:

(1) Inject borated water into the primary coolant system to flood and cool the core following a loss-of-coolant incident;

(2) Provide for the removal of heat from the core for extended periods of time following a loss-of-coolant incident;

(3) Inject borated water into the primary coolant system to increase shutdown margin following a rapid cooldown of the system (such as a steam line rupture incident);

(4) Remove heat from the primary coolant system during normal cooldown and maintain suitable water temperatures during refueling;

(5) Transfer refueling water from the safety injection and refueling water tank to the refueling canal and return it to the tank upon completion of refueling.

The safety injection system piping and instrumentation diagram is shown on Figure 3.2a and Figure 3.2b. A more thorough discussion of the system is made in Palisades Plant Safety Injection System Functional Description No. FD M-30 and a copy is available from CPCO on request.

3.3 Chemical and Volume Control System (CVCS)

The primary functions of the chemical and volume control system are to:

(1) Maintain the required volume of water in the primary coolant system,

(2) Maintain the chemistry and purity of the primary coolant,

(3) Maintain the desired boric acid concentration in the primary coolant, and

(4) Pressure test the primary coolant system.

The Chemical and Volume Control System is shown in Figure 3.3. A more detailed description of this system is outlined in Palisades Plant Chemical and Volume Control System Description No. 2966-020 and a copy is available from CPCO on request.

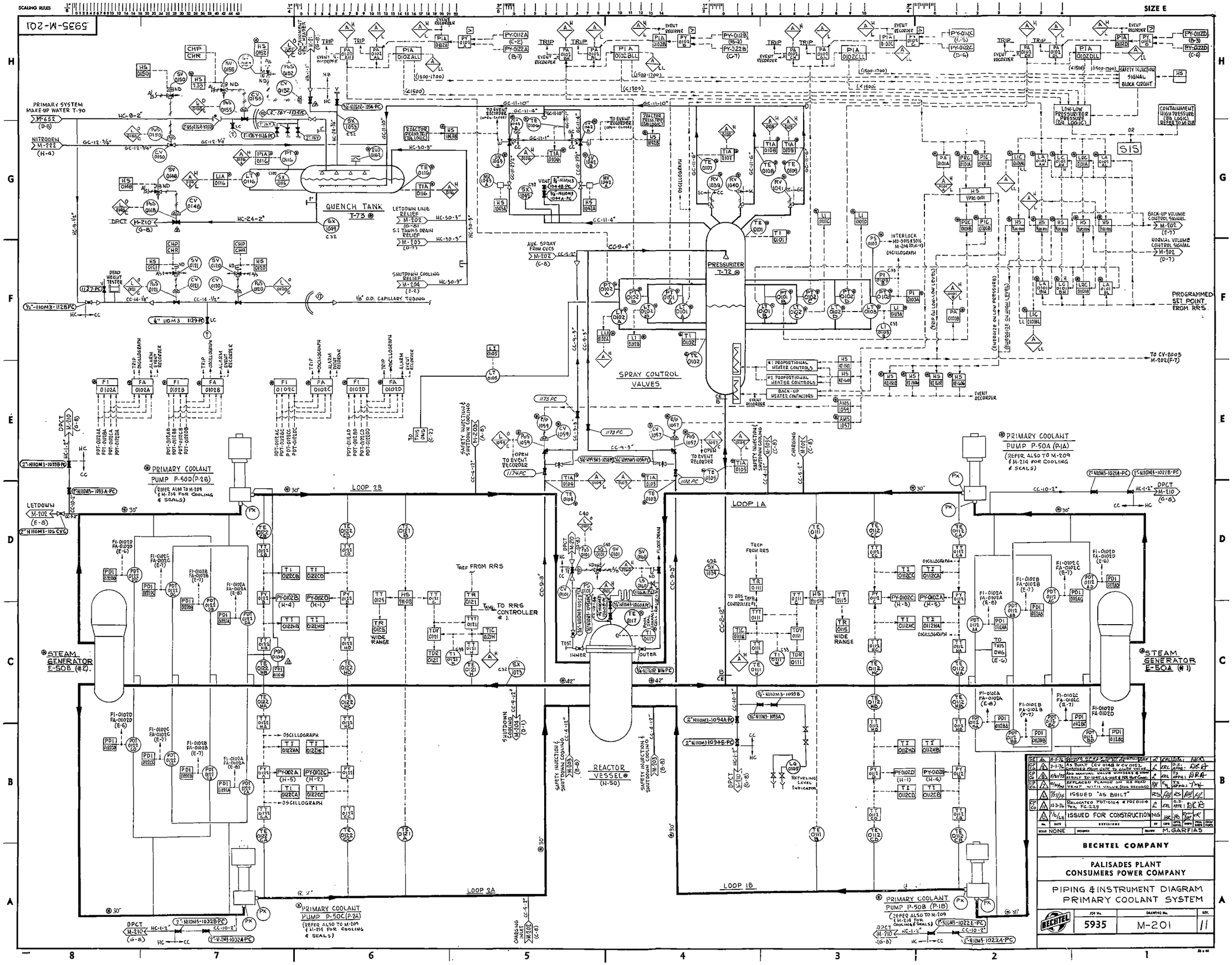

Figure 3.1. PCS Diagram

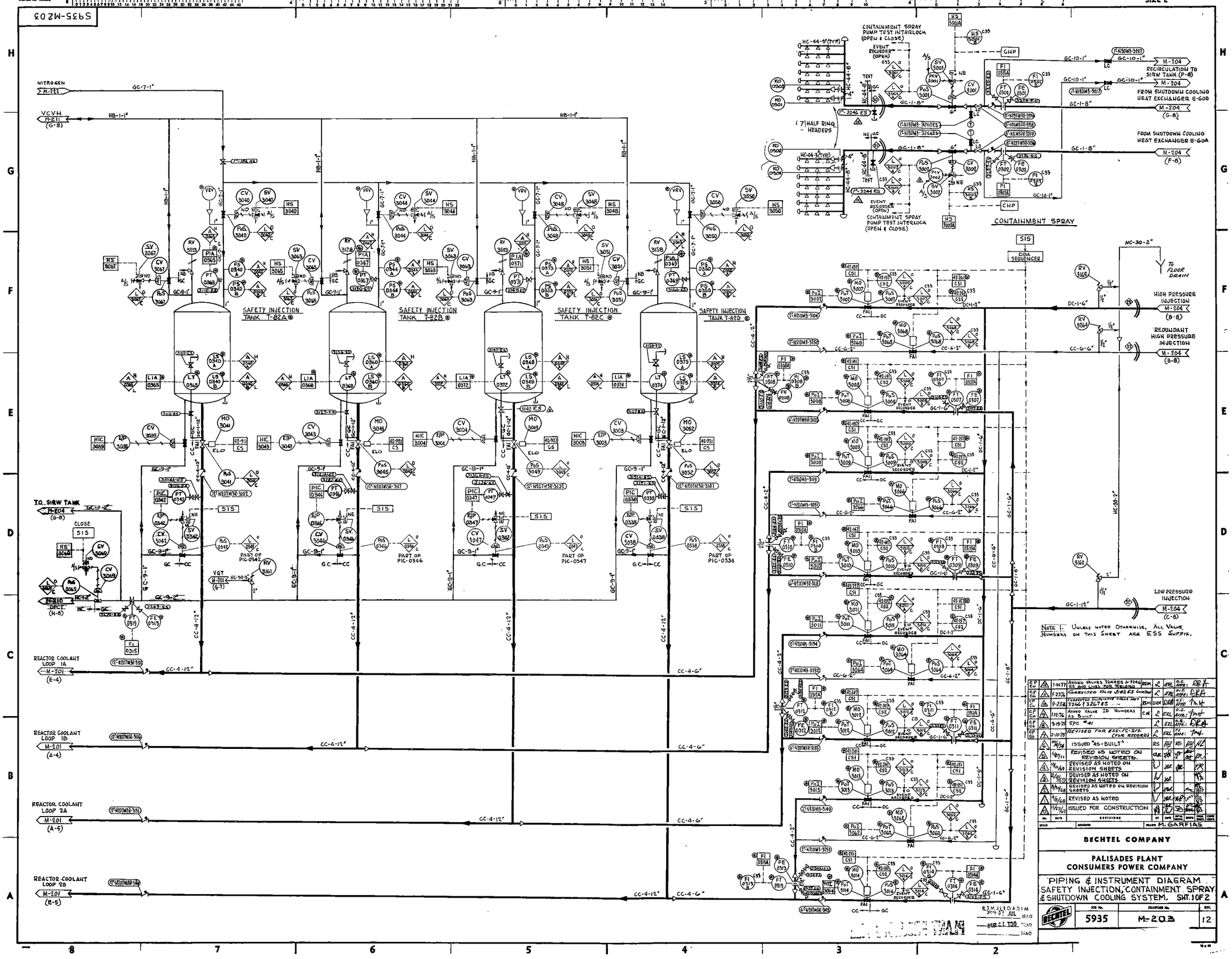

Figure 3.2A. SI, Containment Spray and SDC Diagram

5935-M204

Figure 3.2B. SI, Containment Spray and SDC Diagram

5935-M202

Figure 3.3. Chemical and Volume Control System Diagram

4.0 CONDITIONS CONDUCIVE TO OVERPRESSURIZATION

The following actions at the Palisades Plant could lead to the most severe overpressurization transients:

(1) Primary coolant pump (PCP) start with hot steam generator.

(2) Charging/letdown imbalance

(3) Inadvertent start of a high-pressure safety injection (HPSI) pumps.

The most restrictive fluid conditions that could exist in the Palisades Plant (see Appendix B) before the initiation of an overpressurization transient are:

$T_{\text{steam generator}} = 180°F$

$T_{\text{pressurizer}} = 280°F$

$T_{\text{primary coolant system}} = 120°F$

$P_{\text{primary coolant system}} = 270$ psia

Primary coolant system in water solid condition.

However, in order to provide for a margin of conservatism in the overpressurization analysis for the Palisades Plant, the secondary coolant was assumed to be 212°F.

4.1 Cooldown and Startup Procedures

This section provides descriptions of the cooldown and startup procedures used in the Palisades Plant and descriptions of the fluid conditions in the PCS at which overpressurization transients could be initiated.

4.1.1 Cooldown Procedures

The following are the procedures for Palisades Plant Cooldown:

(1) De-gas PCS for several hours before initiating cooling with steam generator. (De-gassing may require even more time if reduction of dissolved hydrogen is not partially accomplished prior to shutdown.)

(2) Stop PCPs A and D and initiate cooling from 532° to 300° by steaming to the condenser via the Turbine Bypass Valve (TBV) only. Much faster cooling could be accomplished by steaming to atmosphere. (not noramlly done, so as to reduce noise impact and conserve water).

(3) As cooling progresses, the pressurizer (PZR) is sprayed as necessary to cool to no less than PCS average temperature, plus 30°. The 30° margin insures that the steam bubble remains in the PZR.

(4) When PZR pressure is reduced to 1400 psi, the Safety Injection Tanks are valved out. Also at this same point the control system fuses for the high pressure safety injection pumps are physically removed from the circuit. The fuses in their holders are removed as an assembly which in turn has attached to it a yellow tag labeled "PCS <NDTT+60°". This yellow caution tag is obtained from the shift supervisor's office by an operator, recorded in the appropriate log and then attached to the assembly. This log is checked by the shift supervisor prior to start up. The start up procedure describes when the fuses are to be returned to service.

Removing the fuses disables the control room panel indication for the pumps, hence providing the operator verification that the pumps are not available for service. The tagged fuse

assembly is left in the room containing the motor control centers. The start up procedure contains a check list which dictates the sequenced steps that shall be followed as the plant is brought up to power. The procedure has been approved by operations supervisor and compliance with the actual start up check list is observed by the shift supervisor. Inadvertent or premature insertion of the fuse assemblies into the MCC's provides immediate indication on the control panel via the run - no run lamps and is readily observable by the control room operator.

(5) PZR level is allowed to gradually increase as falling pressure reduces letdown capacity, to aid in cooling the PZR.

(6) Cooling of the PCS continues through the steam generators until the temperature drops to 325°F and 250 to 270 psig. At this point, the low pressure safety injection pumps can be aligned to the shutdown cooling configuration. This configuration has an interlock preventing this switch if the pressure is too high. Once shutdown cooling is in service, the system is protected by safety valves. It does not isolate on high pressure. Steam is still allowed to flow to the condenser while shutdown cooling is in service. The turbine bypass valve is closed when the vacuum in the condenser reaches 5 inches of mecury.

(7) Circulation with the primary coolant pumps continues until the PCS is 160° to 180°F. During this time, the level on the pressurizer has been increased, reducing the size of the bubble. Some operators prefer to make the system "hard" before the PCPs are taken off, while some prefer to wait until later. When the system is isothermal the PCPs are stopped and the pressurizer bubble collapsed (if this has not already been done). Cooldown is continued with the SDC system.

(8) When the PCS temperature reaches ~120°F the PCS pressure is reduced to a atmospheric (charging pumps secured).

The pressure temperature behavior of the PCS during a normal cooldown (shutdown) is characterized in Figure 4.1. The sharp drop in the pressure limit line @ ~12 hours is due to the additive nature of pressure and differential thermal stresses while cooling. Once cooling has ceased, and temperature gradient across vessel walls is reduced to essentially nil, the permissable pressure (pressure limit line) returns to a value representing pressure stresses only. Also shown in Figure 4.1 is the administrative and Technical Specification pressure limit curve.

4.1.2 Startup Procedures

The following numbered items are the startup procedures for the Palisades Plant. The pressure temperature behavior of the PCS during a normal startup are shown in Figure 4.2. Also shown is the administrative and technical specification pressure limit curve.

(1) The initial temperature drop shown in Figure 4.2 commencing at time 0 is the result of filling the intact Primary Coolant System (PCS) from the level at which the reactor vessel head can be installed, with water from the Safety Injection and Refueling Water Tank (SIRWT) which can be as low as 40°F. (PCS pressure rises during filling and venting, until sufficient pressure for seal venting is achieved; controlled by Letdown control valve CV-2001.)

(2) During this fill, and until PCS temperature reaches 180° (@ ~6 hours), circulation is maintained by the Low Pressure Safety Injection pumps (LPSI), bypassing the Shutdown Cooling Heat Exchangers, to allow PCS temperature recovery. Also during this time, the Primary Coolant Pump (PCP) seals are vented to remove air, the PCP are run to sweep air from the Steam Generators (S-G), and the reactor head and pressurizer (PZR) are vented.

If necessary, the PCP seals will be 'run-in' as well. A maximum of 2 PCP will be running with PCS temperature below 250°.

(3) When the PCS temperature reaches 180°, the Shutdown Cooling is secured and a moderate pressure leak check is made (PCS pressure to 1200 psi*).

(4) If this check reveals no need for repairs, pressure is reduced only to 500 psi, and PCS heating from PCP heat, decay heat, and PZR heaters continues over the next 4 hours, until the PCS temperature is at 350°. (A third PCP is started at PCS temperature of 250°).

(5) At this time the PZR temperature should be ∿450°, and the Letdown controls are adjusted to give maximum Letdown with minimun charging. The resulting pressure drop terminates at the saturation pressure for the coolant in the PRZ (∿423 psia) as the PZR coolant flashes to steam and the steam bubble is formed.

(6) Once normal level is established in the PZR, PZR level control is placed in AUTO. PCS heating continues from PCP heat, decay heat, and PZR heaters. Rate of PZR heating (and hence PCS pressure rise) is controlled by adjusting number of PZR heaters on, or amount of PZR spray flow.

(7) After PCS temperature reaches 450°, the Fourth PCP is started.

(8) When PZR Pressure reaches 1400 psia, the Safety Injection tanks are valved and the HPSI pump fuses are returned to service.

(9) At Hot Standby conditions (rated temperature and pressure, zero steam flow).

---

* Based on amendment No. 25 to the Palisades Plant License the leak check pressure test will be performed at approximately 600 psi.

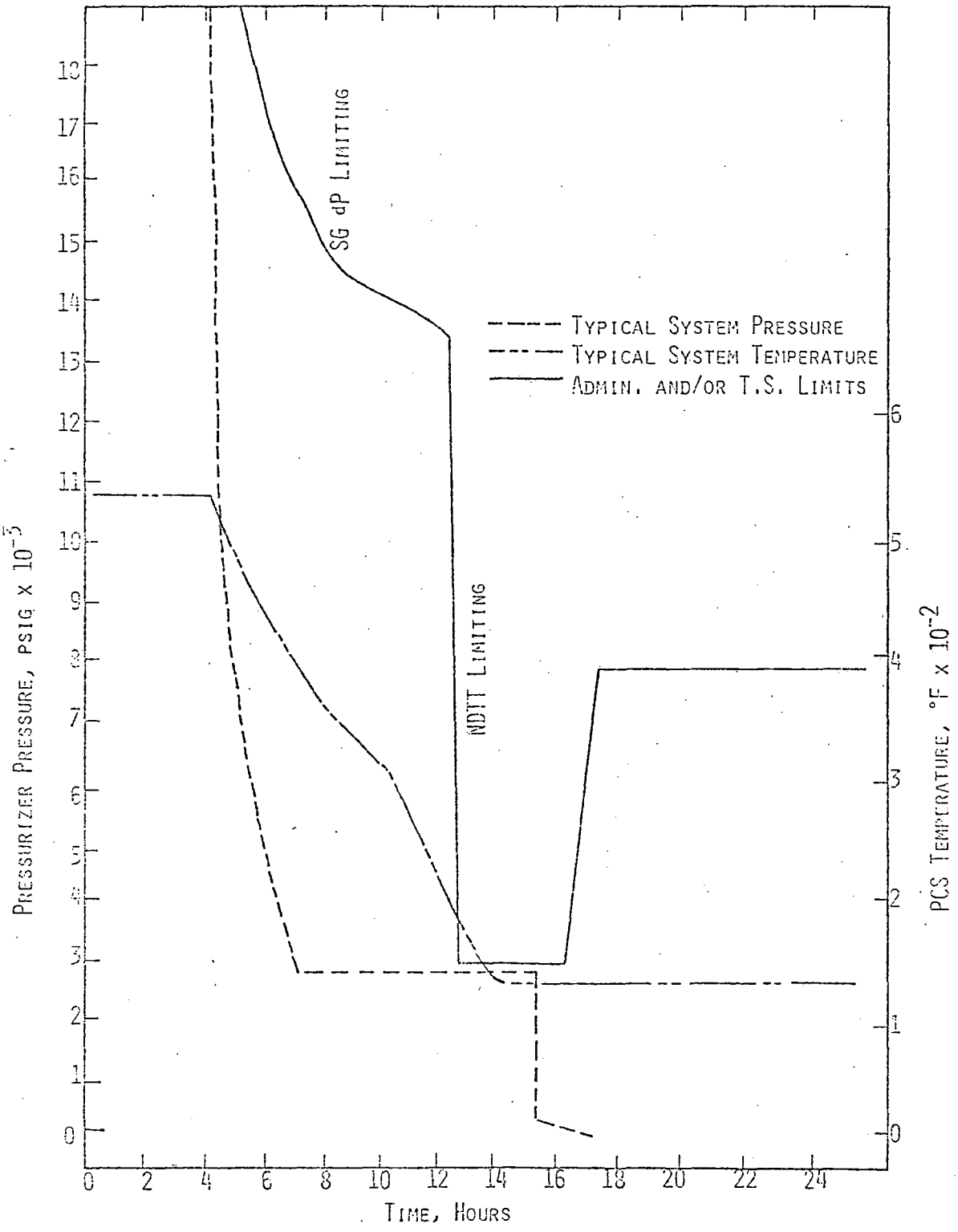

FIGURE 4.1. PALISADES PLANT - PRESSURE-TEMPERATURE RELATIONSHIP DURING NORMAL SHUTDOWN

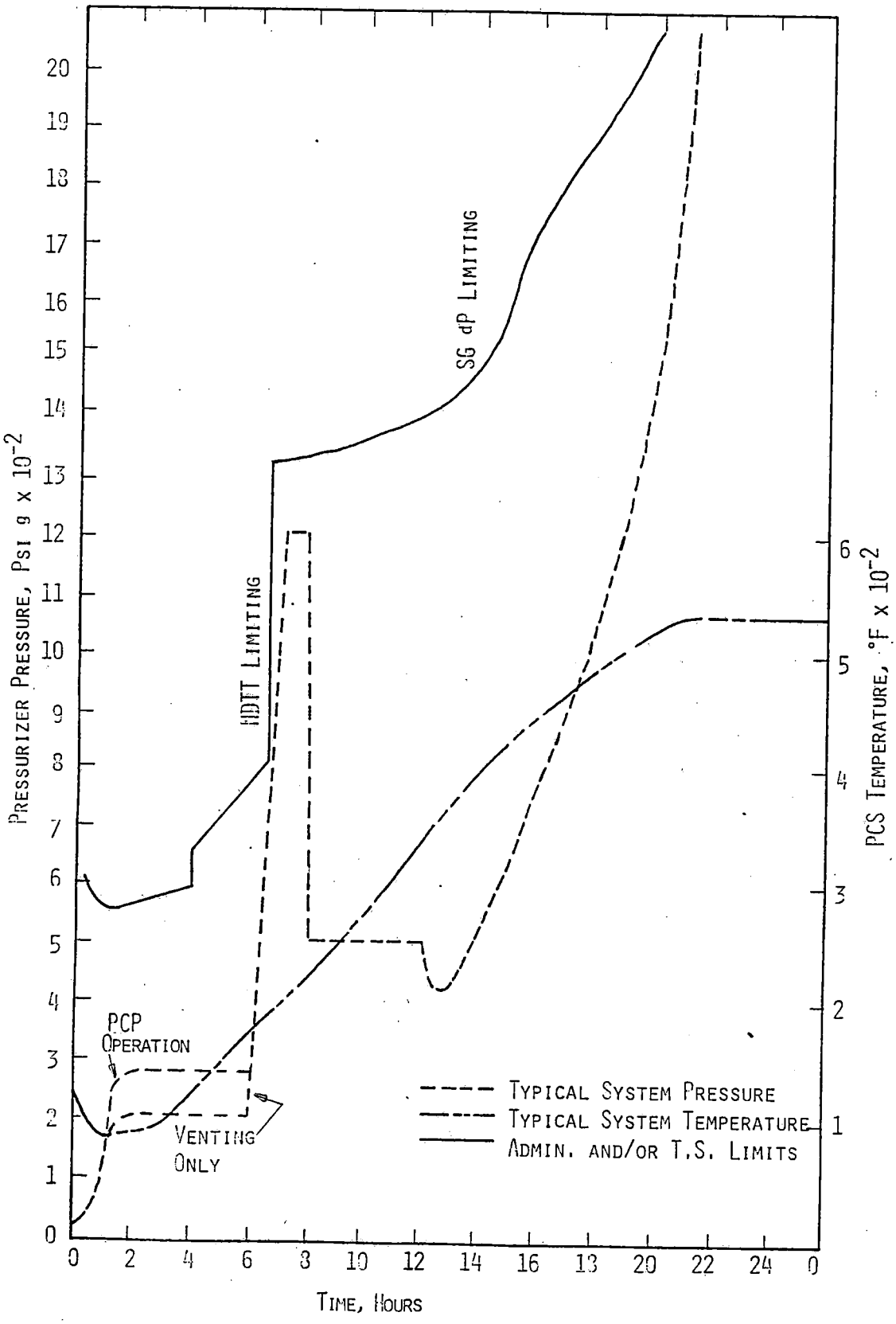

FIGURE 4.2. PALISADES PLANT - PRESSURE-TEMPERATURE RELATIONSHIP DURING NORMAL STARTUP

5.0 ANALYSIS

Overpressurization transients for the Palisades Plant were analyzed with the RETRAN computer code. RETRAN is a modified version of RELAP4, Mod 03, Update 95, which provides the capability to analyze light water reactor plant transients. The basic code has been used extensively for LOCA analyses, and essentially contains the same heat transfer, fluid flow and thermodynamics models in RELAP4. RETRAN includes several modifications and improvements to analyze the less severe operational plant transients. A more detailed description of the RETRAN code is presented in Appendix A.

Initiating events applicable to the Palisades Plant were analyzed on an individual basis to compare their relative contribution towards overpressurization. Design parameters used in analyzing the transients are given in Table 5.1.

Before the overpressurization transients for the Palisades Plant were analyzed, the predictive capabilities of the RETRAN code were evaluated by performing analyses similar to those reported by Combustion Engineering (CE) in a generic report[2] and comparing RETRAN results with those presented in the report.

Analytical results for the RETRAN predictions of a generic CE NSS are presented in this section. Also, valve models for power operated relief valve (PORV) operation and heat transfer models for the secondary side of steam generators are presented in this section.

5.1 Generic Analysis Comparisons

A one-volume RETRAN model was used to perform analyses of mass addition, heat addition, and mass and heat additions events similar to those performed by CE and reported in a generic report.[2] The one-volume RETRAN analyses were performed to assess the adequacy of RETRAN by comparing RETRAN results against similar analytical results.

RETRAN modeling information and initial conditions were obtained from the generic report. Table 5.2 summarizes the assumptions and initial conditions used in the RETRAN analysis. The entire Primary Coolant System (PCS) was modeled as a single control volume. Mass addition was simulated using a FILL Table Option, which allows a fill flux to be specified as a function of either time or pressure via a table of up to twenty pairs of data points. Energy addition was simulated using the simplified Non-conduction Heat Exchanger Option. For this analysis the heat exchanger model was modified to allow calculation of heat addition by the control system model in RETRAN. The arithmetic elements in the control system model calculated the heat transfer rate using the areas and overall heat transfer coefficients given in the generic report.

Figure 5.2 presents the results of the RETRAN calculations compared with the results from analyses performed by CE. The CE results shown in Figure 5.2 were presented to the NRC on April 19, 1977 by CE and are modifications of the results previously presented in the CE generic report.

Close agreement between RETRAN and CE predictions was obtained for those transients involving only mass addition, In view of the close agreement obtained for the "Pressurizer heaters" transients, closer agreement for the "SDC isolation" transient was expected. However, the disagreement was judged to be small enough to be acceptable.

The comparatively large differences calculated for the "PCP start" transient were attributed to the conservatism arising from the use of a one volume RETRAN model. CE used a three volume model where each of the two steam generators was represented by a separate volume. The temperature of the water on primary sides of the steam generators (SG) was initialized to be at the same temperature as the secondary side. Under these conditions and even assuming instantaneous startup of the reactor coolant pump, the rate of heat transfer starts slowly and increases as cold water displaces hot water in the primary side of the SG. In the one-volume RETRAN analysis it was effectively assumed that the full temperature difference existed immediately upon initiation of the transient.

In general, the results of the RETRAN analysis either agreed with the CE analysis or were more conservative.

5.2 Valve Models

Discharge capabilities of relief valves were modeled in RETRAN to simulate their effect on overpressurization. Using the Bernoulli equation and continuity principles, the liquid discharge rate was modeled as an orifice discharge, since the set pressure of the PORVs of the Palisades Plant will be 415 psia and the maximum possible temperature of the pressurizer is 280°F which is far below the saturation temperature. The liquid discharge rate for a relief valve is then given as

$$Q = C_D A_t \sqrt{\frac{2(Ppcs - P_b)\, g_c}{\rho}} \qquad (1)$$

where

Q	=	volumetric flowrate (ft^3/sec)
C_D	=	discharge coefficient
A_t	=	valve throat area (ft^2)
Ppcs	=	PCS pressure (psf)
P_b	=	back pressure of discharge quench tank (psf)
ρ	=	fluid density (lbm/ft^3)
g_c	=	conversion factor (32.17 lbm ft/lb_f sec^2)

Since the relief valve overpressure protection would occur during liquid conditions, and the valve has not been tested under liquid flow conditions, a discharge coefficient of 0.6 was used. The discharge coefficient can be transformed into a K factor as used in the RETRAN code by the following procedure.

$$Ppcs - P_b = \Delta P = K_V \frac{\rho V^2}{2g_c} = \frac{K_V \rho Q^2}{2A_t^2 g_c} \qquad (2)$$

Combining Equation (1) and (2), we can get

$$K = \frac{1}{C_D^2} = \frac{1}{0.36} = 2.78 \qquad (3)$$

However, since the PORVs are connected to the quench tank through pipes with many elbows, a K factor for pipes must be included to account for the pressure due to the piping. One PORV (RV1042B) is connected with nine and the other (RV1043B) is connected with ten 90° elbows to the quench tank. The K factor for a 90° elbow was determined from the following correlation[3]

$$K_p = \frac{0.21}{\sqrt{R_o/D}} \qquad (4)$$

where

R_o = radius of curvature of elbow

D = diameter of pipe

For a conservative calculation, a value of 0.21 for K_p was used. Therefore, the total K factor for RV1042B is calculated as

$$K_T = 2.78 + 0.21 \times 9 = 4.67 \qquad (5)$$

and the total K factor for RV1043B is similarly

$$K_T = 2.78 + 0.21 \times 10 = 4.88 \qquad (6)$$

Valve discharge capabilities are pressure dependent relative to the rated capacity at the valve set point; i.e. as PCS pressure increases the valve discharge increases as function of the square-root ratio to the set pressure.

The steam and water flow capacities for the PORVs are shown below. The water flow capacities were calculated using a discharge coefficient of 0.6. The actual water flow capacity of the PORV installed in the Palisades plant will be determined during PORV flow tests to be conducted for the CE owners group by an independent laboratory.

Capacity of a PORV

Set Pressure (psig)	Sat. Steam (lbm/hr)	Water (gpm)
400	---	460
2485	153,000	1500

5.3 Heat Transfer Models

A heat transfer correlation was added to the RETRAN code to account for natural convection heat transfer on the secondary side of a steam generator. Assuming that natural convection exists on the secondary side of the steam generator is a conservative assumption.

Heat transfer coefficients for free (natural) convection were determined from the following correlation[4]

$$\frac{hL}{k} = a\left[\frac{L^3\rho^2 g\beta\Delta t}{\mu^2}\left(\frac{C_p\mu}{k}\right)\right]^m = a\left[X\right]^m \qquad (7)$$

where

- h = heat transfer coefficient
- L = length of the vertical surface
- k = conductivity
- a = constant
- ρ = fluid density
- g = gravitational constant
- β = coefficient of thermal expansion
- μ = fluid viscosity
- Δt = temperature difference between fluid and surface temperature
- C_p = isopiestic heat capacity of fluid
- m = constant

Values of the numerical constant a and m are given below

X greater than 10^9	a = 0.13; m = 1/3
X from 10^4 to 10^9	a = 0.59; m = 1/4
X less than 10^4	a = 1.36; m = 1/6

TABLE 5.1

DESIGN DATA SUMMARY

System	Type	Pump Data Design Pressure	Capacity	Shut-Off Head
HPSI	Seven Stage Horizontal Centrifugal	1750 psig	See Fig. 5.1	2800 ft. (1223 psig)
Charging pump	Positive Displacement (1-var. speed 2 const. speed)	2735 psig	35-53 gpm & 40 gpm	2900 psig The charging pump discharge relief values are set at 2735 psig.
		Design Power		
	Thermal Output	2530 MW		

TABLE 5.2

INITIAL CONDITIONS FOR GENERIC ANALYSIS

Event*	Pressure	Temperature	Mass/Energy Input
Pressurizer Heater Actuation	Ppcs = 300 psia	T_{ave} = 160°F	1500 KW
SDC Isolation	Ppcs = 250 psia	T_{ave} = 200°F	26.5 Mwt (Decay Heat)
Charging/Letdown Imbalance	Ppcs = 300 psia	T_{ave} = 160°F	44 gpm/pump One and Two Pump Inputs
HPSI Pump Start	Ppcs = 300 psia	T_{ave} = 200°F	per Generic Report Delivery Curve
SI Actuation	Ppcs = 300 psia	T_{ave} = 200°F	1 HPSI Pumps 3 Charging Pumps
PCP Start w/Hot Steam Generator	Ppcs = 300 psia	T_{sdc} = 100°F T_{sec} = 200°F	Steam Generator Heat Transfer per Generic Report.

* PCS is water solid in all cases

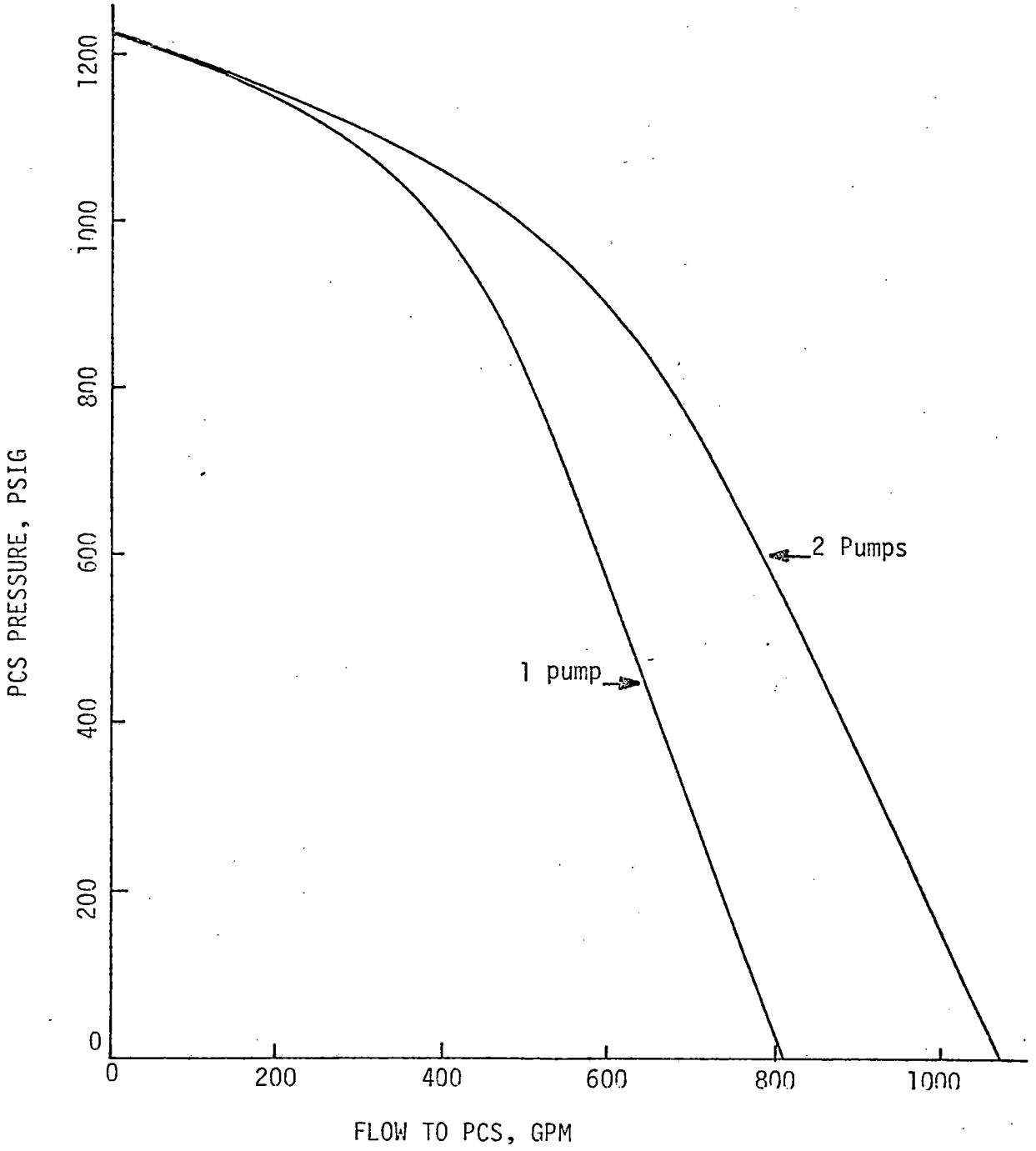

FIGURE 5.1. HPSI DELIVERY

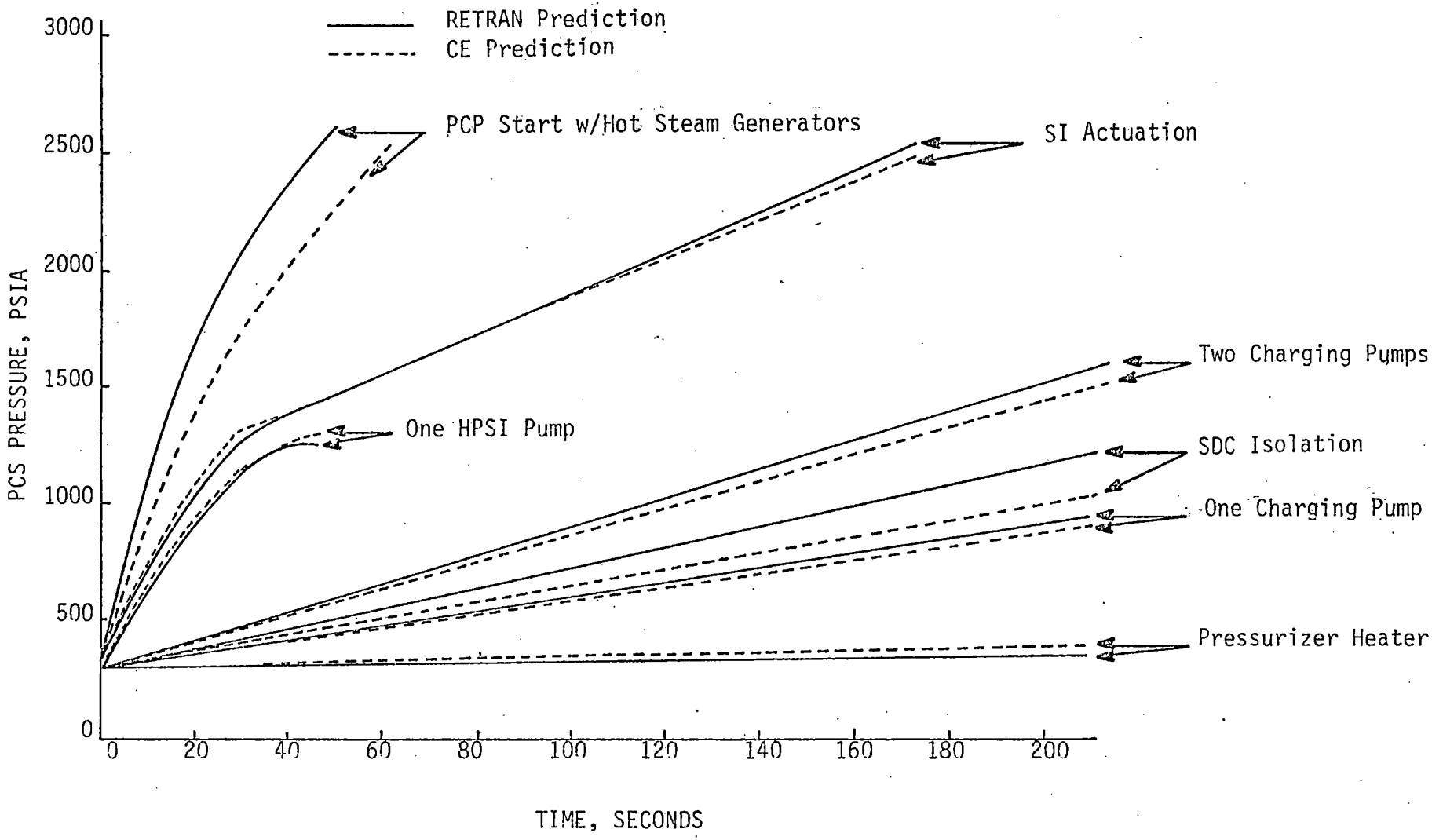

FIGURE 5.2. GENERIC ANALYSIS COMPARISONS

6.0 RESULTS

The nodalization of the Palisades Power Plant for the RETRAN input is shown in Figure 6.1. The number of fluid volumes was optimized to save computer running time and to preserve the thermal-hydraulic characteristics of the primary coolant system. The quench tank was modeled with RETRAN as a volume with a cover gas and consequently backpressure was calculated as a function of time throughout the transients analyzed. The initial quench tank pressure was modeled as 3 psig and for the forty second transients analyzed the backpressure did not increase more than 3 psi.

Initial conditions for each overpressurizing event analyzed by RETRAN were chosen from operating procedures with the maximum possible pressure and the lowest possible temperature at the shutdown cooling stage of the plant to obtain conservative results. For the initial conditions shown in Table 6.1, the Palisades Plant fluid pressure and temperature could reach the limitation of 10CFR50 Appendix G within a short time during overpressurizing transients as the system presently is configured. Analyses with RETRAN indicate Palisades Plant modifications and modified operating procedures can eliminate the possibility of exceeding the limitations of 10CFR50 Appendix G for the Palisades Plant.

Parametric studies including the design base incident for Palisades Plant, will be discussed in this section.

The following assumptions were made for the RETRAN analyses of the system's overpressurization:

(1) Water solid systems are considered.

(2) Metal masses do not act as heat sink.

(3) Mass addition rates are specified by the pertinent pump delivery curves.

(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.

6.1 Overpressurization Results

Numerical experiments were necessary to get reasonable flow rates of each flow path for a single primary coolant pump operation by adjusting reverse flow loss coefficient in RETRAN input. The flow-split calculated by RETRAN for a single primary coolant pump operation in Palisades is shown in Figure 6.2. It should be pointed out that "PCP 2" in Figure 6.2 represents two primary coolant pumps with twice the capacity of a primary coolant pump. The simplification of the primary coolant loops to 3 loops instead of 4 loops was used because two loops are at identical operating conditions for an overpressuring event.

The heat transfer area of each steam generator was adjusted for plugged tubes and is 71,852 ft^2 for the steam generator in the operating loop, and 73,869 ft^2 for the steam generator in the non-operating loop. Presently, 1,929 tubes (22.64%) of 8,519 tubes for steam generator of the operating loop and 1,744 tubes (20.47%) of 8,519 tubes for steam generator of the non-operating loop have been plugged.

The results of RETRAN calculations for the Palisades overpressurization transients are shown in Figure 6.3. The worse case transient is a primary coolant pump (PCP) start with hot steam generators. In addition to steam generator heat input, pressurizer heaters also are assumed to provide 1500 kW of power at the time of the inadvertent PCP start, and a decay heat equivalent to one-percent of 2530 MWt was also considered. Hot steam generators mean that the secondary side of the steam generators have a higher fluid temperature than the primary coolant system temperature. Primary side fluid temperature was assumed to be the same as the fluid temperature on the secondary side of steam generators initially. This clearly is the worse combination of inputs and is therefore used as the design base incident.

It should be noted that the inadvertent SIS transient during water solid conditions would involve only 3 charging pumps and 2 LPSI pumps (see Operating Procedures for Palisades Plant) and is equivalent to a charging/letdown imbalance transient since the shut-off head of a LPSI pump is 410 ft, far below the initial system pressure (270 psia). Therefore, no inadvertent SIS overpressurization transient incident for Palisades can occur.

Calculations with different temperatures for the fluid on the secondary side of steam generators produced significantly different results as shown in Figure 6.4. As shown in Figures 6.5 and 6.6, if the heat transfer area is assumed to be five percent higher than the heat transfer area values calculated to presently exist in the steam generator, no significant change in the results occurred. A five percent increase in SG surface area may be realized in the future if some of the tubes presently plugged are deplugged.

6.2 Design Base Incident With PORV Protection

As mentioned in the previous Section (6.1), the worse case transient (design base incident) for Palisades is a PCP start with hot steam generators, 1500 kW pressurizer heat, and 1% decay heat. For the PCP start incident, as with other overpressurizing incidents, if the mass and energy input rates to the system are larger than the output rates, the possibility of system overpressurization exists. 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. An effective way to relieve mass and energy from a system is through a relief type valve.

Calculations were performed with RETRAN to determine whether one or two of the PORVs installed on the Palisades system when utilized during water solid conduction, would protect the PCS from exceeding 10CFR50 Appendix G limits. Also included in the calculations performed are those calculations which give relief capacity credit to the Palisades

Plant for two SDC relief valves in addition to one PORV. These valves are Suction Relief Valve (RV3164 on P&ID M-204, drawing location D&E-2) which is set to relieve at 300 psia with relief flow capacity of 133 gpm and Discharge Relief Valve (RV3162 on P&ID M-203, drawing location C&D-1) which is set to relieve at 500 psia with relief flow capacity of 5 gpm. The flows from the SDC valves were modeled as constant flows throughout the transients analyzed by using the negative fill option in RETRAN.

The calculational results of RETRAN, for the prediction of design base incidents with one and two PORVs utilized, are shown in Figures 6.7. In Figure 6.7, the dashed line shown represents the pressure limit for system heatup which is based on the average temperature of the reactor vessel wall (see Appendix B for the detailed calculation of the average temperature of the reactor vessel). The results of the analysis in which one PORV and the SDC valves are modeled for a design base incident are shown in Figure 6.8. The pressure-temperature heatup limits are also shown in Figure 6.8. As shown by the data presented in Figure 6.8, if credit is allowed for the SDC valves opening the overpressurization transient is much less severe.

The heatup limit information presented in Figures 6.7 and 6.8 was obtained from data provided in Figure 6.9 which in turn was extracted from the Palisades Plant Technical Specification.[6]

TABLE 6.1

INITIAL CONDITIONS FOR PALISADES PLANT ANALYSIS

Event	PCS Pressure (psia)	Temperature (°F)	Mass/Energy Input
PCP Start W/Hot Steam Generators	270	T_{pcs} = 120 T_{sec} = 212 T_{pzr} = 280	Steam Generator Heat Transfer 1% Decay Heat, 1500 KW Pressurizer Heat
HPSI Pump Start	270	T_{pcs} = 120	per Fig. 5.1 Delivery Curve 1% Decay Heat
Charging/Letdown Imbalance	270	T_{pcs} = 120	40 GPM - 2 pumps 33-53 GPM** - 1 pump 1% Decay Heat
SI Actuation*	270	T_{pcs} = 120	3 Charging Pumps 2 LPSI Pumps 1% Decay Heat 1500 KW Pressurizer Heat

* This case has not been analyzed since the shut-off head of a LPSI pump is below the PCS initial pressure.

** The maximum flow rate of 53 gpm was used in the analysis.

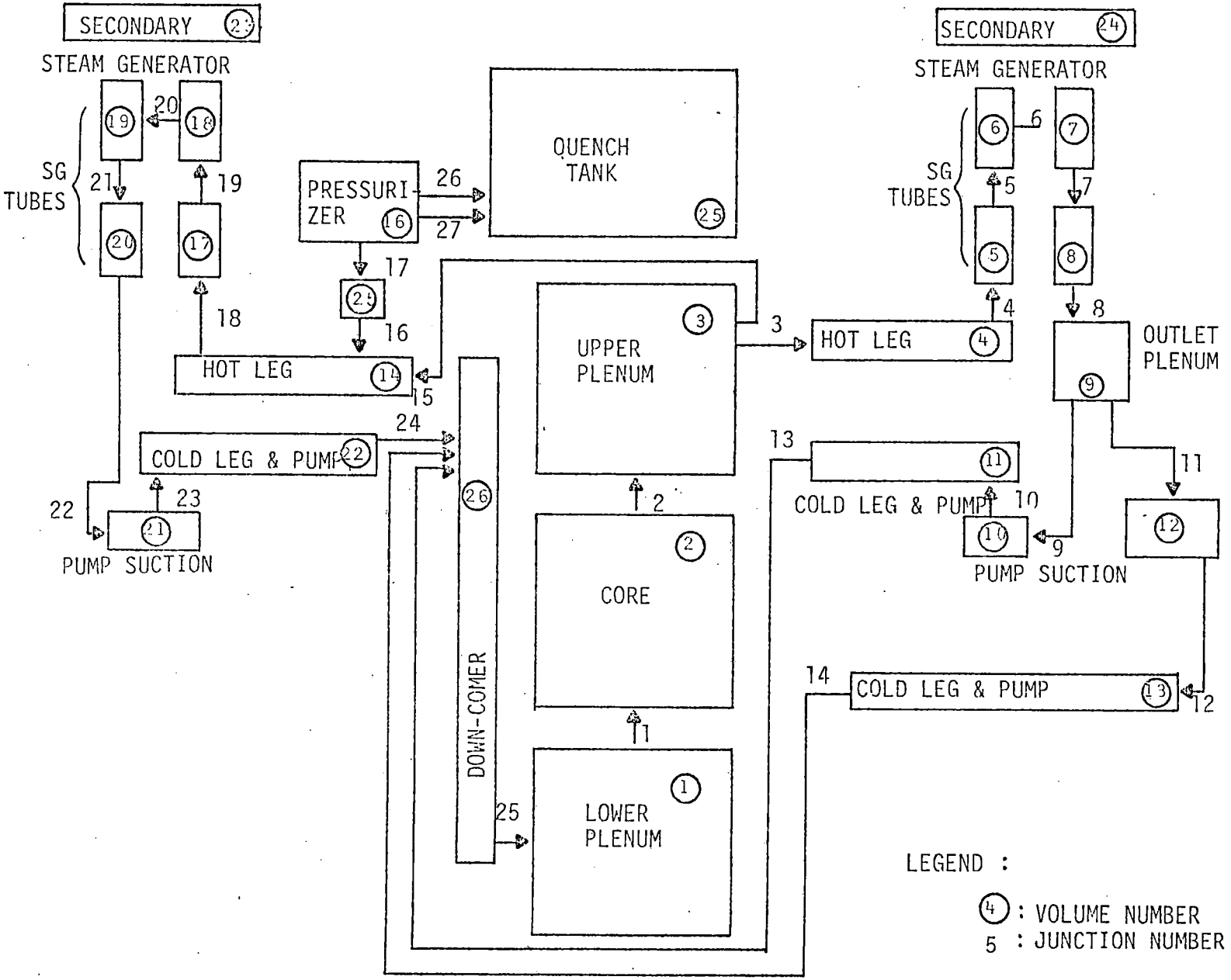

FIGURE 6.1. RETRAN NODALIZATION OF PALISADES SYSTEM

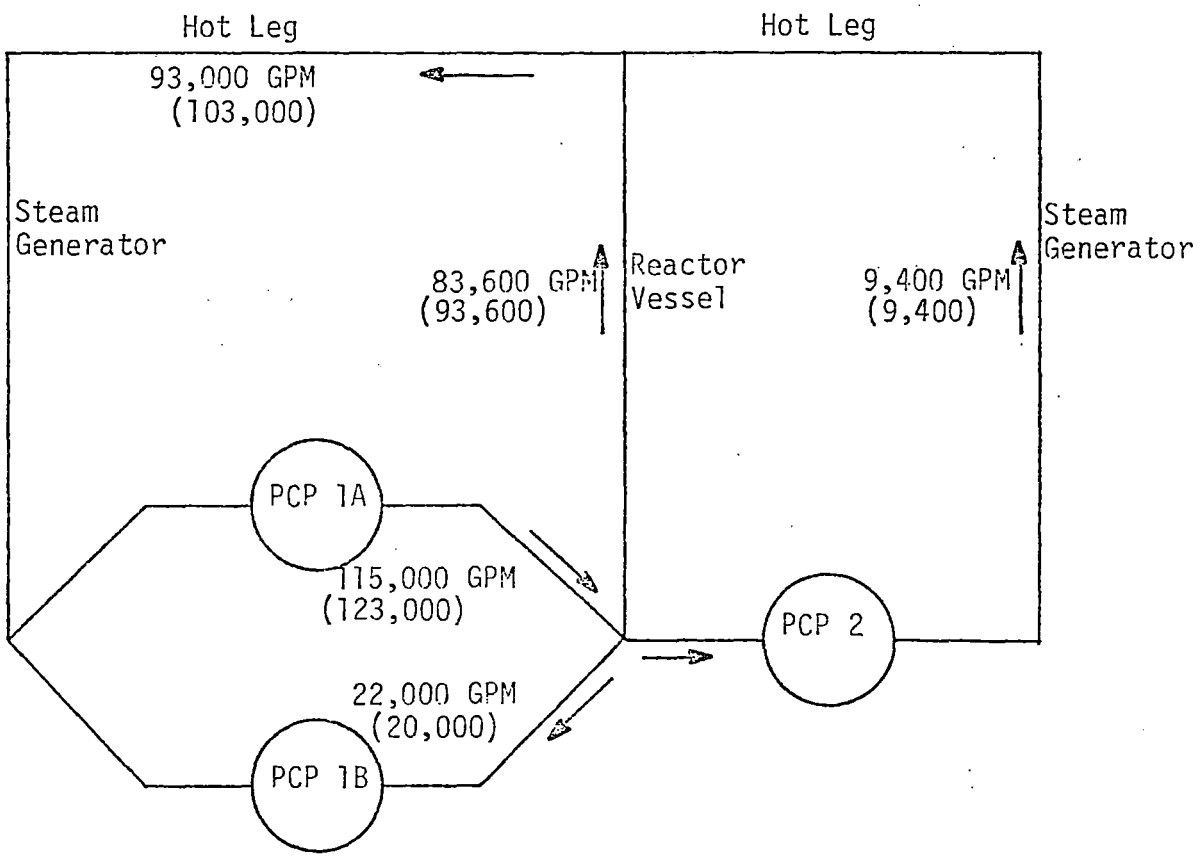

FIGURE 6.2. SINGLE PUMP OPERATION FLOW-SPLIT

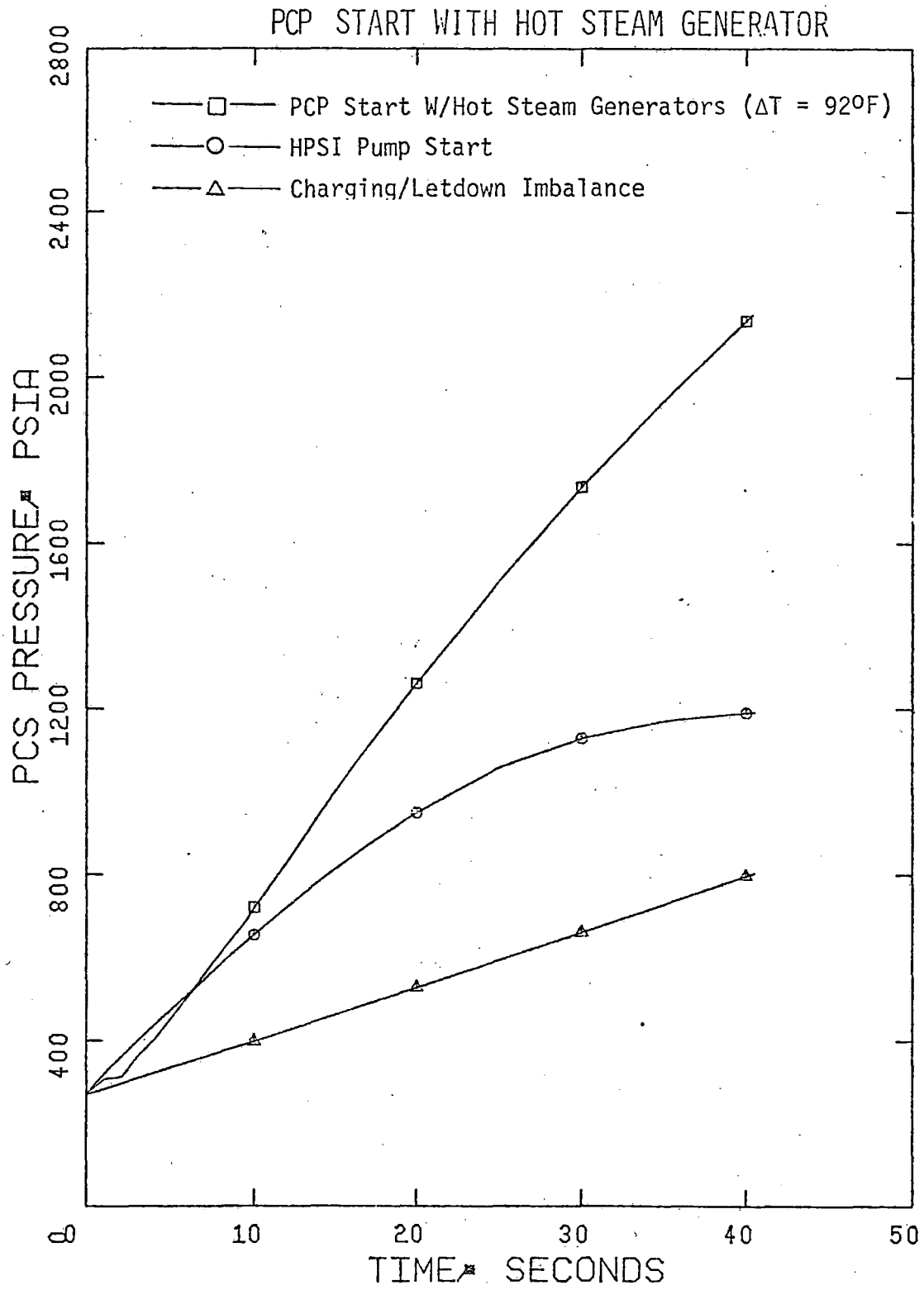

FIGURE 6.3. PALISADES OVERPRESSURIZATION TRANSIENTS

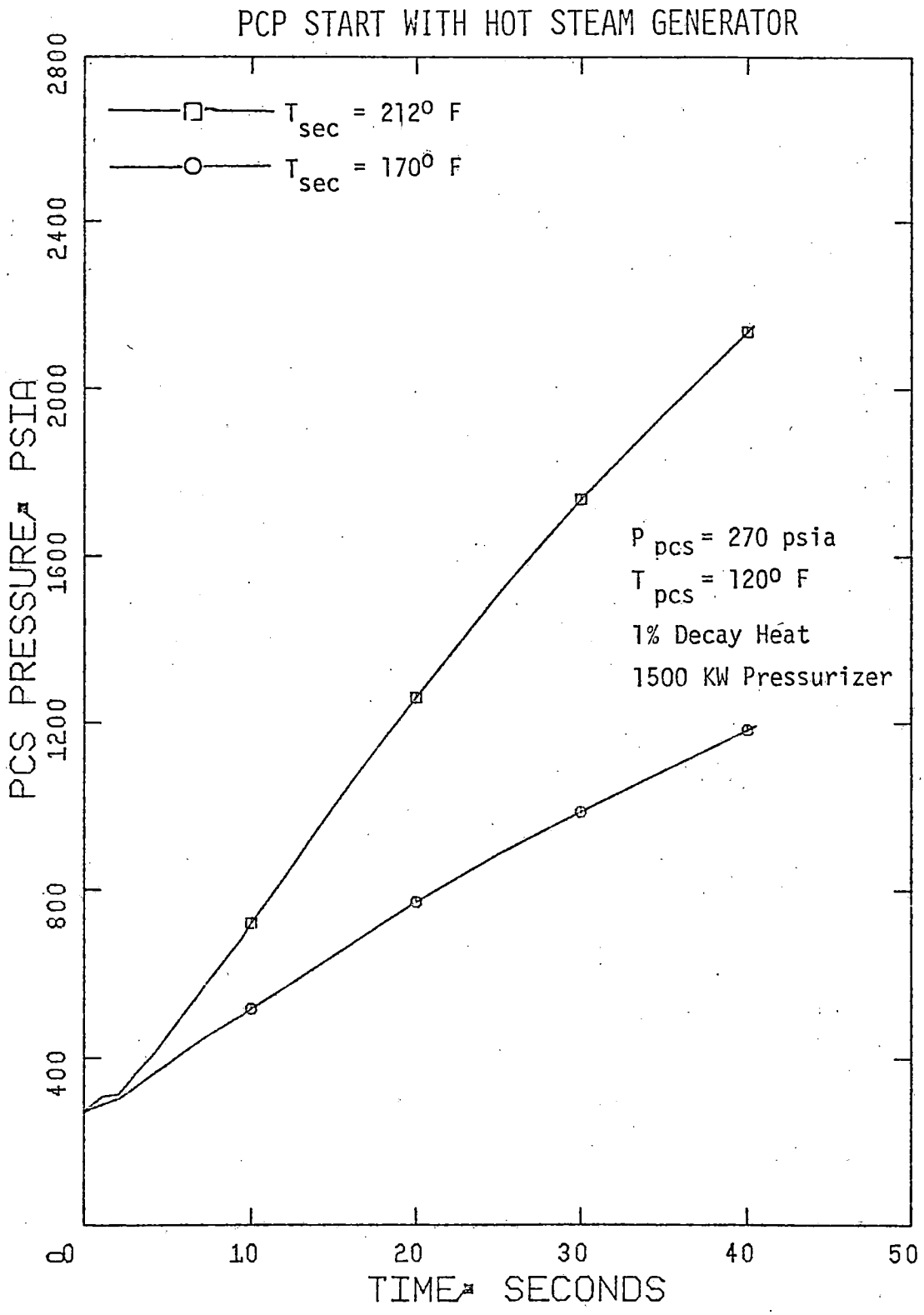

FIGURE 6.4 SENSITIVITY TO SECONDARY TEMPERATURE

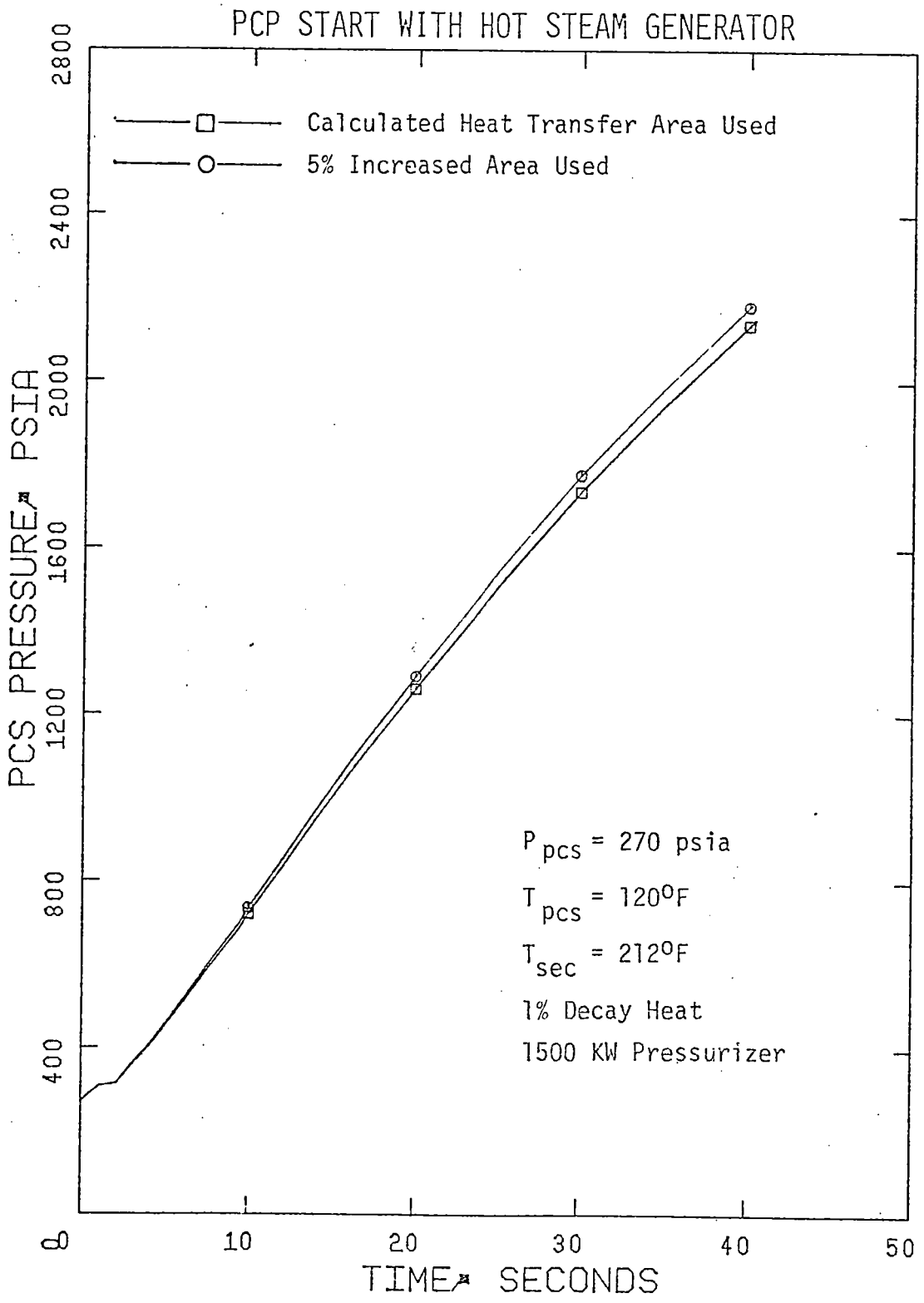

FIGURE 6.5. SENSITIVITY TO HEAT TRANSFER AREA (ΔT=92°F)

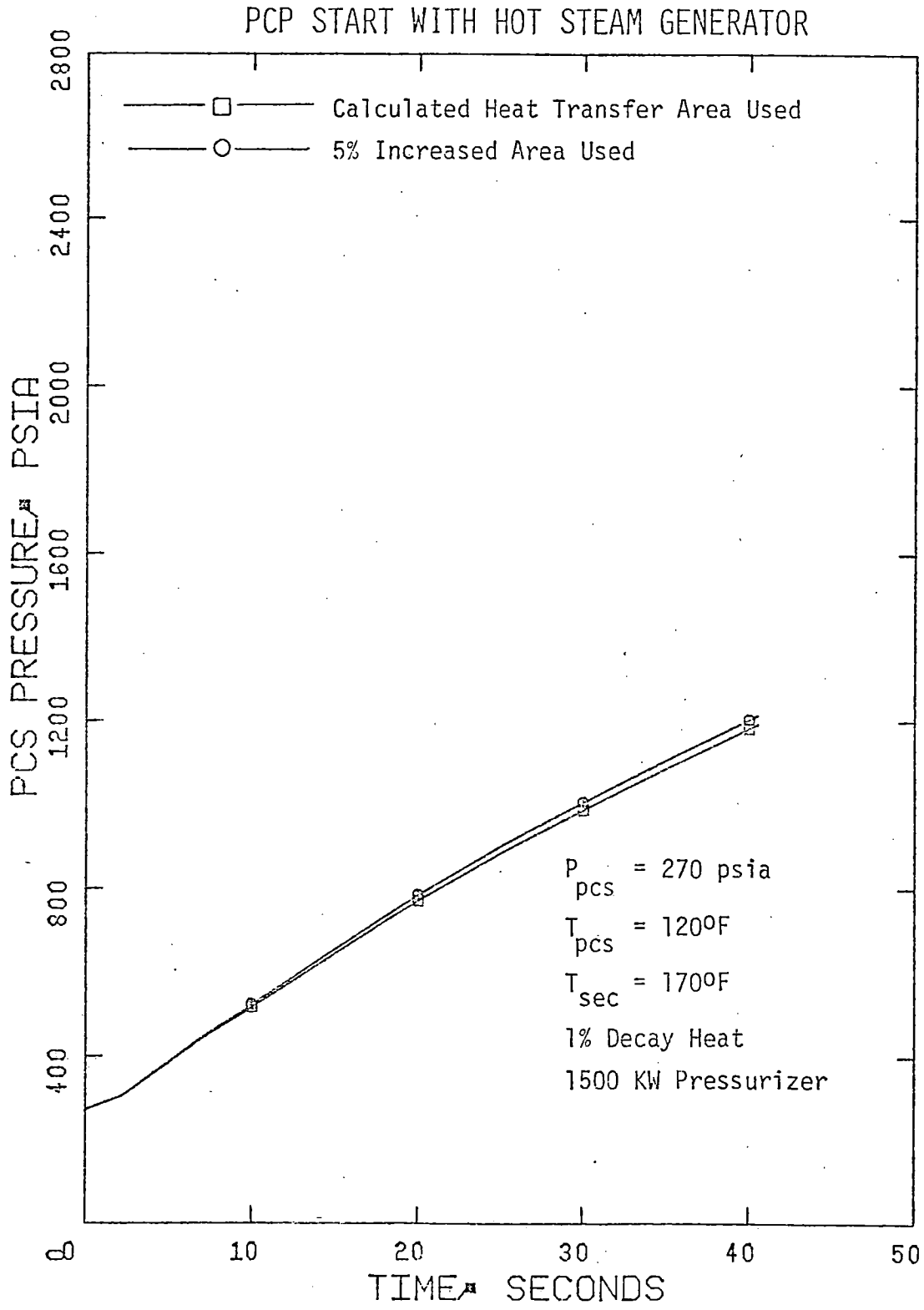

FIGURE 6.6. SENSITIVITY TO HEAT TRANSFER AREA (ΔT=50°F)

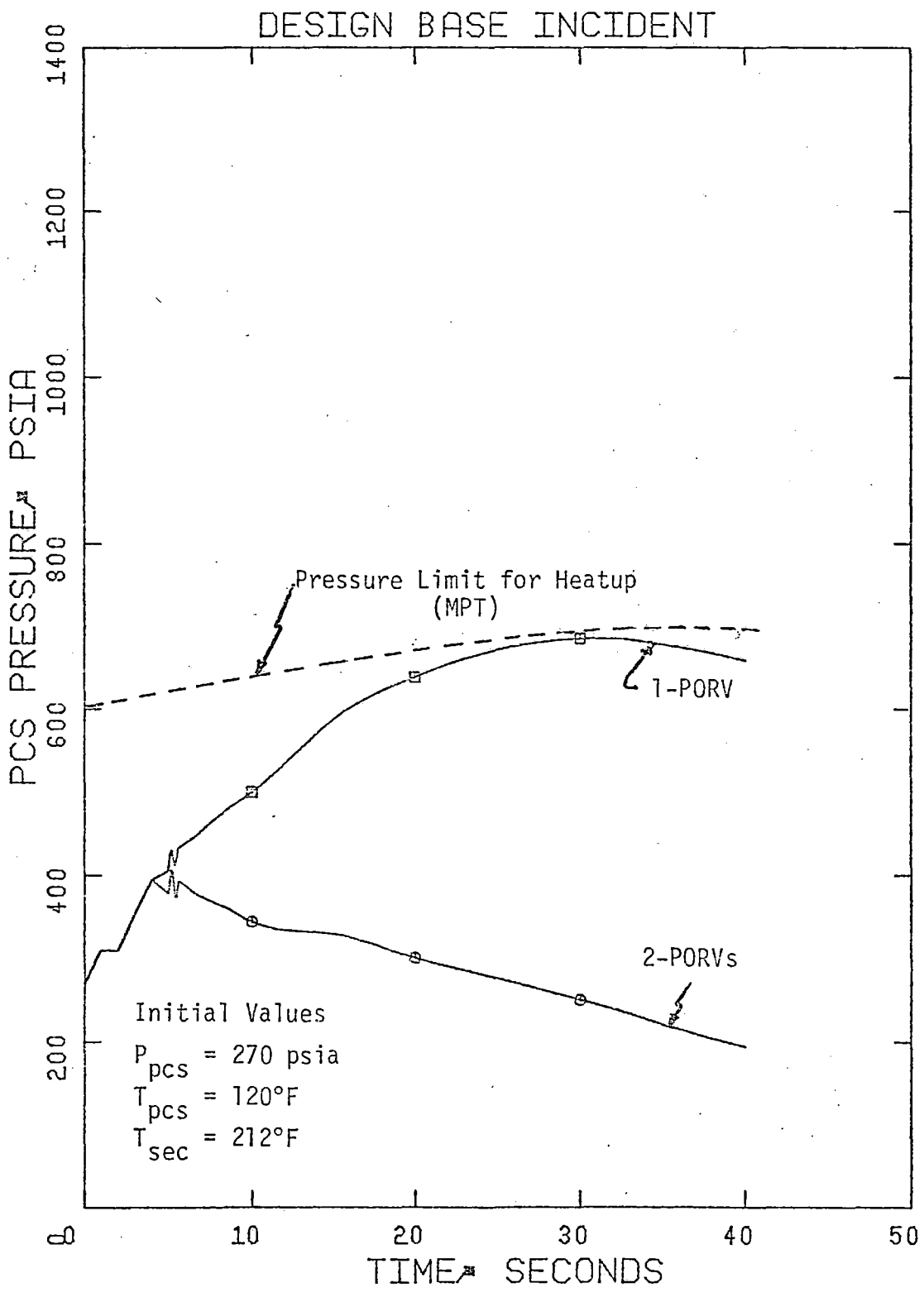

FIGURE 6.7. EFFECT OF ONE OR TWO PORVS ON DESIGN BASE INCIDENT

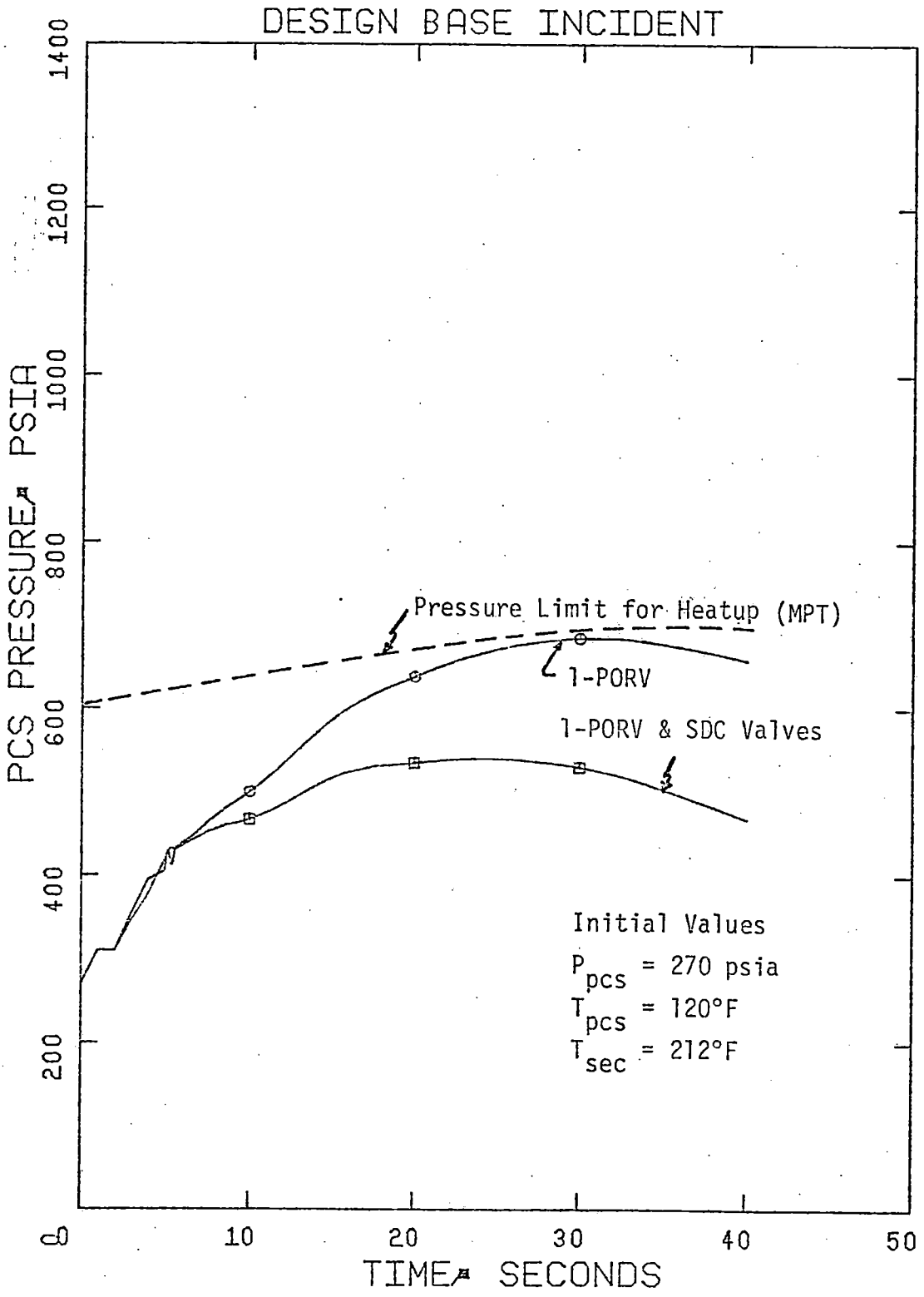

FIGURE 6.8. EFFECT OF SDC VALVES ON DESIGN BASE INCIDENT

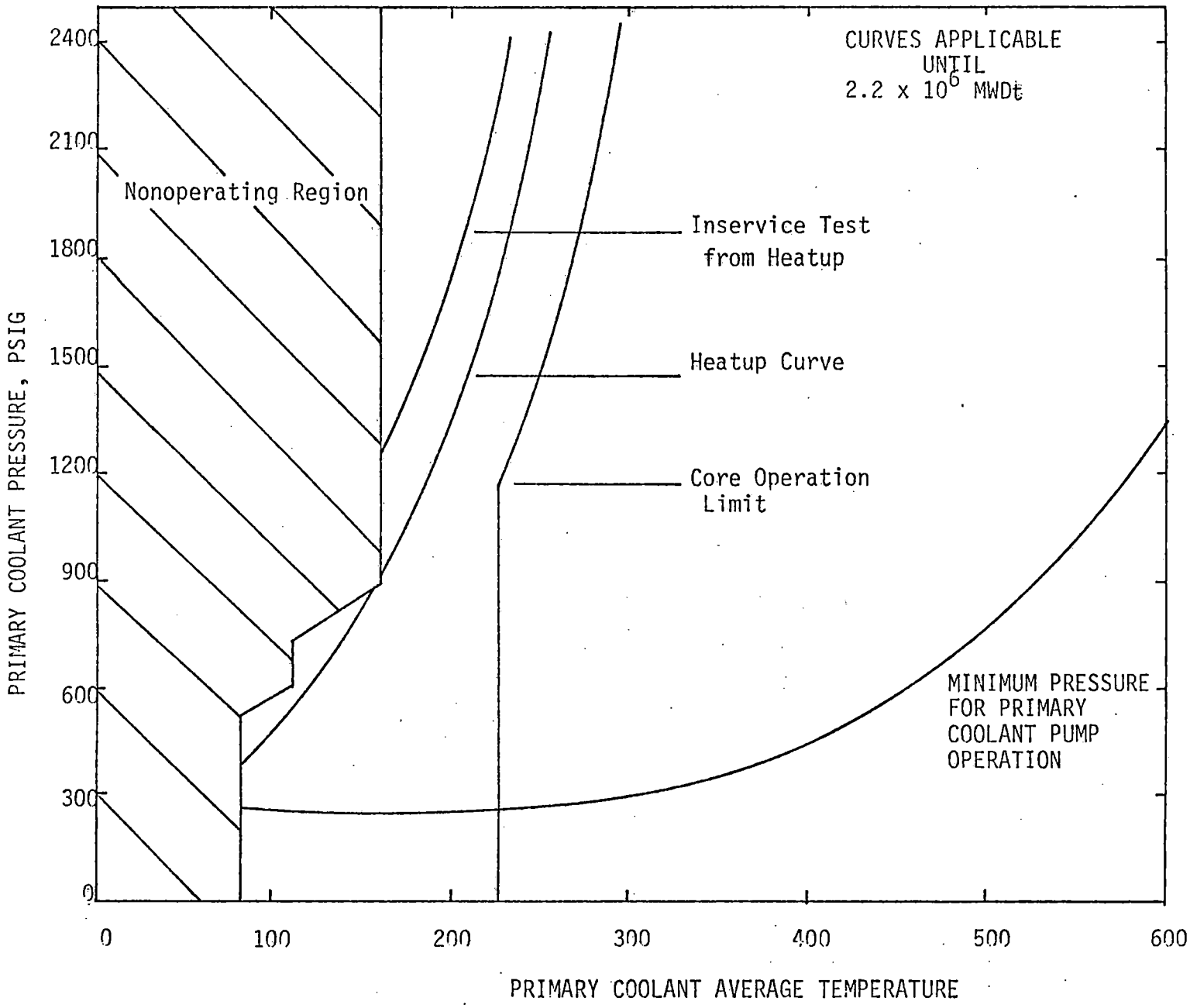

FIGURE 6.9. MPT CURVE FOR PALISADES PLANT HEATUP

7.0 SOLUTIONS AND RECOMMENDATIONS

7.1 Short Term Measures

The short term measures implemented to prevent primary coolant system overpressurization events are administrative in nature. Changes in the plant operating procedures were made. The details are related in CPCO letters to the NRC dated November 5, 1976, December 6, 1976 and March 8, 1977. Additionally, preliminary investigations of the equipment or operator actions that might produce an overpressurization event were conducted and corrections made where possible. Further, informational classes were conducted for the plant operating staff to impress upon them the proper courses of action that should be taken to prevent an event from occuring and the inportance of doing so. Details of the latter two courses of action are also described in the above letters.

7.2 Long Term Measures

As demonstrated conclusively by analytical methods earlier in this report, the relief capacity of one PORV is sufficient to mitigate the worst case overpressurization event that the Palisades Plant primary coolant system would be subjected to when in a solid water conditions. Therefore, a hardware modification to the system will be implemented to insure that at least one and, with a high degree of probability, two PORVs are activated automatically if an overpressurization event occurs in the Palisades Plant PCS when its condition is solid. This modification will consist of installing two individual and completely redundant PCS pressure sensing instrument loops. One loop will control CV1042B and the other will control CV1043B. Each loop will derive its operating power from a source independent of the other. Associated with each loop will be an increasing pressure alarm that will be displayed on an annunciator window inscribed PCS OVER PRESSURE.

These control loops will be activated during the plant cooldown procedure by operator action when the PCS pressure decreases to 500 psia and the

temperature decreases to 250°F. The temperature signal for each loop will be derived from the temperature measurement loops associated with recorders TR0115 and TR0125. These overpressurization control circuits will be deactivated by operator action during normal startup when the PCS rises to a temperature of 250°F.

This hardware modification will be implemented during the next refueling outage. The most desirable pressure transmitter for the environmental conditions encountered is the Rosemount Model 1152. Unfortunately, delivery time on this device is presently 5 to 6 months which in turn does not permit the installation of this model during the August 1977 outage. As an alternative, we will utilize the Rosemount model 1151 pressure transmitter and at a convenient later date replace them with the Model 1152 transmitters. The two models of transmitters are essentially the same with the exception that the 1152 is better qualified to operate continuously in the radiation environment existing in the desired location. The model 1151 should perform satisfactorily for at least one year which in turn provide ample time to obtain and install model 1152 transmitters.

Figure 7.1 is a schematic circuit diagram of the proposed PORV control modification.

7.2.1 Administrative Controls

The plant operating procedures will be modified to include during cooldown a warning that the overpressurization protective system must be activated when a PCS pressure of 500 psia is reached. Also an initialed step will be added to the procedures to verify that activation of the protective system was in fact accomplished.

The plant operating procedures for start up will have in the initial conditions a caution warning that the PCS overpressurization system must be placed in the normal operation mode when the PCS temperature rises to 250°F. An initialed step will also be included in the procedure to insure that the overpressure protection circuit is transfered to the normal operation mode.

7.2.2 Hardware and Piping Modification

Preliminary analyses have shown that the thrust loads on the Palisades Plant primary coolant system, during water solid conditions, are approximately twenty-five percent of the thrust loads calculated for the steam flow design conditions. Thus, no hardware or piping modifications are required.

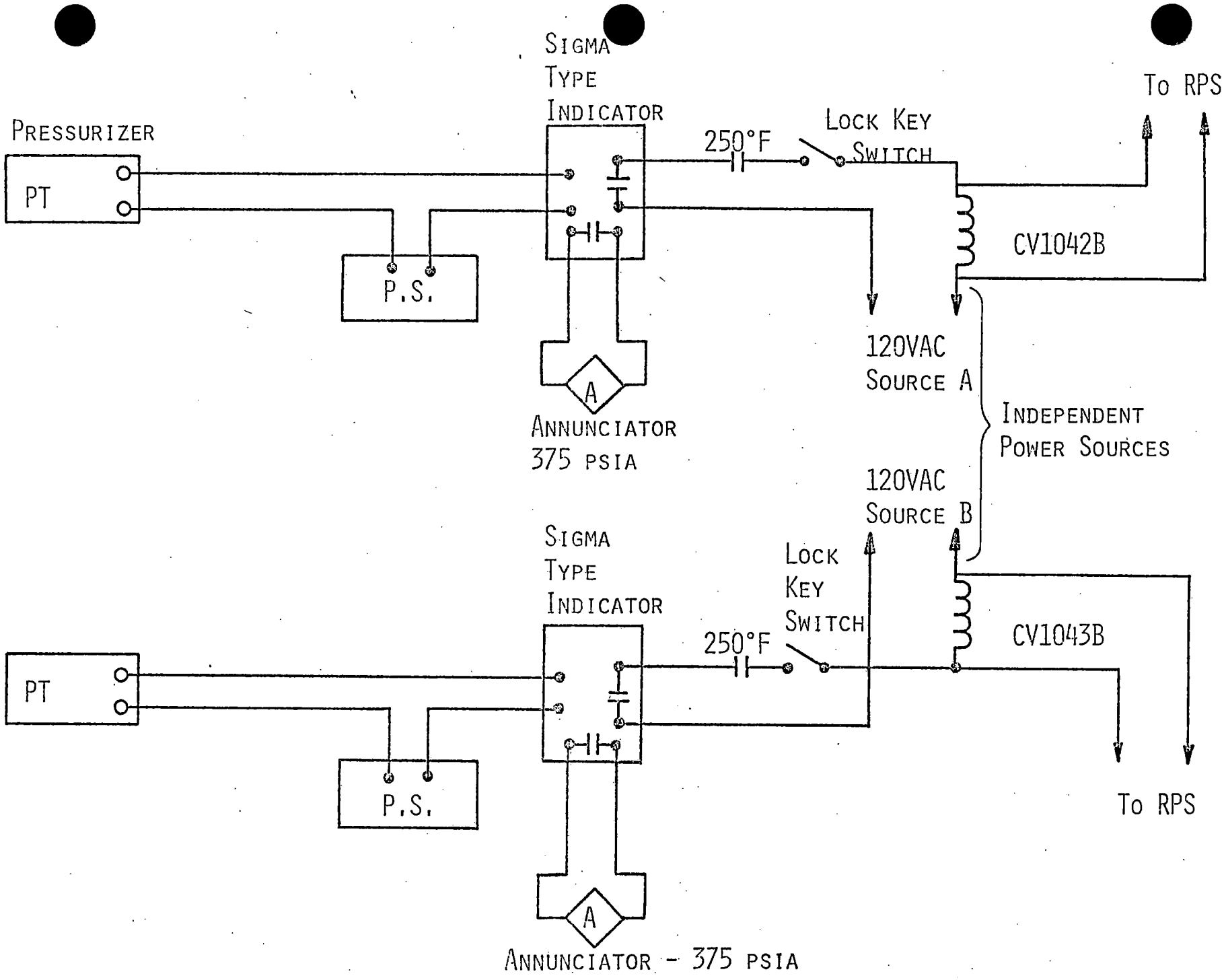

FIGURE 7.1. CIRCUIT DIAGRAM FOR PORV CONTROL

8.0 CONCLUSIONS

The analytical results provided by the RETRAN computer code demonstrate that the Palisades Plant will not exceed 10CFR50 Appendix G limitations when subjected to design base overpressurization condition even with conservative assumption such as only one PORV actuator, T_{sec}=212°F, T_{pcs}=120°F, and P_{pcs}=270 psia are applied. With the likely successful operation of both the PORVs and the SDC valves the Palisades Plant can easily sustain any overpressurization incident.

9.0 REFERENCES

1. Letters, A. Schwencer NRC to R. B. Sewell-CPCO, Docket No. 50-255, August 11, 1976 and January 10, 1977.

2. Combustion Engineers, "Generic Report Overpressure Protection For Operating CE NSSS", December 3, 1976.

3. I. E. Idel'chik, "Handbook of Hydraulic Resistance Coefficients of Local Resistance and of Friction", AEC-TR-6630, Page 208 (1966).

4. E. J. Perry, C. H. Chilton and S. D. Kirkpatrick, "Chemical Engineers' Handbook", Fourth Edition, McGraw-Hill Book Co., Inc., New York.

5. Letter, D. P. Hoffman-CPC to A. Schwencer-NRC, "Docket 50-255-License DPR-20-Palisades Plant-Reactor Vessel Overpressurization", March 8, 1977.

6. Palisades Plant Technical Specification.

APPENDIX A

RETRAN COMPUTER CODE

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

RETRAN is a modified version of RELAP4, Mod 03, Update 95, which provides the capability to analyze light water reactor plant transients. The basic RELAP code has been used for a considerable time for LOCA analyses, and contains detailed representations of heat transfer, fluid flow and thermodynamics. However, it was developed specifically for the more severe LOCA transient and therefore required several modifications and extensions to analyze the less severe plant transients. RETRAN incorporates some of these required modifications and extensions.

RETRAN represents the initial step in modifying RELAP4 to perform plant transient analysis and as such is released as a preliminary version. RETRAN does not have the capability to analyze transients requiring consideration of regional kinetics, such as the PWR rod ejection accident. Future versions of RETRAN will incorporate a TDA routine which comprises a coupling of the one-dimensional time-dependent ANISN transport code with RETRAN.[1,2] Future versions of RETRAN will be based on RELAP/E rather than RELAP4, and refinements to the code will be made based on the results of initial studies performed with RETRAN.

This report is written on the assumption that the reader is familar with the RELAP4 base code, and that the RETRAN user will treat this as a supplement to the RELAP4 manual.[3] The notations and variable names used in this report are consistent, where applicable, with those used in the RELAP4 manual. Only those sections of RELAP4 which have been modified in RETRAN are addressed. Section II of the report presents a summary description of the RETRAN code. The remaining sections of the report contain descriptions of the modifications and the input data requirements for these models. The reader is referred to the RELAP4 manual for a detailed program description and those input requirements not affected by the RETRAN modifications.

II. PROGRAM SUMMARY DESCRIPTION

The majority of the RELAP4 base code models have been retained in RETRAN. The program control, data input, restart capability, and output control are identical to RELAP4 except as noted in Section III describing the RETRAN modifications. Consequently RETRAN maintains the flexibility to perform a wide spectrum of plant transients for both pressurized water reactors (PWR) and boiling water reactors (BWR). This flexibility is derived in part by the general scheme in which the system is described for code input by a number of regions (volumes) and junctions between regions. Thus single and multiloop models with various degrees of detail in both the primary and secondary systems may be utilized by simply changing the input. The following sections present an overview of various models within RELAP4, their applicability to plant transient analyses, and how they have been modified or extended in RETRAN.

1.0 RETRAN MODIFICATIONS

1.1 Region State Solution

RELAP4 determines the region state (based on ASME tables) at the end of each time step based on homogeneous thermodynamic conditions within each particular region covering conditions from subcooled through saturated, into the superheated region. RETRAN preserves the RELAP4 state solution in all regions except the pressurizer, which is discussed in Section 1.5.

1.2 Loop Flow Solution

The flow rate for each junction in RELAP4 is determined from a complete one-dimensional momentum equation. In situations where the fluid remains subcooled this degree of detail is probably not reuiqred; however, when compressibility becomes an important consideration the momentum equation solution between regions becomes a necessity. Therefore, the momentum equation solution scheme is preserved in RETRAN.

RETRAN will also utilize the RELAP4 models for transient pump and motor performance. These models allow a complete description of the pump characteristics, rotating inertia, friction and windage, and motor torque versus speed.

1.3 Plenum and Piping Models

The junction fluid conditions at the outlet of a RELAP4 volume is determined based on a homogeneous mixture of the volume, assuming that the volume is single phase or two phase without a phase separation model. This is a proper representation for plenums and is utilized in RETRAN. On the other hand, in piping volumes where the flow basically moves through as a slug, the outlet conditions are physically represented by a $(T-\tau)$ type of delay where τ accounts for the time required to transport a pipe volume of fluid through the region. In other words, the outlet fluid conditions at time T equal the inlet conditions at time $(T-\tau)$. RETRAN has been modified to account for this type of transport delay.

1.4 Heat Conduction

RELAP4 has the capability to model up to 50 heat conductors (total for the system model), but only provides for surface heat transfer coefficient calculations on one side of the conductor. Two surface heat conduction needs to be accounted for in modeling the primary and secondary sides of a PWR steam generator, and in modeling the can surrounding the fuel rods in a BWR. RETRAN has been expanded to provide surface heat transfer coefficient calculations on two sides of the conductor.

In a PWR steam generator secondary side different heat transfer regimes exist above and below the mixture level. To account for this RETRAN was expanded such that separate heat transfer coefficients are calculated above and below the mixture level based on the local fluid conditions.

1.5 PWR Pressurizer

Given the current RELAP4 state scheme, the pressurizer pressure is simply the saturation pressure of the volume mixture. This approach does not physically represent the performance of the pressurizer in PWR transients. A pressurizer model has been incorporated into RETRAN which includes the necessary physical parameters. Non-equilibrium conditions between the pressurizer liquid and vapor regions are considered along with appropriate interactions at the liquid-vapor interface.

1.6 PWR Auxillary DNB Calculation

The majority of the transients to be analyzed will not exceed the critical heat flux (CHF) for hot rod conditions. Indeed, acceptable margin above the Minimum Departure from Nucleate Boiling Ratio (MDNBR), is a design requirement for the less severe PWR plant transients. For such transients a detailed core-wide DNB analysis is not required. These transients will be analyzed via a subchannel model available in RETRAN. This model performs separative hydraulic analysis on a single hot subchannel using RETRAN boundary conditions during the transient. Input for the DNB routine consists of modeling options, miscellaneous input, and standard heat flux and hot channel factors commonly used in DNB analyses for PWR's. When setting up RETRAN for a specific power plant, the hot channel-flow redistribution factor should be adjusted until the RETRAN predicted MDNBR agrees with a detailed COBRA-IV, or equivalent, analysis. Model options available include common CHF correlations, axial correction factor for CHF, grid space flow mixing correlation, an approximation for turbulent cross flow mixing, and a "cold wall" CHF correction factor.

1.7 Reactor Kinetics

Due to the preliminary aspect of RETRAN and the scope of work in the development, the space-independent reactor kinetics equations presently in RELAP were maintained in RETRAN without any modifications. This limits the RETRAN analysis capability to those transients not requiring

consideration of regional kinetics. Future versions of RETRAN will be modified to account for these regional kinetic affects by the coupling of the one-dimensional time-dependent ANISN transport code with RETRAN.[2]

1.8 Trip Logic

RELAP4 provides "OR" logic trips on several basic system parameters. To model the more detailed interlocks associated with the systems involved in plant transients it was necessary to expand the trip logic in RETRAN The expanded trip logic includes the base code "OR" trip logic as well as "AND" logic, indirect trips and reset trips. The "AND" logic trips allow modeling of trips which are activiated when all of several conditions are met. The indirect trips account for trips actuated by other trips, while the reset trips allow previously activated trips to be reset. The RETRAN trip logic was also expanded to include trip capability from control system output. This feature allows trip actuation from functions of system variables, such as a feedflow-steamflow mismatch.

1.9 Plant Control Logic

In order to evaluate plant transients, it is necessary to predict plant system control feedback such as a change in feedwater flow due to a change in water level. RELAP4 does not provide for simulation of this type of control, however, the existing trip logic can be used as an on-off approximation of some controls. RETRAN has been expanded to include the capability of simulating control system feedback. The capability has also been expanded to include the control system output as trip logic input.

1.10 Program Time Step Control

In order to reduce the program running time and dampen time step size induced oscillations, an optional time step selection technique was added in RETRAN. This time step selection technique is based upon a built-in integration accuracy algorithm for the flow equations using an explicit iteration.

III. MODEL DESCRIPTIONS

As previously discussed, RETRAN incorporates several modifications and extensions to the models in RELAP4. These RETRAN model changes are described below.

1.0 TRIP LOGIC MODIFICATIONS

The control functions normally needed to simulate a reactor system with RELAP4 are described through the trip control data. The user selects signals, setpoints, and delays. Signals representing conditions in the reactor are compared with the setpoints. After the setpoint threshhold is crossed and after a delay time, the trip is actuated. A trip is identified by the value of IDTRP assigned to it on the trip data cards. By using the same value of IDTRP on several cards, the user can model a trip which is actuated when any one of several conditions is met. In addition, a single trip may initiate several actions, all beginning at the same time.

In RETRAN the trip logic model is extended to include:

(1) Coincidence trips (also called "AND" trips)
(2) Indirect trips
(3) Reset trips (also called "blocking" or "reverse" trips)
(4) Control system trips.

Coincidence trips allow modeling of trips which are activated when all of several conditions are met. In RELAP4, only the "OR" logic function is available. Coincidence trips make the "AND" logic function available. With coincidence trips, it is possible to model "majority logic" where a trip is actuated only when at least two out of three conditions are met.

Indirect trips are trips actuated by another trip but with an additional delay. Indirect trips allow a trip condition to initiate several actions

at different times. With indirect trips, it is possible to model a sequence of events occurring at different times, all triggered by the same trip.

Reset trips allow previously activated trips to be reset. A reset trip used this way is sometimes called a "reverse" trip or an "off" trip. Reset trips also reset trips whose setpoint threshold has been crossed, but whose delay time has not yet expired. An indirect trip used this way is sometimes called a "blocking" trip.

Control system trips allow modeling of trips that are a function of various system parameters. For example, with a control system trip a trip can be actuated from a steamflow-feedflow mismatch signal.

Implementing these extensions resulted in the following fringe benefits:

(1) One hundred (100) trip cards are allowed instead of fifty (50). However, the maximum allowed value of IDTRP is still fifty (50).

(2) The combination of "AND" plus "OR" trips allowed is limited only by the number of trip cards.

The extensions to the trip logic are discussed in more detail in Section 1.1 while Section 1.2 summarizes the new input data requirements for trip data.

1.1 Trip Logic Description

1.1.1 Coincidence Trip

The coincidence trip, also called 'AND' trip, refers to a trip which occurs only after both of two conditions have been satisfied. For example, a PWR may trip a safety injection system when there is low pressure and low level in the pressurizer. Consider the following example.

	IDTRP	IDSIG	IX1	IX2	SETPT	DELAY	
040020	2	4	10	0	2000.	0.0	*Hi Pressure Trip
040030	3	-6	10	0	10.	0.0	*Lo Water Level Trip
040040	4	13	2	3	0.0	0.0	*Coincidence Trip

Trip 2 is actuated when the pressure in volume 10 exceeds 2000.0 psia. Trip 3 is actuated when the water level in volume 10 drops below 10.0 ft. Trip 4 represents the safety injection system trip. Consider card 040040. IDSIG = 13 denotes that a coincidence trip is being used. IX1 = 2 denotes that trip 2 is one operand trip. IX2 = 3 denotes that trip 3 is the other operand trip. SETPT is not used and is arbitrarily set to zero. Delay was set to zero for this example. The card 040040 represents the logic that the safety relief system is activated with zero delay after both trip 2 and trip 3 have been actuated.

In preparing trip data using coincidence trip the user must define operand trips before a coincidence trip can refer to them. In this example trip 2 and trip 3 are defined before the coincidence trip is defined.

1.1.2 Indirect Trip

An indirect trip is defined to be a trip which is actuated by another trip. The indirect trip simplifies modeling of trip logic which would be very cumbersome to model with RELAP4. Consider a system which trips the turbine whenever the reactor is scrammed. The reactor scram could be tripped by a number of different signals, say, six signals. The reactor scram logic could be modeled using six cards. To model the turbine trip, RELAP4 would have to duplicate those six cards with a different value of IDTRP and a larger value for the delays. If an indirect trip is used, only one additional trip card would be required. See example below.

	IDTRP	IDSIG	IX1	IX2	SETPT	DELAY	
040020	2	2	0	0	1.2	.5	*Scram on Hi Power
040030	2	4	10	0	1070.	1.0	*Scram on Hi Pres
040040	2	-6	5	0	1.0	1.0	*Scram on Lo Level
040050	3	12	2	0	0	1.0	*Indirect Turbine Trip
							*1.0 Sec Delay

The value of IDTRP corresponding to reactor scram is 2. The reactor is scrammed if reactor power is high or if vessel pressure is high or if liquid level is low. The value of IDTRP corresponding to turbine trip is 3. The turbine is to be tripped one second after the reactor is scrammed.

Card 040050 represents the logic that the turbine is to be tripped one second after the reactor is scrammed. IDSIG = 12 denotes that an indirect trip will be used. IX1 = 2 denotes that the trip with IDTRP = 2 will be the initiating trip. IX2 is not used and must be set to zero. SETPT is not used and is arbitrarily set to zero. Delay is set to 1.0 second.

IX2 is not used in the above example, so it is set to zero. IX2 may denote another initiating trip. When IX1 and IX2 are used to denote different initiating trips, the interpretation is that the indirect trip is actuated when either trip IX1 or IX2 is actuated.

In preparing trip data which uses indirect trips the user must observe the following rule. Initiating trips must be defined before an indirect trip can refer to them. In the example above, the scram trip is defined before the indirect trip.

1.1.3 Reset Trips

In RELAP4 a trip cannot be deactivated after it has been activated. For example, RELAP4 could model a safety relief valve as a valve which is tripped open by a high pressure, but RELAP4 could not model the closing

of the same valve when the pressure was reduced. Using the reset trip modifications, RETRAN can now model both the opening and the closing of the same valve. In addition, the valve may be opened and closed repeatedly if required by the pressure variation.

Consider the following example, where the trip logic for a relief valve is modeled. The valve is opened when the pressure in volume 10 exceeds 2400 psia and is closed when the pressure in volume 10 drops below 2300 psia.

	IDTRP	IDSIG	IX1	IX2	SETPT	DELAY	
040020	2	4	10	0	2400.	0.0	*Hi Pressure Normal Trip
040030	-2	-4	10	0	2300.	0.0	*Lo Pressure Reset Trip

The data on the reset trip card is analogous to the data on a normal trip card. The only difference is that the sign of IDTRP on all reset trip cards is negative. The absolute value of IDTRP on a reset trip card is equal to the value of IDTRP of the normal trip which is to be reset. In this example IDTRP = -2 for the reset trip and IDTRP = 2 for the corresponding normal trip. All other parameters on a reset trip card may have different values from the normal trip which is to be reset. The reset trip may monitor a different signal, have a different setpoint or have a different delay time from the normal trip.

Other points which the user should be aware of are:

- Any number of reset trip cards may be specified for a particular value of IDTRP. If the condition on any one reset card is met, then the trip is reset.

- If a normal trip and a corresponding reset trip is actuated at the same time, the reset trip dominates, and the normal trip is not actuated.

- Consider the following situation. The setpoint of a normal trip has been reached, but has not been actuated because of the delay time specified. If a reset trip is actuated during that delay time, the normal trip is reset and will not remember that the setpoint had been reached.

- Just as it is possible to build an oscillator in practice, it is possible to set up an oscillation which is contained entirely within the trip logic. If the delays specified on reset trips are all smaller than every delay specified on corresponding normal trips, then oscillations within the trip logic are avoided.

1.1.4 Control System Trips

The control system trips greatly increase the capability of the trip logic. With control system trips, a trip can be actuated from functions of various papameters within the limits of the control system capabilities. Consider a reactor scram from a steamflow-feedflow mismatch signal. The control system trip is setup to trip from this signal. See example below.

	IDTRP	IDSIG	IX1	IX2	SETPT	DELAY	
040020	2	14	-8	0	10	0.5	*Scram from steam flow feedflow mismatch

The value of IDTRP corresponding to reactor scram is 2. The reactor is scrammed after a 0.5 second delay when the mismatch signal exceeds 10.0. IDSIG=14 denotes that a control system trip will be used. IX1=-8 denotes that the trip will be on control block number -8 output. IX2 is not used for control system trips and must be set to zero.

1.2 Input Description

Input data modifications were only required on the Trip Control Data Cards (04XXX0). Data quantities 1 through 4 were extended to account for the additional trip logic. The new data input requirements are listed in Section IV.

2.0 CONTROL SYSTEM MODELS

The response of various plant systems may have a large effect on the overall system response depending on the particular transient being analyzed. For example in a BWR loss of feedwater heater transient, an accurate simulation of the feedwater flow response is necessary because of its large effect on the reactivity feedback. RELAP4 could provide only a zero-order model via the trip logic control with delay times. RETRAN provides greatly expanded capability to model a variety of reactor control systems. The RETRAN control system model truly models the dynamics of linear control systems. In addition, "real-world" non-linear characteristics of control elements, such as clipping, saturation, and recovery time after saturation can be modeled. These additional capabilities allow easy representation of the various controllers in common use, such as a proportional-integral-derivative (PID) controller, or, in fact, any arbitrary transfer function desired by the user.

The input for the control system is compatible with the standard free-formatted input used by RELAP4. Control elements available to the user include all of the more common analog computer elements plus a few that an analog computer can model only with difficulty. The types of elements available include integrators, differentiators, weighted summers, multipliers, dividers, delays, and function generators. The choice of components and their interconnections are specified via RETRAN input data and may be completely arbitrary.

2.1 Model Description

Table I defines the nomenclature that is used to describe the control system model. The letter "x" refers to signals related to the input of a control block. The letter "y" refers to signals related to the output of a control block. The letter "h" refers to time step intervals. A scale factor "G" is used by all control blocks.

TABLE I

CONTROL SYSTEM MODEL NOMENCLATURE

$F_m[\ ]$	=	functional relation defined by the user via 20 pairs of values of the independent and dependent variables in Fill Table m
g_1, g_2	=	user specified gains which apply to input 1 and input 2 respectively; these gains are used by SUM block only
G	=	user specified value for the overall gain of a control block
h_i	=	$t_i - t_{i-1}$, the i^{th} time interval
i	=	subscript used to denote values evaluated at i^{th} value of time
IDC	=	control block identification number
m	=	Fill Table index; only the FNG block uses m
n	=	user specified integer value denoting the number of samples taken and saved per delay interval; only the DLY block uses n
s	=	complex frequency in radians per second
t	=	time in seconds
t'	=	dummy variable representing time
t_i	=	i^{th} value of time
t_{i-1}	=	$(i-1)^{th}$ value of time
T	=	Delay time interval; T is used by DLY block only
v_{down}	=	user specified maximum negative rate of change for control block output, maximum "downward slew rate"; only the VLM block uses v_{down}
v_{up}	=	user specified maximum positive rate of change for control block output, maximum "upward slew rate"; only the VLM block uses v_{up}
x_i	=	value of x_1 (t) when $t=t_i$
x_0	=	value of $x_1(t)$ when t=0
$x_1(t)$	=	input 1 of control block represented as a function of time
$x_2(t)$	=	input 2 of control block represented as a function of time

TABLE I (Contd.)

$y(t)$	=	output of control block represented as a function of time
y_i	=	value of $y(t)$ when $t=t_i$
y_{i-1}	=	value of $y(t)$ when $t=t_{i-1}$
y_{max}	=	user specified maximum value of $y(t)$
y_{min}	=	user specified minimum value of $y(t)$
y_0	=	value of $y(t)$ when $t=0$
t_1	=	lead time constant
t_2	=	lag time constant

Table II presents the mathematical definition for each control block. The output is expressed either explicitly, as a function of the input, or implicitly, as the solution of a differential equation where the input is a given function of time. In addition Table II briefly describes the numerical approximations used by the RETRAN coding to represent the control block.

The object of a control system model is to determine the output of a system given the input and information characterizing the system. The input is a given function of time. The output is a function of time to be determined. When the input and output time functions can be related by a linear differential equation, the system is said to be linear. If information concerning the state of the system in terms of the initial output is known, the differential equation can be solved for the output given an arbitrary input. The DER, INT, LAG and LLG control blocks represent systems which are linear. RETRAN solves the differential equation characterizing these blocks by using a backward difference approximation to the first derivative. Solving the resulting difference equation for y_i in terms of X_i, x_{i-1}, y_{i-1}, and h_i represents an explicit formula for calculating the output of each block for each time step. This formula applies as long as the linear difference equation is a good approximation to the differential equation and the differential equation accurately represents the actual hardware.

In reality the input-output relation of the hardware can be represented by a linear system over only a finite range. To model this non-linear characteristic RETRAN assumes that a control block is linear whenever its output is greater than y_{min} and less than y_{max}. If the linear model predicts an output greater than y_{max}, then the output is assumed to be equal to y_{max}. If the linear model predicts an output less than y_{min}, then the output is y_{min}. The user specifies the parameters y_{min} and y_{max}. In addition, RETRAN provides non-linear control blocks such as the FNG and VLM blocks to allow the user to model other types of non-linear behavior which may be in the hardware.

The numerical approximations used for the control blocks are straightforward. The DER, INT, LAG, and LLG blocks were discussed above. The DIV, MUL, and SUM blocks simply take the inputs at time t_i and perform the operations indicated by their names to calculate the output. The FNG block takes the input at time t_i and linearly interpolates over the user supplied table to calculate the output. The VLM block calculates the maximum and minimum values the output may have without exceeding the user-specified rate limitations and calculates the output according to the conditions described in Table II.

The method used to model the DLY block is conceptually simple, but difficult to describe symbolicly. The details are described here to explain the significance of the n parameter required by the DLY block. The DLY block stores the values of the input for the past T seconds. The output of the DLY block at time t_i is the input that it had at time (t_i-T) multiplied by the scale factor G. The manner in which the DLY BLOCK block stores the input values is to make a stepwise continuous function out of the input, sample the input at fixed time intervals equal to (t/n), and save each sample for T seconds. Thus, n is equal to the number of samples of the input the DLY block has stored over the past T seconds. A larger value of n results in a more accurate representation of the past input at the cost of more storage. The user should strive to choose the smallest value of n consistent with acceptable accuracy.

2.1.1 Limitations, Precautions and Instructions

The OUT block does not represent an actual control element. Its function is to provide the user with a convenient means to monitor the output of any control block output or control input for the purposes of debugging. Use of the OUT block will result in the printing of the output of the specified control block or control input signal at every time step.

The order in which the output of each block is calculated affects the numerical results calculated by the control system for interconnected

TABLE II

MODELS FOR CONTROL BLOCKS

Symbol	Descriptive name	Mathematical definition	Numerical approximation used by RETRAN
DER	Differentiator	$y(t) = G \cdot \frac{dx(t)}{dt}$	$y_i = G \cdot \frac{x_i - x_{i-1}}{h_i}$
DIV	Divider	$y(t) = G \cdot \frac{x_1(t)}{x_2(t)}$	$y_i = G \cdot \frac{x_1(t_i)}{x_2(t_i)}$
DLY	Time delay	$y(t) = y_0$ for $0 \leq t \leq T$ $= G \cdot x(t-T)$ for $t > T$	Numerical approximation used is difficult to represent symbolicly. See text.
FNG	Function generator	$y(t) = G \cdot F_m[x(t)]$	$y_i = G \cdot F_m[x_i]$ where $F_m[\cdot]$ represents linear interpolation over a table of ordered pairs of independent and dependent variables.
INT	Integrator	$y(t) = y_0 + G \cdot \int_0^t x(t')\, dt'$	$y_i = y_{i-1} + G \cdot (x_i - x_{i-1}) \cdot h_i$ with y_0 given
LAG	Lag compensation	$y(t) + \tau_2 \cdot \frac{dy(t)}{dt} = G \cdot x(t)$ with $y(0) = y_0$	$y_i = y_{i-1} + \frac{h_i \cdot (G \cdot x_i - y_{i-1})}{2}$ with y_0 given

TABLE II - (Cont'd)

MODELS FOR CONTROL BLOCKS

Symbol	Descriptive name	Mathematical definition	Numerical approximation used by RETRAN
LLG	Lead-lag compensation	$y(t) + \tau_2 \cdot \frac{dy(t)}{dt} = G \cdot x_1(t) + \tau_2 \cdot \frac{dx_1(t)}{dt}$ with $y(0) = y_0$	$y_i = y_{i-1} + \frac{G \cdot x_i + G \cdot \tau_1 \cdot (x_i - x_{i-1}) - y_{i-1}}{\tau_1}$ with y_0 given
MUL	Multiplier	$y(t) = x_1(t) \cdot x_2(t)$	$y_i = x_1(t_i) \cdot x_2(t_i)$
SUM	Weighted summer	$y(t) = G \cdot [g_1 \cdot x_1(t) + g_2 \cdot x_2(t)]$	$y_i = G \cdot [g_1 \cdot x_1(t_i) + g_2 \cdot x_2(t_i)]$
VLM	Velocity limiter	$y_i = y_{down}$ if $G \cdot x_i < y_{down}$ $= y_{up}$ if $G \cdot x_i > y_{up}$ $= G \cdot x_i$ otherwise where $y_{down} = y_{i-1} - h_i \cdot v_{down}$ $y_{up} = y_{i-1} + h_i \cdot v_{up}$	Same as mathematical definition

blocks. The order of computation is determined by the order of the control block description cards, which contain the interconnection information. Therefore, when control blocks are cascaded, the burden is upon the user to order computations sequentially from the beginning of the cascade to the end by ordering the control block description cards sequentially.

From Table II it can be seen that the control blocks which have to be initialized are only the DLY, INT, LAG, LLG, and VLM blocks. They are the only blocks which require past values of the output to calculate the new value of the output y_i. However, it is recommended that all control blocks and all control inputs be assigned an initial value of output by the user on the input data cards. This is recommended so that the control system model interfaces properly with the trip logic model in RETRAN. Only trips which monitor signals which are controlled by the control system are affected. These trips are affected only at time zero by the initial values. The values used for initialization for blocks other than those listed above need not be exact and need only be on the same side of the setpoints as the exact value for all trips monitoring those control signals. In other words, if the correct initial values would cause a trip to be actuated, any initial value which would cause the trip to be actuated may be input. It is recommended that the user initializes all values as nearly exact as practical. If the user wishes to cut corners, he may choose the initial value such that no trip monitoring that control signal will be activated by the initial value input. The only consequence of the short cut is the delay by one time step of the actuation of a trip which might have occurred at time zero. The user is to be reminded that the initialization of the DLY, INT, LLG, and VLM blocks must be done as exactly as practical.

One extra location of storage is required for every block of the following type used: DER, FNG, and LLG. For a DLY block using n_0 samples, n_0+3 extra locations of storage are required. The input routine for the control system automatically assigns storage, keeps account of the extra storage required, and deletes execution if the storage requirements exceed the storage available.

By the nature of digital computation, calculations are performed sequentially. If a loop is constructed using only those control blocks whose outputs are algebraic functions of their inputs (DIV, FNG, MUL, and SUM), the resulting outputs will not be correct and will not converge. Oscillations will occur in this case because the input for one element in the loop must be taken from calculations during the previous time step to start off the calculations around the loop. Unless that initial value happens to equal the new value calculated for that signal after going around the loop, oscillations will occur. These control blocks are idealized and do not exist alone in practice, just as an amplifier with infinite bandwidth does not exist in practice. Thus, the inability to model algebraic loops does not restrict the user from modeling practical systems with their practical limitations.

2.2 Input Description

The input for the control system model consists of a group of data cards (70XXXX cards) describing the input to the control system, the parameters of each control block, and their interconnections. In addition, the data cards pertaining to those portions of the reactor system which are controlled by the control system have been modified to indicate which control block output is in control.

The Control System Problem Dimensions Card (701000) specifies the number of inputs (NCI) and the number of control blocks (NCB) needed to model the reactor control system. Up to 20 inputs and 100 control blocks may be requested.

The Control Input Definitions Cards (702XXX, $1 \leq XXX \leq 20$) specify the input variables which the control system is to monitor and assigns a unique identification number (IDC) to each variable. IDC may have any integer value between 1 and 20. If an identical value of IDC is used on more than one card, the last such card will replace all earlier definitions. At present, the control system may monitor the following variables:

(1) Average pressure in any volume
(2) Mixture level in any volume
(3) Liquid level in any volume
(4) Average temperature in any volume
(5) Mass flow in any junction
(6) Normalized power of reactor system
(7) Elapsed problem time
(8) Any constant value specified by the user

The Control Block Description Cards (703XXX, $1 \leq XXX \leq 100$) select the types of control blocks the user needs, assign a unique identification number (IDC) to each block, specify the values of parameters for each block, and describe the interconnections between all blocks and all input variables. The types of control blocks the user may select are listed in Table III. IDC may have any integer value between -1 and -100. The number of control parameters needed to describe each block depends on the block type. The parameters needed by each block type are outlined in Table III. Each block has only one output; therefore the output of a block may be referenced by the IDC of the block. This allows the interconnections of the blocks to be specified by associating each input of a block with the IDC of the block whose output provides the input.

The 70XXXX cards describe the inputs to the control system and the control blocks making up the control system. The output of the control system may control various conditions at different places in the reactor system. Thus, the user may, via the control system, monitor conditions at various places in the reactor and, based on those conditions, control conditions at various other places in the reactor. The present RETRAN control system allows control of the flux from a fill junction, the valve area, reactivity insertion or power addition, and trips. Each of these options required modification of the associated RELAP4 input data cards to identify the control block controlling the parameters. Those input data cards which were modified are discussed below.

TABLE III

CONTROL BLOCK PARAMETERS

Symbol	Description	INC1	INC2	CCAIN	CP1	CP2	CMIN	CMAX
DER	Differentiator	IDC for $x_1(t)$	0	G	0.0	0.0	y_{min}	y_{max}
DIV	Divider	IDC for $x_1(t)$	IDC for $x_2(t)$	G	0.0	0.0	y_{min}	y_{max}
DLY	Time delay	IDC for $x_1(t)$	n	G	T	0.0	y_{min}	y_{max}
FNG	Function generator	IDC for $x_1(t)$	m	G	0.0	0.0	y_{min}	y_{max}
INT	Integrator	IDC for	0	G	0.0	0.0	y_{min}	y_{max}
LAG	Lag compensation	IDC for $x_1(t)$	0	G	t_2	0.0	y_{min}	y_{max}
LLG	Lead-lag compensation	IDC for $x_1(t)$	0	G	t_1	t_2	y_{min}	y_{max}
MUL	Multiplier	IDC for $x_1(t)$	IDC for $x_2(t)$	G	0.0	0.0	y_{min}	y_{max}
OUT	Output	IDC for $x_1(t)$	IDC for $x_2(t)$	-	-	-	-	-
SUM	Weighted summer	IDC for $x_1(t)$	IDC for $x_2(t)$	G	g_1	g_2	y_{min}	y_{max}
VLM	Velocity limiter	IDC for $x_1(t)$	0	G	v_{up}	v_{down}	y_{min}	y_{max}

The Fill Table Data Cards (13XXYY) were modified to identify the control block ID for fills which are controlled by the control system instead of the input table values. Use of both positive and negative fill for the same junction is not recommended because of the way the momentum equations are handled in RETRAN. The user must set MVMIX on the junction data cards according to whether a positive or negative fill flux is used. The fill table data cards were also modified to allow the fill table to be used as a function description for the function generator control block.

The Valve Data Cards (11XXX0) were modified to specify that the valve was being controlled by the control system and to identify the control block providing the normalized valve area data.

The Reactivity Table Data Cards (14XXYY) were modified to provide reactivity insertion or power addition from the control system. If NODEL, the power calculation indicator on the Kinetics Constants Data Card, is greater than zero, a reactivity contribution from the control system may be specified via the Reactivity Table Data Card. If NODEL is equal to zero, an addition to total power from the control system may be specified via the Reactivity Table Data Card.

The Trip Control Data Cards (04XXX0) were modified to allow trips from the control system. This coupling of the control system with the trip logic increases the flexibility of the trip logic model. It is now possible to model "functional trips", trips which are actuated when an algebraic combination of two or more signals exceeds a setpoint.

3.0 TIME STEP CONTROL

The optional time step selection technique addition to RETRAN is based upon a built-in integration accuracy algorithm for the flow equations using an explicit iteration. The explicit iteration technique takes advantage of the computational efficiency of the matrix inversion subroutine NIFTE. Accuracy is based upon pointwise integration of the flow equations for the incremental change in junction flow, ΔW_j.

The complete thermal hydraulic solution in RETRAN can be divided into two basic stages. The first stage is the flow solution. The flow solution at a new point in time is computed based on quantities at the old point in time. The second stage then updates certain thermodynamic properties of the system from the equations of state (subroutines BAL and STATE) after a mass and energy balance are obtained.

The second stage is much more time consuming than the first stage. The advantage of the explicit iterative method comes from utilizing the high calculation speed of the first stage for flow calculations with differing time steps. An estimated error in the flow solution can be made by comparison of two consecutive results. When the desired accuracy is obtained the flow solution and time step are accepted and then the state properties are updated in the second stage.

The explicit iterative method allows the time step to be increased or decreased depending upon the behavior of the flow solution. If nonlinear behavior is detected, the time step size is decreased until the solution has converged within accuracy requirements. However, if the flow solution behaves in a linear manner the time step size is increased until the solution falls within required accuracy. Both upper and lower limits for the convergence criteria are defined. If the calculated error for any junction flow falls above the upper limit, the time step is decreased. If all calculated errors are below the lower error limit the time step is increased. If one or more calculated errors in the flow solution are within the error band with none exceeding the upper

error limit, the flow solution and time step size are accepted and the state properties are updated in the second stage.

3.1 Input Description

The necessary input data modifications pertaining to the time step selection options are made only to the Time Step Data Cards (03XXX0). Data quantity 4 was changed so that the value of 2 selects the time step option based only on flow nonlinearities.

4.0 PIPE TRANSPORT MODEL

The timing of temperature changes in the primary system can be very important in the simulation of plant transients for both BWR and PWR(s) because of the effects reactivity feedback and/or steam generator heat removal have on the system transient response. Temperature changes move through some regions (such as piping) essentially as a front, that is, the incoming fluid does not mix with the fluid within the particular region but only displaces it. The standard RELAP4 method for determining the junction enthalpy is to homogeneously mix incoming fluid with the contents of a particular region; thus the outlet enthalpy begins to respond immediately to changes in the inlet. This is the type of response that best represents a plenum. Other options available in RELAP4 to affect the determination of junction enthalpy (out of a volume) include a vapor-liquid separation model and an enthalpy transport model to more appropriately model heated sections. The RELAP4 solution taking the number of nodes (control volumes) to a theoretical infinite number would account for the transport phenomena. Unfortunately, there are realistic limitations on problem run time and size such that an approximate submodel is necessary to keep track of the enthalpy movement within a region. The pipe transport model in RETRAN is intended to serve this purpose and is not designed to solve the transport problem in the most general sense.

The piping transport model considers the movement of fluid through a region as a slug. In other words, the fluid coming into a region at time (t) leaves that region at time ($t + \tau$) where τ represents the time required to transport that fluid through the volume. Thus the timing of feedback effects either from the core or the steam generator are properly modeled.

4.1 Model Description

4.1.1 General Approach and Assumptions

The transport of fluid through a region with one inlet, one outlet and with the flow always moving in the same direction is not a particularly difficult problem to fit into RELAP4. However, to cover situations such as a single loop pump coastdown (or locked rotor), to handle a variety of junctions into and out of a volume, and handle flow reversals appropriately; the overall approach and objective of the transport model include:

(1) The ability to define the enthalpy distribution spatially (one-dimensionally) within the volume such that major flow reversals will be handled appropriately.

(2) The ability to model several junctions into and out of a given "transport" volume.

(3) The ability to handle flow oscillations such as might occur intermittently due to numerics or other problems.

In order to accomplish the aforementioned objectives a mesh is defined by which the enthalpy distribution within the volume is maintained. The mesh is defined by user input for each volume which is to be treated as a "transport" volume. This mesh divides the volume into equal segments of mass; these segments then being used to define the enthalpy distribution within the volume and the movement of temperature changes through the volume.

4.1.2 Detailed Description and Solution Technique

The enthalpy of each mass interval defined for each transport volume are updated according to the mass flow and energy into the volume during each time step. The enthalpy associated with each mesh is shifted in the volume by the mass that has moved into the volume during that time

step. The junction flow rates into a "transport" volume are integrated and summed to indicate the shift in the distribution. Similarly, the integrated average enthalpy is attached to the new mass in the "transport" volume. Because of the variety of geometries and transient situations that may be simulated, a primary flow direction is defined which is used to indicate direction of the shift in enthalpy distribution. In other words, if the primary flow is positive the junctions on the inlet side of the volume are integrated for the shift and, similarly; the outlet end, if the primary flow is negative. The primary inlet and outlet junctions are those junctions with the largest absolute flow rates at initial conditions and are assumed to be in the same direction.

The mesh enthalpy for each of the "n" mass intervals is maintained until sufficient mass has been accumulated into the volume to shift an entire mass interval. Given this approach, the new mesh enthalpy for the leading mesh is the integrated average of the inlet enthalpy over the transient time period required to accumulate the mass of one mesh. This new mesh enthalpy is then shifted through the volume as the transient progresses.

If the primary flow is positive, the shift is performed from volume inlet to outlet and vice versa for negative flow. In RELAP4 there may arise situations where particular junctions flow counter to the primary direction. When this occurs on the inlet side of a "transport" volume (with positive flow) it is considered in the summation for the shift. However, on the outlet side, the mesh enthalpy is adjusted to account for junctions counter to the primary direction. The same approach is used if the primary flow direction is negative.

The determination of the outlet junction enthalpy(s) from the "transport" volume is based on the enthalpy of the outlet mass interval. If more than one interval is affected, then the outlet enthalpy is the mass average of the interval enthalpy. The mass moved out of a "transport" volume is extrapolated from the two previous time steps to estimate the current time step junction enthalpy.

Given the general approach of the transport model, it is conceivable that the integrated average enthalpy in the "transport" volume would not equal the average enthalpy from the overall volume mass and energy balance. This is rectified by normalizing the mesh enthalpies after each shift is performed to the volume average enthalpy. Thus, if heat conductors are considered in volumes which are to be treated as "transport" regions the enthalpy distribution will be shifted up or down as the heat transfer is reflected in the volume averaged enthalpy. The heat transfer calculations continue to use the volume average conditions to determine the heat transfer rate.

4.1.3 Limitations, Precautions and Instructions

The pipe transport model is designed for the specific purpose of simulating the movement of one dimensional enthalpy variations in a region. Therefore the user should study the problem at hand very closely to ascertain that the "transport" $(t - \tau)$ process is really the best representation for the problem.

The transport problem in the general sense is an exceptionally complicated one and the approach developed for RETRAN is a simple approach which models the process of a temperature variation moving one dimensionally without any energy transfer. The complications of compressibility are ignored and, should a volume specified to use the "transport" model cross the saturation line, all further calculations would be based on the normal RELAP4 models.

The "transport" model can also introduce sensitivity due to time step size and number of mesh intervals into the problem solution. This is normally not a problem for typical volume sizes, flow rates, time step sizes, and intervals but could be if a large quantity of mass were being shifted out of a volume each time step. The user should perform some hand calculation checks over the expected ranges of the transient flow rates and problem time step sizes to ascertain that this will not be a problem. If it does appear to be a problem, perhaps the problem should be restructured and/or the "transport" model not ultilized.

The "from" and "to" designation on the junction input cards describe for the transport volume the location of these junctions spatially. The "to" side of the junction is assumed to be connected to the inlet side of the volume and similarly the "from" is connected to the outlet side of the volume. The user should be cautious about this convention particularly with more than one inlet or outlet or when a second dimension is involved such as a pressurizer surge line connected into a primary hot leg.

The number of volumes which may use the "transport" model is limited to twenty with twenty mass intervals per volume. The enthalpy transport model (W18-I on Card 08XXXY) should not be activated in volumes where the pipe transport model is being used.

4.2 Input Description

In order to activate the pipe transport model two additional parameters are required on the desired volume input card (05XXXY).

W15-1	IPTN	=	Flag indicating that the volume is to be handled as a pipe transport volume
		=	0 or blank, standard junction enthalpy calculation.
		=	1, transport calculation to determine junction enthalpy
W16-I	MESH	=	Number of intervals into which the volume is to be divided to maintain the enthalpy distribution

5.0 TWO SURFACE HEAT CONDUCTION

RELAP4 allows modeling of heat conductors with fluid volumes on both the left and right surface of the conductor only if there is no internal heat generation within the conductor. A heat conductor with a heat transfer surface on the right side and none on the left is the only one which can have internal heat generation. RETRAN has been extended to permit heat generating conductors with fluid volumes on both sides as required in modeling the BWR fuel cans. This generalization has additional advantages in that it incorporates consistent treatment of the heat transfer regime selection process at both the left and right surface of a conductor. This results in more consistent treatment of the heat transfer in a PWR steam generator.

5.1 Input Description

There are no input modifications required for utilization of the two surface heat conduction model. The specification of IVSL equal to zero on the 15XXX1 cards for core section conductors in Reference 3 can be disregarded, since the modified core conductors can now conduct heat through both the left and right surfaces.

6.0 LOCAL FLUID CONDITIONS MODEL

In the secondary side of a PWR steam generator, a distinct mixture level is present which may vary throughout a given transient. The heat transfer regimes above and below this mixture level are quite different. Accounting for this heat transfer during some transients is very important. A model has been developed and incorporated into RETRAN to calculate different heat transfer regimes above and below the mixture level in a single RELAP volume. This model is described below.

6.1 Model Description

The local fluid conditions model extends the previous RELAP4 heat transfer calculational capability by providing an estimate of the local quality and mass flow rate at specified elevations. These local conditions are then used to determine the heat transfer regime and surface heat flux at these locations. Interpolation is then used to provide the surface heat flux as a function of elevation which is integrated over the volume height to establish the total thermal energy entering the given volume.

The elevation of each desired one-dimensional heat conductor is specified in the input. Each elevation is then compared against the volume mixture level. If the conductor is above the mixture level, the local quality is taken to be one and the mass flow rate is assumed to be that of the junction leaving the top of the volume. If the conductor level is equal to or below the mixture level, the mass flow rate is assumed to be that of the junction at the bottom of the volume. The local quality within the mixture is determined from the steam bubble density:

$$\rho_{gb} = M \frac{Z}{Z_m} + b \qquad (1)$$

where:

ρ_{gb} = partial steam density within the mixture
m,b = time dependent slope and intercept, respectively

Z = height above the bottom of the volume

Z_m = height of the mixture interface

Equation 1 is the same as Equation 41 in Reference 3. This is the standard equation describing the RETRAN bubble rise model and is used also to determine junction quality in RETRAN.

The local quality and mass flow rate are applied in two RETRAN calculations. The first application is in the determination of the critical heat flux. The local quality and mass flow terms are parameters of the critical heat flux model (subroutine PCHF) in RELAP4.

The second application of these parameters is to the heat transfer correlation selection medel (subroutines HTRC and QDOT) in RELAP4.

These local conditions determine an estimate of the local surface heat flux at each of the specified elevations.

The interpolation procedure used to establish a surface heat flux at intermediate elevations is as follows. Let C_n denote the one-dimensional heat conduction node at elevation Z_n as shown in Figure III-1. The surface area associated with heat conductor C_n is taken to be the surface area bounded above at elevation $Z_{top} = (Z_n = Z_{n+1})/2$, below at elevation $Z_{bottom} = (Z_{n-1} + Z_n)/2$. For the conductor C_n at the top of Volume I take $Z_{top} = Z_n$ and for heat conductor C_0 at the bottom of the volume take $Z_{bottom} = 0$.

For those conductors with an associated area completely above or below the mixture level, the surface heat flux at the conductor elevation is taken to apply to this associated area. RETRAN also uses this as a common assumption. When the associated area contains the mixture level, as for conductor C_n in Figure III-1, two cases must be considered. In one case the mixture level lies above the elevation of the corresponding conductor and in the second case the mixture level lies below the conductor level.

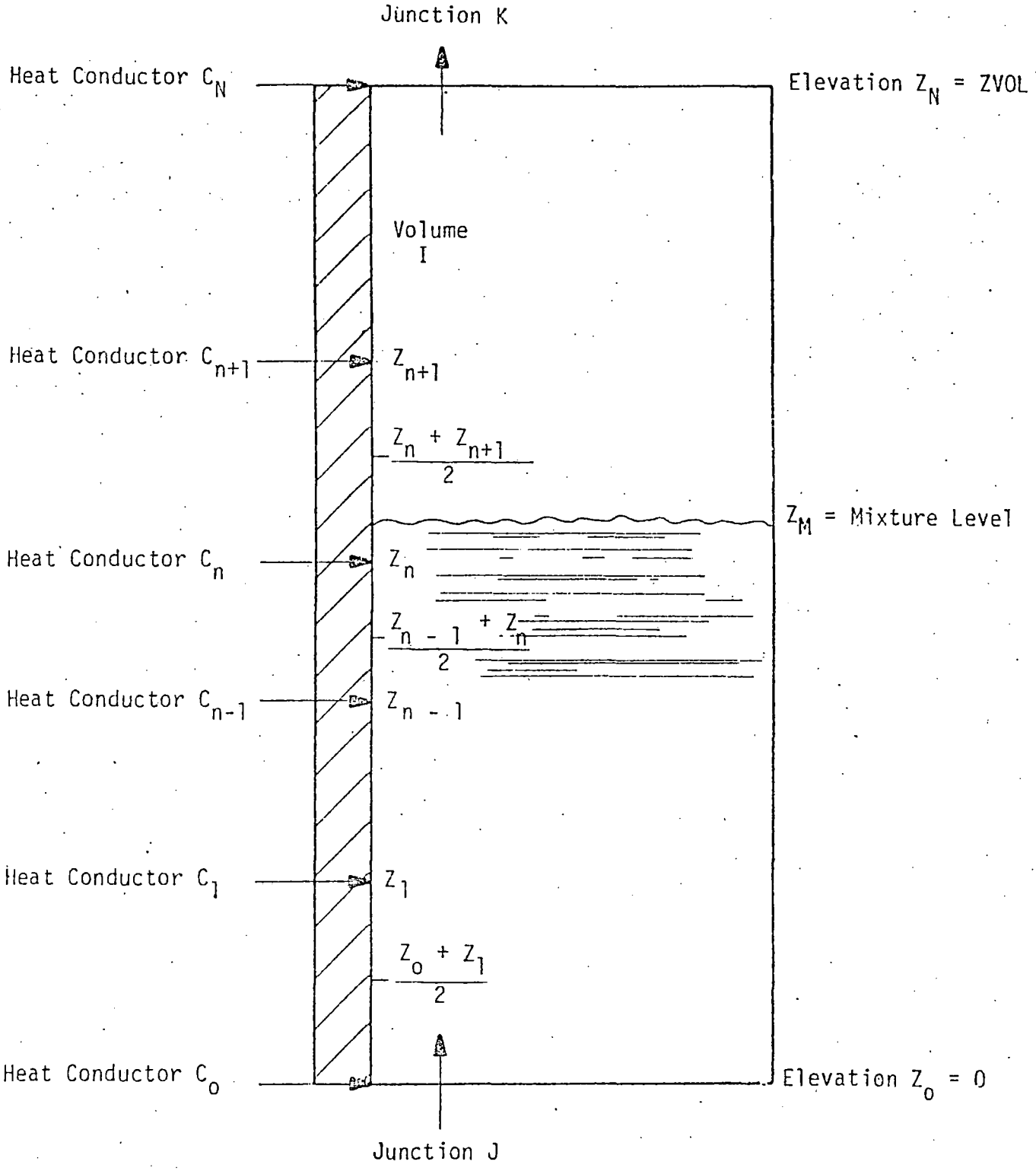

Figure III-1 One Dimensional Heat Conduction Model

Case 1 is illustrated in Figure III-1. The surface heat flux assumed to apply above the mixture level between elevation Z_m and Z_{top} is the surface heat flux calculated for conductor C_{n+1} while between Z_m and elevation Z_{bottom} is the surface heat flux of conductor C_n. This allows that surface area exposed to a steam atmosphere to have a surface heat flux based on a forced convection to steam heat transfer correlation while the surface area still covered by the mixture has a surface heat flux based on a realistic estimate of local two phase conditions.

In Case 2 the surface area associated with C_n above the mixture level would have the surface heat flux of C_n, which is now above the mixture level. The corresponding surface area below the mixture level would have the surface heat flux of C_{n-1}.

The heat transfer rate to the fluid in Volume I from the surface area associated with heat conductor C_n is given by Equation 2 when the mixture level is above elevation Z_n and by Equation 3 when the mixture level is below Z_n.

$$WQCR_n = \left[\left(\frac{Z_{top} - Z_m}{Z_{top} - Z_{bottom}}\right)\phi_{n+1} + \left(\frac{Z_m - Z_{bottom}}{Z_{top} - Z_{bottom}}\right)\phi_n\right] A_n \quad \text{for } Z_m > Z_n \tag{2}$$

$$WQCR_n = \left[\left(\frac{Z_{top} - Z_m}{Z_{top} - Z_{bottom}}\right)\phi_n + \left(\frac{Z_m - Z_{bottom}}{Z_{top} - Z_{bottom}}\right)\phi_{n-1}\right] A_n \quad \text{for } Z_m < Z_n \tag{3}$$

where:

$WQCR_n$ = heat transfer rate associated with area A_n
A_n = heat transfer area associated with C_n
ϕ_n = surface heat flux from C_n

The above algorithm requires that the local surface heat flux be computed at conditions both above and below the mixture level. This requires that heat conduction models be placed at both the top and bottom elevations of the corresponding volume.

All heat conductors connected to a given fluid volume are positioned in the same stack. The stack indicator in RETRAN is used to in dicate which heat conductors lie at the top and the bottom of the fluid volume. This model can be applied to both surfaces of a heat conductor. In this case, the fluid volumes on the left and right sides should be at the same elevation, since the same heat conductor is used at the bottom of each fluid volume.

6.2 Input Description

The necessary input data modifications pertaining to the local fluid condition model are made only to the Heat Conductor Data Cards (15XXXY). Data quantities 1 through 17 remain unchanged from RELAP4 and are listed in Section IV. Data quantites 18 and 19 described below have been added and are required only if the local fluid condition heat transfer model is to be applied.

W18-R	CELV	=	Elevation of this heat conductor relative to the conductor located at the bottom.
W19-I	LCOND	=	1 for right surface (only) local condition heat transfer model.
		=	2 for left surface (only) local condition heat transfer model.
		=	3 for both left and right surfaces local condition heat transfer models.

7.0 PRESSURIZER MODEL

The simulation of PWR plant transients, such as the loss of reactor coolant flow, uncontrolled rod withdrawal, loss of feedwater flow, and the like, require a model of the pressurizer that considers the physical processes taking place during these types of transients. A standard RELAP4 state solution of the pressurizer would assume that all of the contents are in thermal equilibrium. However, the pressurizer rather than behaving in an equilibrium manner has two somewhat distinct regions such that a state solution of the whole volume is not a proper physical representation of the processes occurring. Non-equilibrium between pressurizer regions is particularly necessary when the transient involves a surge of subcooled liquid into the pressurizer.

Various pressurizer models have been used to describe the thermodynamic processes and non-equilibrium conditions between the regions.[4,8] Several of these approaches, beginning with the TOP's model in 1965[4], apply separate mass and energy conservation equations to a "liquid" and a "vapor" region within the pressurizer. The heat and mass transfer interfaces with the pressurizer walls, between regions, and with the spray are then described with different models and varying degrees of detail depending on the author's assumptions.

7.1 Model Description

7.1.1 General Approach and Assumptions

The RETRAN pressurizer model defines two separate thermodynamic regions which are not required to be in thermal equilibrium. The two regions are termed a "liquid" a "vapor" region although each region may contain both liquid and vapor. Each region thermodynamic state solution is determined from a distinct mass and energy balance on that region. Hence, the thermodynamic state for each region is determined without restrictions as to the other. In other words the vapor region can be superheated and the liquid region subcooled, both saturated, vapor

region saturated and liquid region subcooled, and so on. However, should the pressure rise above the critical point all further calculations are performed using a single region equilibrium approach.

The mass and energy balance provides the total mass and energy in each region as a function of time through the transient. The solution of the thermodynamic state in each region then involves the determination of each region volume (constrained that the sum equals the total volume) such that the calculated pressure is equal in each region.

Included at the interface between the liquid and vapor regions is a flashing model which describes the movement of vapor from the liquid to vapor region and a rainout model which describes the movement of liquid from the vapor region to the liquid region. Heat transfer between the regions is omitted as it is not considered significant relative to the other phenomena. The present RETRAN pressurizer model does not allow heat conductors to be specified in the pressurizer as their contribution is typically a second order effect in most transients. The pressurizer safety and relief valves are modeled as junctions from the vapor region and can be modeled using standard "fill" junction options or in conjunction with the control models as described in Section III.2.0.

The pressurizer model non-equilibrium solution is specified through user input on the volume parameter input cards. RETRAN volume and junction options continue as with RELAP4 except as noted in Section 7.1.5.

7.1.2 Mass and Energy Equations

The fluid mass and energy equations are basically the same as those discussed in Section IV of ANCR-1127 Rev. 1.[3] The primary difference is that the rate of change of mass and energy is determined for each region of a non-equilibrium volume. Several terms are included in the equations which account for specific phenomena and equipment unique to the pressurizer. Kinetic and potential energy terms associated with the

non-equilibrium volume are neglected. The following equations are written for each liquid and vapor region of non-equilibrium volume "i".

Liquid Region Mass Equation

$$\frac{dM_L}{dt} = \sum_j W_{ij}^{(L)} + W_r - W_{fl} + W_{sp} + W_{cs} \qquad (4)$$

where

M_L = Mass in liquid region

$W_{ij}^{(L)}$ = Flows from junction j into the liquid region of volume i

W_r = Rainout of liquid droplets from the vapor region to the liquid region

W_{fl} = Flashing of vapor from the liquid region to the vapor region

W_{sp} = Mass flow rate of spray into non-equilibrium volume if special spray option selected (details in Section 7.1.3)

W_{cs} = Mass flow rate from the vapor region of mass condensing on the spray if special spray option selected (details in Section 7.1.3)

Vapor Region Mass Equation

$$\frac{dM_v}{dt} = \sum_j W_{ij}^{(v)} + W_{fl} - W_r - W_{cs} \qquad (5)$$

where

M_v = Mass in vapor region

$W_{ij}^{(v)}$ = Flows from junction j into the vapor region of volume i

Liquid Region Energy Equation

$$\frac{dU_l}{dt} = \sum_j W_{ij}^{(L)} h_{ij} + W_r h_f - W_{fl} h_g + (W_{sp} + W_{cs}) h_f + Q_h - \frac{P\dot{V}_l}{J} \qquad (6)$$

where

U_l = Internal energy of the liquid region

h_f, h_g = Saturated fluid and gas enthalpy at volume pressure

Q_h = Heat input rate of pressurizer heaters

P = Transient pressure of the non-equilibrium volume i

$\dot{V}_l$ = Time rate of change of liquid region volume

Vapor Region Energy Equation

$$\frac{dU_v}{dt} = \sum_j W_{ij}^{(v)} h_{ij} + W_{fl} h_g - W_r h_f - W_{cs} h_v + \frac{P\dot{V}_l}{J} \qquad (7)$$

where

h_v = Enthalpy of gas in vapor region

7.1.3 Region Interface Models

Pressurizer Spray

The effects of spray on the pressurizer response can be modeled in one of two ways in RETRAN. The first is simply the specification through input that the spray junction is in the vapor region. This option desuperheats the vapor region. The second option is a special spray option called for by specifying a flag on the junction input card and involves the removal of mass and energy from the vapor region but does not desuperheat the region. This option assumes that the spray in falling through the atmosphere condenses vapor from that region such that result is a saturated liquid being deposited in the liquid region. The spray plus condensed mass is deposited directly in the liquid region without a time delay. The following equation defines the quantity of mass condensed on the spray:

$$W_{cs} = W_{sp}\left[\frac{h_f - h_{sp}}{h_v - h_f}\right] \qquad (8)$$

where

W_{sp} = Mass flow rate of the spray junction

h_f = Saturated liquid enthalpy at the volume pressure

h_{sp} = Enthalpy of the spray

h_v = Enthalpy of gas in the vapor region

The pressurizer spray is controlled through the definition of appropriate trips to turn the spray on and off and by a control system (if required) to modulate the spray after the valve is open. The discussion of the trip and control capabilities is included in Sections III.1.0 and 2.0.

Pressurizer Heaters

The energy input to the liquid region of each pressurizer heater is simulated by a first order differential equation as each heater is turned on or off through the trip inputs. The following equation describes the heater performance:

$$\frac{\tau dq_o}{dT} + q_o = q_{in} \qquad (9)$$

where

τ = time constant relating electrical input to the element to thermal output to the liquid region fluid

q_o = heat input to the liquid region

q_{in} = electrical input to the heaters

The total energy input to the fluid region is the sum of "q_o" for each of the heaters modeled. The pressurizer heater characteristics are defined on the heat exchanger input cards and turned off and on through standard RETRAN trips.

Rainout Model

The rainout of liquid droplets from the vapor to the liquid region is modeled in the RETRAN pressurizer model. Other phenomena such as interfacial condensation and condensation on the pressurizer vessel walls are assumed to be second order effects. The vapor region is assumed to be homogeneous and the rainout mass flow rate is calculated as follows:

$$W_r = V_r A (1 - \alpha) \rho \qquad (10)$$

where

W_r = rainout mass flow rate

V_r = liquid droplet rainout velocity

A = cross sectional area of the volume

α = Void fraction of the vapor region

ρ = liquid density in the vapor region

The droplet rainout velocity is an input parameter for any volume specified to use a non-equilibrium solution and is assumed to be constant during the transient.

Flashing Model

The movement of vapor from the liquid region to the vapor region is modeled in RETRAN using the Wilson[9] bubble velocity model and the bubble density gradient parameter as currently used in RELAP4 and described in Reference 3, Section V.3. Surface evaporation is assumed to be an insignificant effect relative to the mass and energy movement accomplished by flashing. Following is the equation representing the vapor movement:

$$W_{fl} = V_B \, (\rho_{gb})_{zm} \, A \qquad (11)$$

where

W_{fl} = vapor mass flow rate from liquid region to vapor region

V_B = vapor bubble velocity as determined from the relationships defined by Wilson, et al[9]

A = Cross-sectional area of the volume

$(\rho_{gb})_{zm}$ = Void fraction of the liquid region at the mixture surface times the vapor density (See Reference 3, Section V.3)

The bubble velocity model is hardwired into the pressurizer subroutine but the user is required to specify on the volume input card the desired bubble gradient constant.

7.1.4 Solution Technique

As discussed previously there is a unique mass and energy balance on each of the two regions within the pressurizer and thus there is a thermodynamic state solution for each region. The basic problem in the solution for the transient pressurizer pressure is in the determination of the volume associated with each region as the solution is advanced, such that the resulting state pressure for each region is equal. In order to accomplish the solution the following procedure is used:

1. The specific volume of the liquid region is extrapolated linearly from the two previous time steps and along with the updated mass in that region establishes an initial liquid region volume.

2. Using this volume, the thermodynamic state of each region is calculated and if the difference in the predicted pressure for each region is less than the convergence criteria the sequence is exited.

3. If the difference in pressure is greater than the convergence criteria the volumes are adjusted using the $\frac{\partial v}{\partial P}\Big|_h$ for each region. A linear equation is written for each region and the two solved simultaneously for the volume that would cause the pressure in each region to be equal. These new volumes are then used in the state solution and the convergence criteria checked again. This process is repeated until convergence is achieved.

4. A special situation exists when crossing phase lines such that the above approach will not always converge; therefore, when the solution has not converged in more than three iterations, the aforementioned solution technique is used in combination with interval halving to accomplish convergence.

Presently the pressurizer model uses a criteria for convergence between the liquid and vapor pressures of 0.1 psi. The sensitivity of the transient predictions have been examined with a 0.05 criteria and no noticeable differences found over a 600 second transient. Using the above approach, the region pressure convergence will normally be achieved in one iteration and many times using the extrapolated specific volume the first time through the subroutine (no iterations).

7.1.5 Limitations, Precautions, and Instructions

The pressurizer model has been developed for that specific simulation with the assumptions and approximations as outlined in the previous sections and as such not all of the options available for standard RELAP4 volumes and junctions can be utilized with a non-equilibrium volume. The following items summarize the assumptions and limitations as currently programmed:

(1) Pressurizer volumes must be initialized two-phase, equilibrium, and without air.

(2) Time dependent non-equilibrium volumes are not allowed.

(3) Volume characteristics used in the flow solution in NIFTE are approximated with the mass fraction ratio of each region in a non-equilibrium volume.

(4) After the pressure goes above the critical point, all further pressurizer calculations are done on an equilibrium basis.

(5) The vapor region is assumed to be homogeneous and junctions in this region use the homogeneous properties.

(6) The junction smoothing option JVERTL = 0 is not allowed for junctions joining the pressurizer volume.

(7) Effective liquid level calculations should not be looped over the pressurizer.

(8) The mass and energy integration for non-equilibrium volumes is performed explicitly.

(9) Proper heat transfer relationships and temperatures are not available in the heat conductor routines for the pressurizer situation, therefore heat conductors should not be specified in non-equilibrium volumes. The contribution of wall heat is considered insignificant for typical transients.

(10) No more than five pressurizer (non-equilibrium) volumes are allowed.

7.2 Input Description

In order to activate the pressurizer model two addtional parameters are required on the desired volume input card (05XXXY).

W13-I	INEQ	=	Flag indicating that the volume is to be handled in a non-equilibrium manner
		=	0 or blank, standard calculation
		=	1 Pressurizer calculation
W14-R	VR	=	Rainout velocity for liquid droplets in the vapor region of the pressurizer, ft/sec

In order to activate the spray option as described in Section 7.1.3 one additional parameter is required on the junction input card (08XXXY).

W19-I	ISP	=	Flag indicating that this is a spray junction
		=	0 or blank, the junction is handled in the normal manner
		=	1, the junction flow rate has the effects as described in Section 7.1.3

The pressurizer heaters are modeled using the heat exchanger (21XXYY) input cards. The number of pressurizer heaters is only limited by total number of heat exchangers and the total number of trips. If the pressurizer heater option is to be utilized the following input parameters are changed.

If W3-I JVOL is a non-equilibrium volume then,

W4-R	QHTR	=	Pressurizer heater capacity, kw
W5-R	QTAU	=	Pressurizer heater time contant, sec
W6-R	Not used		

8.0 PWR AUXILIARY DNB MODEL

When studying the various operational transient situations in pressurized water reactors (PWR), the majority of these cases involve thermal-hydraulic conditions in which departure from nucleate boiling (DNB) does not occur. Indeed, for licensing calculations involving Condition II events (defined in ANSI 18.2) some margin above the minimum DNB ratio (MDNBR) is required. Thus, for these types of transients a single hot sub-channel model is entirely sufficient. RETRAN provides modeling for analysis of a hot subchannel with determination of DNBR as a function of channel position.

For a given set of steady-state conditions the RETRAN DNB input model should be benchmarked against a detailed hydraulic representation.[17] Such a detailed analysis should provide RETRAN DNB model with correct flow redistribution factors for both the hot bundle and the hot subchannel. In addition, the total enthalpy rise factor, as determined by RETRAN should agree with design assumptions at steady state.

8.1 Model Description

The principal consideration in modeling for an auxiliary DNB calculation was to minimize computer running time while reducing as much as practical the conservatism with respect to a more detailed analysis. The present RETRAN model employees an enthalpy rise calculation, for every six inches, through the hot subchannel. The heat flux as a function of axial position is developed from the core heat conductor data as determined within RETRAN. Solving for fluid enthalpy allows for determination of local quality. This and other local condition parameters are then used to determine the critical heat flux, thus the DNB ratio as a function of axial position. A summary of the model is presented in Table IV, while details are described in the following paragraphs. Much of the modeling is straight forward in nature but is included here for ease in future improvement and increased sophistication.

8.1.1 Heat Flux Estimate

The heat flux values used in the fluid energy equation and for the DNBR calculation are developed in the following manner. Average heat flux valves (q''_{core} (z,t)) are obtained from the core heat conductors used in RETRAN. It is recommended that three conductors be modeled, describing the various average core conditions. A fit to a power series is developed describing the hot rod flux, ($q''_{hot\ rod}$ (z,t)), as corrected for a detailed axial power profile and heat flux factors.

$$q''_{hot\ rod}(z,t) = F_Q^{ENG}\ F_R^N\ F_Q^{UNC}\ \ F_z^N(z,t)\ \ \bar{q}''_{core}(t)\ \ f \qquad (12)$$

where:

F_Q^{ENG} = Engineering heat flux factor

F_R^N = Total radial x local nuclear heat flux factor

F_Q^{UNC} = Uncertainity factor on heat flux

F_z^N (z,t) = Variable for axial nuclear heat flux factor

f = Fraction of power generated within the fuel rod.

$\bar{q}''_{core}$ (t) = Average RETRAN core heat flux.

F_z^N (z,t) is approximated as:

$$F_z^N(z,t) = \frac{q''_{core}(z,t)}{\bar{q}''_{core}(t)}\ \ \frac{\bar{q}''_{core}(o)}{q''_{core}(z,o)}\ \ \frac{q''_{hot\ rod}(z,o)}{\bar{q}''_{hot\ rod}(o)} \qquad (13)$$

In the above expression the last term is F_z^N (z,o) as defined by detailed user input. q''_{core} (z,t) is given as:

$$q''_{core}(z,t) = C_1 + C_2 z + \ldots + C_m z^{m-1} \qquad (14)$$

where:

m = number of core volumes

C_i = Constants, normalized to $\bar{q}''_{core}$ from RETRAN.

8.1.2 Hot Channel Calculation

For the Condition-II events the transient variation in fluid enthalpy is generally small. Thus, as an approximation, the steady state fluid energy equation is used to develop subchannel local quality.

$$G_{DNB} \frac{\partial h}{\partial z} = \frac{\pi D_{he}}{Af} q''_{hot\ rod}(z,t) \qquad (15)$$

If more sever transients, such as anticipated transients without scram or very rapid fluid changes are considered, then the above expression may not prove adequate. If such is the case, then the complete transient energy equation should be used with its internal time step control logic.

For the energy equation the following definitions of mass flux are used

$$G_{HOT\ BUNDLE}(z,t) = F_{\Delta H}^{BUNDLE} \left(\frac{W_{core}(z,t)}{A_{core}} \right) \qquad (16)$$

$$G_{DNB} = F_{\Delta H}^{REDIST} \left[G_{HOT\ BUNDLE} + W_{ij} \left(\frac{\Delta Z}{A_{chan}} \right) \right] \qquad (17)$$

where:

$F_{\Delta H}^{BUNDLE}$ = Accounts for bypass flow, plenum mixing, etc.

$F_{\Delta H}^{REDIST}$ = Redistribution factor as effecting the hot subchannel.

W_{ij} = Turbulent cross flow mixing term as related to an assumed flow area.

8.1.3 Correlations and Usage

The turbulent cross flow term is given by the following expression.[10]

$$W_{ij} = 0.0058 \left(\frac{P - D}{D}\right)^{-1.46} \left(\frac{D_{he}}{D}\right) \left[(P - D)\, G_{HOT\ BUNDLE}\ (z,t)\right] Re^{-0.10} \quad (18)$$

Critical heat flux correlations used are either the B&W-2[11], W-3[12], or Mac Beth[13] correlations. This value, $q''_{CHF,\ uniform}$, can be corrected as follows:

$$q''_{CHF,CORR}\ (z) = q''_{CHF,UNIFORM}\ (z) \left[\left(\frac{1}{F_{CNU}}\right)(1.0 - F_{CW})(F_S)\right] \quad (19)$$

The correction factors adjust for the following effects[14,15,16] non-uniform axial power shape; cold wall effects of guide tubes; and grid spacer effects. Correlations for these correctors are given by the following expressions.

$$F_S = 1.0 + 0.03 \left(\frac{G_{HOT\ BUNDLE}\ (z,t)}{10^6}\right)\left(\frac{TDC}{0.019}\right)^{0.35} \quad (20)$$

where:

TDC = thermal diffusion coefficient for grid spacer mixing effects.

$$F_{CW} = R^* \left[13.76 - 1.372\, e^{1.78x} - 4.732 \left(\frac{G_{HOT\ BUNDLE}\ (z,t)}{10^6}\right)^{-0.0535} - 0.0619 \left(\frac{P}{10^3}\right)^{0.14} - 8.509\, D_{he}^{0.107}\right] \quad (21)$$

where:

P = Pressure within core region, interpolated

x = local thermodynamic quality

$R^* = 1.0 - \frac{D_{hy}}{D_{he}}$

$$F_{CNU}(Z_I) = \frac{RC \int_{Z_o}^{Z_I} q''_{hot\ rod}(z)\, e^{-C(Z_I - z)}\, dz}{q''_{hot\ rod}(Z_I)[1.0 - \exp(-CZ_I)]} \qquad (22)$$

where:

$$C = S(1 - x)^T (G_{HOT\ BUNDLE}/10^6)^{-U} \qquad (23)$$

For the B&W correlation:

R = 1.02508, T = 7.82293
S = 0.2486, U = 0.45758
Z_I = Pt. of calc., Z_o = 0.000

For the Westinghouse correlation:

R = 1.000, T = 7.900
S = 0.440, U = 1.720
Z_I = Pt. of calc., Z_o = 0.000

The integral within the F_{CNU} correlation is evaluated using Lagrangian interpolation, which develops the following expression.

$$\int_{Z_o}^{Z_I} q''_{hot\ rod}(z)\, e^{-C(Z_I - z)}\, dz = \frac{1}{C} \sum_{i=1}^{I} \left\{ q''(z_i) - \frac{1}{C} \frac{q''(z_i) - q''(z_{i-1})}{z_i - z_{i-1}} \right.$$

$$\left. - e^{-C(z_i - z_{i-1})} \left[q''(z_{i-1}) - \frac{1}{C} \frac{q''(z_i) - q''(z_{i-1})}{z_i - z_{i-1}} \right] \right\} \qquad (24)$$

Finally the DNBR is evaluated at every three inches up the hot channel and at every specified time step. Output consists of DNBR at several locations, the lowest channel position of interest, the hot spot location, and at the point of minimum DNBR.

8.1.4 Model Limitations

The auxiliary DNB model is intended for use with three core volumes and heat conductors, in connection with transient analysis of current PWR plants. If steady state hydraulic conditions are unique, additional detailed benchmarking will be required. As minimum bounding conditions the model should not be optioned outside of the CHF correlation limits, typically between 1000 and 2400 psia.

8.2 Input Description

Input parameters required for the DNB model are input on data cards 8001XX through 8004XX as desdribed in Chapter IV. Note that the limit of interest for calculation of DNB ratios is such that $(Z_{max} - Z_{min}) \leq 7.25$ ft. Also note that the detailed axial heat flux factors should normalize to unity, although the code's internal check is $\pm$ 1.0%. Typical time step selection is 0.5 seconds which appears to present adequate information.

TABLE IV

PWR AUXILIARY DNB MODELING

Model	Formation
Subchannel Array	Single channel, normalized to multiple subchannel array
Turbulent cross flow mixing	Rogers and Rosehart correlation
Heat flux factors and flow redistribution factors	Input from design assumptions or detailed hydraulic analysis
Engineering enthalpy rise factor	Output at initialization of RETRAN
CHF correlations	B&W-2, W-3 or MacBeth correlations available
Non-Uniform Axial Power Shape Correction	B&W or Westinghouse available, values vary with time and position
Grid Spacer Mixing and Cold Wall Effects on CHF	Westinghouse correlations available
DNB Calculation	Calculated at every 3 inch interval between input axial limits
Subchannel Mass Velocity	Varies with time and position as interpolated from RETRAN

IV. INPUT DATA MODIFICATIONS

This section describes the RELAP4 input data card modifications required for RETRAN. Changes were made to the Time Step (03XXX0), Trip Control (04XXX0), Volume (05XXXY), Function (08XXXY), Valve (11XXX0), Fill Table (13XXYY), Reactivity Table (14XXYY), Heat Slab (15XXXY), and Heat Exchanger (21XXYY) input data cards. The Control System Problem Dimensions (701000), Control System Input (702XXX), Control Block Description (703XXX), DNB Problem Dimensions (8001XX), DNB Hot Channel (802XX), DNB Geometry (8003XX), and DNB Axial Power Profile (8004XX) input data cards were added. The reader is referred to the RELAP4 user manual for those input data requirements not affected by the RETRAN modifications.

Time Step Data Cards 03XXX0

NTC (on Card 010001) cards must be entered with XXX=001, 002, ..., NTC.

W1-I NMIN = Number of time steps per minor edit and number of time steps per plot tape edit (0 is interpreted as 1)

W2-I NMAJ = Number of minor edits per major edit (0 is interpreted as 50)

W3-I NDMP = Number of major edits per restart tape edit (0 is interpreted as 20)

W4-I NCHK = Option for time step control
- =-1, time step control on nonlinear conditions only
- =0, time step control on linear and nonlinear conditions
- =1, no time step control
- =2, time step control based only on flow non linearities.

W5-R DELTM = Maximum time step size (sec)
(0<DELTM)

W6-R DTMIN = Minimum sub-time-size step when under time step control
(0<DTMIN≤DELTM). NCHK=1, DTMIN must be 0.0

W7-R TLAST = End of current time step data

Trip Control Data Cards 04XXX0

NTRP (on card 010001) cards must be entered with XXX=001, 002, ..., NTRP. (1≤NTRP≤100)

W1-I IDTRP = Action to be taken
For normal trips 1≤IDTRP≤50
For reset trip -1≥IDTRP≥-50
IDTRP correspond to entry on pertinent card elsewhere in input where trip action is desired
1=End of problem

W2-1 IDSIG = Signal being compared (1≤|IDSIG|≤14)

	Trip Limit
1 = Elapsed time	+=HIGH,-=LOW
2 = Normalized reactor power	+=HIGH,-=LOW
3 = Reactor period	+=HIGH,-=LOW
4 = Pressure (Vol IX1)	+=HIGH,-=LOW
5 = Mixture level (Vol IX1)	+=HIGH,-=LOW
6 = Liquid level (Vol IX1)	+=HIGH,-=LOW
7 = Water Temperature (Vol IX1)	+=HIGH,-=LOW
8 = Metal Temperature	

(Core Vol IX1)		+=HIGH,-=LOW
9 = Flow (Junction IX1)		+=HIGH,-=LOW
10 = Cladding Surface Temperature (Core Vol IX1)		+=HIGH,-=LOW
11 = Acceleration trip (Junction IX1)		+=HIGH,-=LOW
12 = Indirect trip (Trip IX1 or Trip IX2)		Not applicable
13 = Coincidence trip (Trip IX1 and Trip IX2)		Not applicable
14 = Control Block Output		+=HIGH,-=Low

W3-1 IX1 = Volume, junction, control block, or trip index
($1 \leq IX1 \leq NC\emptyset R$ for IDSIG=8 or 10)
($1 \leq IX1 \leq NV\emptyset L$ for IDSIG 4, 5, 6 or 7)
($1 \leq IX1 \leq NJUN$ for IDSIG=9 or 11)
(IX1=IDTRP of a previously defined trip for IDSIG=12 or 13)
(IX1=IDC Control Block for IDSIG=14)

W4-I IX2 = Optional volume or trip index for IDSIG=4, -4, 7, or -7
If IX2>0, a ΔP or ΔT test is used for IDSIG=12 or 13
IX2=IDTRP of a previously defined trip
IX2=0 represents a trip which is never actuated.
For IDSIG=14, IX2=0

W5-R SETPT = Signal set point

W6-R DELAY = Delay time for initiation of action after reaching set point (sec)

On the first trip card a requirement is that IDTRP=IDSIG=1.

Volume Data Cards 05XXXY

NVOL (on Card 010001) sets of cards must be entered with XXX=001, 002, ..., NVOL. The following items may be entered on up to nine cards.

Y is a card sequence number for each set, starting at 1, and must be consecutive.

W1-I	IBUB	=	Bubble data index ($0 \leq IBUB \leq NBUB$)
W2-I	IREAD	=	Volume data retrieval index =0, no retrieval <0, use the data pertaining to volume IREAD stored on the plot-restart tape of a previous run >0, use set IREAD of the time-dependent volume conditions
W3-R	P	=	Pressure ($0.0 \leq P \leq 3625.94$)(psia)
W4-R	TEMP	=	Temperature ($32.018 < TEMP < 1472$)(°F) (TEMP<0.0 used as logic control)
W5-R	HORX	=	Quality or relative humidity (dimensionless)
W6-R	V	=	Volume (ft^3)($0. < V$)
W7-R	ZVOL	=	Volume height, bottom to top (ft) ($0. \leq ZVOL$)

W8-R	ZM	=	Mixture level (from bottom)(ft) (0.≤ZM≤ZVOL)
W9-I	JTPMV	=	Two-phase friction index =0, use two-phase friction multiplier with Fanning friction losses =1, no two-phase multiplier in Fanning type of friction losses
W10-R	FLOWA	=	Flow area of volume (ft^2)
W11-R	DIAMV	=	Equivalent diameter of flow area (ft) (For Fanning friction calculation only.)
W12-R	ELEV	=	Elevation at the bottom of the volume (ft)
W13-I	INEQ	=	Flag indicating that the volume is to be handled in a non-equalibrium manner =0 or blank, standard calculation =1, pressurizer calculation

Note: The number of non-equilibrium volumes is limited to 5.

W14-R	VR	=	Rainout velocity for liquid droplet in the vapor region of the pressurizer, ft/sec

Note: If data quantities 15 and 16 are entered then data quantities 13 and 14 cannot be blanks. The number of transport volumes is limited to 20.

W15-I	IPTN	=	Flag indicating that the volume is to be handled as a transport volume = 0 or blank, standard calculation = 1 Transport calculation

W16-I MESH = Number of intervals by which the volume is divided
(1≤MESH≤20)

Junction Data Cards 08XXXY

NJUN (on Card 010001) sets of cards must be entered with XXX=001, 002, ..., NJUN. The items listed below may be entered on up to nine cards. Y is a card sequence number for each set, starting at 1, and must be consecutive. All normal junctions must precede the leak and fill junctions when the junction data are input.

W1-I IW1 = Volume index at junction inlet
(0≤IW1≤NVOL)

W2-I IW2 = Volume index at junction exit
(0≤IW2≤NVOL)

W3-I IPUMP = (a)(IW1>0, IW2>0) Pump Index
(1≤|IPUMP|≤NPMPC, and each IPUMP is unique). "Normal" junctions must precede leak and full junctions.
(b)(IW1>0,IW2=0) Leak Index
(1≤IPUMP≤NLK)
(c)(IW1=0,IW2>0) Fill Index
(1≤IPUMP≤NFLL)

For the junctions connecting to the pump volume, the suction side junction should have a negative pump number and the discharge junction should have a positive pump number (IPUMP on the junction card). Flow in these junctions must be positive initially.

W4-I IVALVE = Valve index

(0≤IVALVE≤NCKV)
(a)IVALVE=0, No valve
(b)1≤IVALVE≤NCKV, check valve

W5-R WP = Flow (lb/sec)

W6-R AJUN = Junction flow area in square feet and must be greater than zero. For a leak, AJUN is the full leak area.

W7-R ZJUN = Junction elevation (ft)
(a)IW1>0,IW2>0 the ZJUN must lie between the bottom and top of both volumes IW1 and IW2
(b)IW1>0,IW2=0 the ZJUN must lie between the bottom and top of volume IW1
(c)IW1=0,IW2>0 the ZJUN must lie between the bottom and top of volume IW2

W8-R INERTA = Junction effective L/A (ft^{-1})
(a)IW1>0,IW2>0
INERTA>0
(b)IW1≤0 or IW2≤0
INERTA≥0
INERTA is calculated by the program if the input value is zero and JCALCI=2. The calculated value is one-half of the length of each adjacent volume divided by the volume flow area where volume length is V/FLOWA.

W9-R FJUNF = Forward flow "form loss coefficient".

This is either a dimensionless positive number dependent on geometric changes occurring within the flow control volume or zero. It is the

standard energy loss coefficient, as normally used in text books. The energy loss is

$$K \frac{v^2}{2}$$

where FJUNF is K, and the velocity, v, is based on the junction area.

W10-R FJUNR = Reverse flow "form-loss-coefficient." If FJUNNR is entered as zero and FJUNF is nonzero, the FJUNR is set equal to FJUNF.

W11-I JVERTL = Vertical junction index
=0, junction flow area is not distributed vertically and junction enthalpy is "smoothed" when the two-phase mixture interface is near the junction elavation
=1, junction flow area is assumed to be a circular area centered and distributed vertically about ZJUN
=2, no bubble smoothing, junction flow area not distributed vertically

W12-I JCHOKE = Junction choking index
0=Moody choking or sonic choking
-1=No choking
1=Moody choking only (If MVMIX is $\neq$ 3, this flow solution corresponds to incompressible flow with Bernoulli effects)
2=Sonic choking only

W13-I JCALCI = Initial condition calculation index
=0, use input for inertia and form loss coefficients as given by user

=1, calculate form loss coefficients (FJUNF and FJUNR)(for sharp-edge area changes)
=±2, calculate inertias
=±3, calculate both form loss coefficients and inertias
<0, frictionless junction except in mixed streams

W14-I MVMIX = Flow equation type
=0, compressible flow, single stream
=1, mixed two-stream compressible flow in the volume "from" side.
=2, mixed two-stream compressible flow in the volume "to" side
=3, no momentum flux (incompressible flow, no Bernoulli effects)

W15-R DIAMJ = Junction diameter
If DIAMJ≤0.0, the program will calculate DIAMJ as $2\sqrt{AJUN/\pi}$, (used for junction quality calculations)

W16-R CONCO = Contraction coefficient for leak (0. is interpreted as 1.)

W17-I ICHOKE = Leak type for Moody choking
ICHOKE≤0, no liquid phase choking
ICHOKE>0, liquid phase choking allowed if junction enthalpy is less than the saturated fluid enthalpy.

W18-I IHQCOR = Enthalpy transport index
=0, both sides off
=1, inlet side on, outlet side off (volume "from" heated)
=2, outlet side on, inlet side off (volume "to" heated)

=3, both sides on (both volumes heated)

W19-I	ISP	=	Flag indicating that this is a spray junction =0 or blank, the junction is handled in the normal manner =1, the junction flow is treated as a spray junction

Valve Data Cards 11XXX0

NCKV (on Card 010001) cards must be entered with XXX=0001, 002,...,NCKV. The data on the card are interpreted according to the type of valve being described.

W1-I	ITCV	=	Type of check valve -1 =>intertial valve 0 =>Type 0 check valve 1 =>Type I check valve -20 $\leq$ITCV$\leq$2=>a closed valve to open under control of trip ID=\|ITCV\|. 2$\leq$ITCV$\leq$20=>an open valve to close under control of trip ID=ITCV.
		=	1000, if valve under control of control system
W2-I	IACV	=	Number of area-versus-angle table in the leak table data if ITCV=-1
		=	Number of area-versus-time table in leak table data if |ITCV|$\geq$2
		=	0 otherwise
		=	Control block ID if ITCV=1000
W3-R	PCV	=	Back pressure for closure (psia)

W4-R	CV1	=	Forward flow friction coefficient ITCV≠-1 (dimensionless) Area moment arm ITCV=-1(ft^3)
W5-R	CV2	=	Reverse flow friction coefficient valve open ITCV≠-1 (dimensionless) Moment of Inertia ITCV=-1 (lb_m=ft^2)
W6-R	CV3	=	Reverse flow friction coefficient valve closed ITCV≠-1 (dimensionless) Damping constant ITCV=-1.

Fill Table Data Cards 13XXYY

NFLL (on Card 010001) sets of cards must be entered with XX = 01, 02, ..., NFLL. YY is a card sequence number of each set, 00≤YY≤99; the cards are ordered by YY, but YY need not start at 00 and need not be consecutive. An arbitrary number of items may be entered on each card. At least one table pair must be entered.

W1-I	NFILL	=	Number of data points (1<|NFILL|<20) Positive value indicates no extrapolation; negative value permits extrapolation =1 if ITFILL=1000 and no function generater card referes to this table
W2-I	ITFILL	=	Trip signal to start (2≤ITFILL≤50) =1000 for fill controlled by control system =0 if fill table used as a function generator only.
W3-I	IX	=	Independent variable

			IX=0, time
			IX>0, pressure ($P_{vol}+P_{grav}$)(psia)
			IX<0, differential pressure
		=	ID of control block controlling fill if ITFILL = 1000
			($-100 \leq IX \leq -1$)
		=	0 if ITFILL=0
W4-I	IY	=	Flow type
			IY≤0, flow in $lb_m/sec\text{-}ft^2$
			IY>0, flow in gpm/ft^2
		=	0 if ITFILL=0
W5-R	PORX	=	Pressure or quality in fill reservoir
			PORX=0, saturated liquid
			0<PORX<1, mixture quality
			PORX=1, saturated vapor
			PORX>1, pressure (psi)
		=	0.0 if ITFILL=0
W6-R	TEMP	=	Temperature (°F)
		=	0.0 if ITFILL=0
W7-R	FILTBL(1)	=	Time or pressure (sec or psia)
		=	0.0 if ITFILL=1000 and no function generator refers to this table
		=	Independent variable if ITFILL=0
W8-R	FILTBL(2)	=	Flow ($lb._m/sec\text{-}ft^2$ or gpm/ft^2) This flow is multiplied by junction area generator refers to this table.
		=	0.0 if ITFILL=1000 and no function
		=	Dependent variable if ITFILL=0
W9-R	FILTBL(3)	=	Until NFILL points are entered

W10-R	FILTBL(4)	=	Where the time, pressure or dependent variables are in ascending order

Reactivity Table Data Cards (14XXYY)

A maximum of ten (10) reactivity tables may be input specifying the control reactivity as a function of time. Each table is activated by a trip signal. The total control reactivity is summed over all tables which have been tripped. The reactivity tables are normalized such that the first value is zero to avoid step reactivity changes when the table is first tripped. The reactivity may also be input as a function of the control system output. The data cards must be entered with 10<XX<19 where XX defines the table number, and 00<YY<99 where YY is the sequence number for each table.

W1-I	NSCR	=	Number of data points ($\|NSCR\| \leq 20$) Positive value indicates no extrapolation; negative value permits extrapolation NSCR=1, a constant value.
		=	Control block ID if controlled from control system
W2-I	ITSCPM	=	Trip number
		=	1000, if controlled from control system
W3-R	TSCR(1)	=	Time (sec)
W4-R	TSCR(2)	=	Reactivity
W5-R,	TSCR(3)		until NSCR points are entered, where time
W6-R,	TSCR(4)		values are in ascending order
...	...		

Heat Slab Data Cards 15XXXY

NSLB (on Card 010001) cards must be entered with XXX=001, 002, ..., NSLB. Y is a sequence number, Y=1,2.

W1-I IVSL = Index number of volume at left slab surface (-1≤IVSL≤NVOL)

W2-I IVSR = Index number of volume at right slab surface (-1≤IVSR≤NVOL)

A zero value for either IVSL or IVSR means that the slab surface does not conduct heat. A (-1) value for either IVSL or IVSR means that the slab is being used as a heat exchanger with constant sink conditions on the -1 side. For this case, two more input quantities are needed: a constant heat transfer coefficient and a removal fraction of the total power initially generated. The user can also model a heat exchanger slab using volumes on both sides of the slab. At least one of the quantities IVSL or IVSR must be greater than zero.

W3-I IGOM = Geometry index
(1≤IGOM≤NGOM)

W4-I ISB = Stack indicator
0 means that this slab is at the bottom of a stack.
1 means that this slab is stacked on top of the slab described by the previous card.

W5-I IMCL = Indicator for heat transfer correlations at left surface.
0 - use Groeneveld 5.9
1 - use Groeneveld 5.7
2 - use Dougall Rohsenow

1X - use G.E. CHF Correlation (ten's place digit = 1)

W6-I	IMCR	=	Indicator for heat transfer correlations at right surface. Same as IMCL above.
W7-R	ASUL	=	Heat transfer area at left surface (ft^2) ASUL=0 if IVSL=0 ASUL>0 if IVSL≠0
W8-R	ASUR	=	Heat transfer area at right surface (ft^2) ASUR=0 if IVSR=0 ASUR>0 if IVSR≠0
W9-R	VOLS	=	Total volume of slab (ft^3) 0>VOLS
W10-R	HDML	=	Left side hydraulic diameter (ft) HDML≥0. If HDML=0 and IVSL>0, HDML will be set equal to DIAMV (on Card 05XXXY) for volume IVSL
W11-R	DHEL	=	Left side heated equivalent diameter (ft) HDMR≥0. If HDMR=0 and IVSR>0, HDMR will be set equal to DIAMV (on Card 05XXXY) for volume IVSR
W12-R	DHEL	=	Left side heated equivalent diameter (ft) DHEL≥0. If DHEL=0 and IVSL>0, DHEL will be set equal to HDML
W13-R	DHER	=	Right side heated equivalent diameter (ft) DHER≥0. If DHER=0 and IVSR>0, DHER will be set equal to HDMR

W14-R CHNL = Channel length on left side (ft)
If CHNL=0 and IVSL>0, CHNL will be set equal to ZVOL (on card 05XXXY) for volume IVSL

W15-R CHNR = Channel length on right side (ft)
If CHNR=0 and IVSR>0, CHNR will be set equal to ZVOL (on card 05XXXY) for volume IVSR.

The following two quantities are required only if IVSL or IVSR is -1:

W16-R PFR = Fraction of total power generated removed by this slab ($0 \leq PFR \leq 1$)

W17-R HTC = Constant heat transfer coefficient (Btu/ft^2-hr-°F).

The following two quantities are required only if the local fluid condition heat transfer model is to be applied:

W18-R CELV = Elevation of this conductor relative to the conductor located at the bottom

W19-R LCOND = 1 for right surface (only) local condition heat transfer model
= 2 for left surface (only) local condition heat transfer model
= 3 for both left and right surfaces local condition heat transfer model.

Heat Exchanger Data Cards 21XXYY

This option provides two simplified heat exchanger models, neither model has heat conduction. The third option added in RETRAN provides for a heater model in non-equilibrium volumes.

NHTX (on Card 010001) sets of data must be entered with SS=01, 02, ..., NHTX. YY is the card sequence number for each set, $00 \leq YY \leq 99$; the cards

are ordered by YY, but YY need not start at 00 and need not be consecutive. An arbitrary number of items may be entered on each card, and if a table is entered at least one table pair must be entered.

W1-I IHTX = Number of data points, 0 meaning flow and temperature dependent
(IHTX0 or 2<|IHTX|<20)
Positive value indicates no extrapolation; negative value permits extrapolation.
IHTX=1, a constant value

W2-I ITHTXQ = Trip number controlling heat exchanger ($2 \leq$ ITHTHQ ≤ 20)

W3-I JVOL = Volume number

IfIHTX=0,

W4-R HTQ = Fraction of power removed by heat exchanger

W5-R TSEC = Secondary side temperature (°F)

W6-R HTXCO = Heat exchanger coefficient (Btu-sec/hr-°F-lb_m)

If HTXCO is entered as zero, then the program calculates the steady state value as HTXCO=heat removal rate/(initial flow multiplied by the temperature difference between the primary fluid and secondary fluid)

If initial flow is zero, the user must put in a nonzero value for HTXCO.

The program will always use the input value of HTXCO if it is nonzero.

If |IHTX|>0,

W4-R HTXTBL(1) = Time (sec)

W5-R HTXTBL(2) = Normalized power

W6-R HTXTBL(3) = until IHTX points are entered, where

W7-R HTXTBL(4) = time values are in ascending order

... ...

If JVOL is a non-equilibrium volume,

W4-R QHTR = Pressurizer heater capabity (Kw)

W5-R QTAU = Pressurizer heater time constant (sec)

W6-R ---- = Not used.

Control Problem Dimensions Data Card 701000

If this card is omitted, no control system will be modeled.

W1-I NCI = Number of control input definition cards
(0≤NCI≤20)

W2-I NCB = Number of control block description cards
(0≤NCB≤100)

Control Input Definition Data Cards 702XXX

NCI (on Card 701000) must be entered with XXX=001, 002, ..., NCI.

W1-I IDC = Control input ID
(1≤IDC≤20)

W2-A		=	Variable symbol
W3-I		=	Region number
W4-R	GAIN	=	Input gain
W5-R	CIC	=	Input block initial conditions

Symbols of Available Control Input Variables

Symbol	Variable	Range of Region Number
AP	Average Pressure	$1 \leq W3 \leq 65$
ML	Mixture Level	$1 \leq W3 \leq 65$
AT	Average Temperature	$1 \leq W3 \leq 65$
ZL	Liquid Level	$1 \leq W3 \leq 65$
JW	Junction Flow	$1 \leq W3 \leq 75$
NQ	Normalized Power	W3=0
CONS	Constant	W3=0
TIME	Time	W3=0

Control Block Description Data Cards 703XXX

NCB (on card 701000) must be entered with XXX=001, 002, ..., NCB.

W1-I	IDC	=	Control Block ID $(-100 \leq IDC \leq -1)$
W2-A	ITYPE	=	Control Block type
		=	DLY for delay, e^{-Ts}
		=	LAG for lag network, 1/1+Ts)
		=	INT for integrator, 1/s
		=	FNG for function generator with no dynamic response

		=	LLG for lead-lag network, $(1+\tau_1 s)/1+\tau_2 s)$
		=	SUM for sum of two inputs, A(INCi) + B(INC2)
		=	VLM for rate limited output, -|DOWNLIM|<(dy/dt)<|UPLIM|
		=	OUT for listed output of control blocks and input signals at each time step
		=	MUL for multiplier, (INC1)(INC2)
		=	DIV for divider, (INC1)/(INC2)
		=	DER for differentiator, s
W3-I	INC1	=	Input ID $(1 \leq INC1 \leq 20)$ for input signals $(-100 \leq INC1 \leq -1)$ for control blocks
W4-I	INC2	=	Input ID for second input if ITYPE=SUM, MUL, or OUT
		=	Fill table index if ITYPE=FNG
		=	Number of samples in delay interval if ITYPE=DLY
		=	Input ID for divisor if ITYPE=DIV
		=	0 otherwise
W5-R	CGAIN	=	Gain at output
		=	0.0 if ITYPE=OUT
W6-R	CP1	=	Control parameter 1
		=	T time delay (sec) if ITYPE=DLY
		=	τ lag time constant (sec) if ITYPE=LAG
		=	τ_1 least time constant (sec) if ITYPE=LLG
		=	A, gain on input INC1 if ITYPE=SUM
		=	UPLIM per sec if ITYPE=VLM
		=	0.0 otherwise
W7-R	CP2	=	Control parameter 2
		=	τ_2 lag time constant (sec) if ITYPE=LAG

		=	B, gain in input INC2 if ITYPE=SUM
		=	DOWNLIM per sec if ITYPWE=VLM
		=	0.0 otherwise
W8-R	CIC	=	Output initial conditions
		=	0.0 if ITYPE=OUT
W9-R	CMIN	=	Output minimum limit
		=	0.0 if ITYPE=OUT
W10-R	CMAX	=	Output maximum limit
		=	0.0 if ITYPE=OUT

Auxiliary DNB Problem Dimension Data Cards (8001XX)

The problem dimension data cards must be entered with XX=00, 01, 02, etc.

Note: The auxiliary DNB model requires four input data cards: If the problem dimension card is omitted no auxiliary DNB calculation will be made.

W1-I	LWR	=	Reactor type
		=	0, Auxiliary DNB routine not used
		=	1, PWR
		=	2, BWR
W2-I	ICW	=	Flag for cold wall
		=	0, no correction
		=	1, Westinghouse Correlation
W3-I	NUH	=	Flag for heat flux profile
		=	0, Uniform profile
		=	1, Westinghouse correlation
		=	2, B & W correlation

W4-I	ICHF	=	Flag for CHF correlation
		=	0, Flag not used
		=	1, W-3 correlation
		=	2, B&W-2 correlation
		=	3, MacBeth correlation
W5-I	ITCROF	=	Flag for turbulence cross flow correction
		=	0, No cross flow
		=	1, Rogers and Rosehart correlation
W6-I	NOA	=	Number of axial profile data sets

DNB Hot Assembly Data Card (8002XX)

The data cards must be entered with XX=00, 01, 02,...,etc.

W1-R	FQENG	=	Engineering heat flux factor, F_Q^E
W2-R	FRN	=	Total nuclear radial (radial X local) heat flux factor, F_R^N
W3-R	FQUNC	=	Heat flux uncertainty factor, F_Q^{UN}
W4-R	FDHCOR	=	Hot assembly enthalpy rise factor on mass flux, including effects of bypass flow, plenum mixing, etc., for the hot assembly
W5-R	FDHENG	=	Hot channel enthalpy rise factor on subchannel mass flux
W6-R	ZMIN	=	Minimum height of channel for CHF calculation (Ft)
W7-R	ZMAX	=	Maximum height of channel for CHF calculation (Ft)

Note: It is required that [ZMAX-ZMIN]$\leq$7.25

DNB Geometry Data Cards (8003XX)

The geometry data cards must be entered with XX=00, 01, 02,...,etc.

W1-R	PITCH	=	Rod to rod pitch (ft)
W2-R	RODIA	=	Fuel rod diameter (ft)
W3-R	EQDIA	=	Equivalent diameter based on wetted perimeter per assembly (ft)
W4-R	TDC	=	Thermal diffusivity parameter
W5-R	FRPOW	=	Fraction of power generated in fuel rod
W6-R	DTEDT	=	Time step at which DNB is calculated.

DNB Axial Power Profile Data Card (8004XX)

The axial power profile data cards must be entered with XX=00, 01, 02,...,etc.

W1-R	Y(1)	=	Position (Z/L)
W2-R	AXIAL(1)	=	Axial power profile, normalized to unity
W3-R	Y(2)	=	Until NOA data points are filled
W4-R	AXIAL(2)		

V. REFERENCES

1. "ANISN - A One-Dimensional Discrete Ordinates Transport Code", Oak Ridge National Laboratory, CCC-82.

2. "TDA - Time Dependent Multigroup One-Dimensional Discrete Ordinates Transport Code", RSIC CCC-180, 1971.

3. K. W. Moore, W. H. Rettig, "RELAP4 - A computer Program for Transient Thermal-Hydraulic Analysis", ANCR-1127, Rev. 1, March 1975.

4. J. A. Redfield, S. G. Margolis, TOPS - A Fortran Program for the Transient Thermodynamics of Pressurizers, WAPD-TM-545 (December 1965).

5. A. N. Nahavandi, S. Makkenchery, "An Improved Pressurizer Model with Bubble Rise and Condensate Drop Dynamics," Nuclear Engineering and Design, 12 (1970) 135-147.

6. R. C. Baron, "Digital Model Simulation of a Nuclear Pressurizer," Nuclear Science and Engineering, 52 (1973) 283-291.

7. T. W. T. Burnett, C. J. McIntyre, J. C. Buker, LOFTRAN Code Description, WCAP-7907 (October 1972).

8. H. G. Hargrove, MARVEL - A Digital Computer Code for Transient Analysis of a Multiloop PWR System, WCAP-7909 (October 1972).

9. J. F. Wilson, R. J. Grenda, J. F. Patterson, "The Velocity of Rising Steam in a Bubbling Two-Phase Mixture," ANS Transactions, Vol. 5, Section 25-5, p. 151 (1962).

10. J. T. Rogers & R. G. Rosehart, "Mixing by Turbulent Interchange in Fuel Bundles: Correlations and Inferences," ASME 72-HT-53, 1972.

11. J. S. Gellerstedt, et al., "Correlation of Critical Heat Flux Is A Bundle Cooled by Pressurized Water," Two-Phase Flow and Heat Transfer in Rod Bundles, pp 63-71, ASME.

12. L. S. Tong, "Critical Heat Fluxes in Rod Bundles," Two-Phase Flow and Heat Transfer in Rod Bundles, pp 31-46, ASME.

13. R. V. MacBeth, "Burnout Analysis - Part 5. Examination of Published World Data for Rod Bundles," AEEW-R 358, 1964.

14. L. S. Tong, "Prediction of Departure From Nuclear Boiling For an Axially Non-Uniform Heat Flux Distribution," J. of Nucl. Energy, 21:241-248, 1967.

15. L. S. Tong, Boiling Crisis and Critical Heat Flux, U.S. A.E.C., 1972.

16. R. H. Wilson, et al., "Critical Heat Flux in a Nonuniformly Heated Rod Bundle," Two-Phase Flow and Heat Transfer in Rod Bundles, pp 56-62, ASME, 1969.

17. C. L. Wheeler, et al., "COBRA-IV-I: An Interim Version of COBRA for Thermal-Hydraulic Analysis of Rod Bundle Nuclear Fuel Elements and Cores," BNWL-1962, 1976.

APPENDIX B

PRIMARY/SECONDARY TEMPERATURE DIFFERENCES AND REACTOR VESSEL WALL AVERAGE TEMPERATURE CALCULATIONS

PRIMARY/SECONDARY TEMPERATURE DIFFERENCES AND REACTOR VESSEL WALL AVERAGE TEMPERATURE CALCULATION

It is important to determine the secondary side fluid temperature of the steam generators since the temperature difference between primary and secondary is the driving force of overpressurization for the design base incident. As mentioned in section 4.0, two primary coolant pumps continue to operate until the PCS fluid temperature is 160° to 180°F., The reason of the PCP's operation until the PCS fluid is 160° to 180°F is to cooldown the PCS fluid by heat transfer to the secondary side fluid which is lower than PCS fluid temperature during cooldown to about 180°F in the PCS.

As shown in Figure B-1, the pressure-temperature history of Palisades PCS during normal shutdown is presented. It should be noticed that the time scales of Figure A-1 is in terms of hours. If we assume that the secondary side temperature is 92°F higher than primary temperature and, the heat transfer between primary and secondary is a conduction limited process, the time to be required for secondary side of S.G. to reach from 512°F to 212°F can be computed as followings. The total heat, Q, in a S.G. from 512°F to 212°F is given by

$$Q = (h_1 - h_2)\ \bar{\rho}\ V$$

where

h = enthalpy, Btu/lbm

$\bar{\rho}$ = average density, lbm/ft^3

V = S.G. Volume, ft^3.

Therefore,

$$Q = (502.3 - 180.17) \times 54.04 \times 7704$$

$$Q = 1.34 \times 10^8 \text{ Btu/S.G.}$$

The heat transfer rate, q, is given by

$$q = \frac{Ak}{\Delta x}(T_1 - T_2)$$

where

A = S.G. surface area, ft^2

k = thermal conductivity, Btu/ft-hr°F

T = fluid temperature, °F

Δx = S.G. tube thickness, ft

Therefore,

$$q = \frac{67252 \times 9.5}{4 \times 10^{-3}} \times 92 = 1.47 \times 10^{10} \text{ Btu/hr}$$

Therefore the time, τ, required for secondary to reach 212°F is

$$\tau = \frac{Q}{q} = 9.13 \times 10^{-3} \text{ hr} .$$

Though the above calculations are simplified, 212°F for the secondary fluid temperature seems to be an overconservatism.

In order to obtain the dashed lines (pressure limits) in Figures 6.7 and 6.8, it is necessary to calculate the average temperature of the reactor vessel wall. However, the RETRAN results do not give the average temperature of the vessel wall. The average temperature can be calculated from the one-dimensional conduction equation given by

$$\frac{d^2T}{dr^2} + \frac{1}{r}\frac{dT}{dr} = 0$$

where

T = temperature, °F

r = distance to radial direction, ft.

Therefore,

$$T = a \ln r + b$$

where a and b are constants to be determined from the boundary conditions, which are the surface temperature of the vessel wall. The inner surface temperatures have been obtained from the RETRAN results and the outer surface temperature can be assumed to be 120°F since the plant cooldown takes more than 10 hours and the outer surface of the vessel is insulated. The average temperature of the wall can be calculated from the above equation, knowing a and b, as

$$T_{ave} = \frac{\int_{r_{in}}^{r_{out}} T \, dr}{\int_{r_{in}}^{r_{out}} dr} .$$

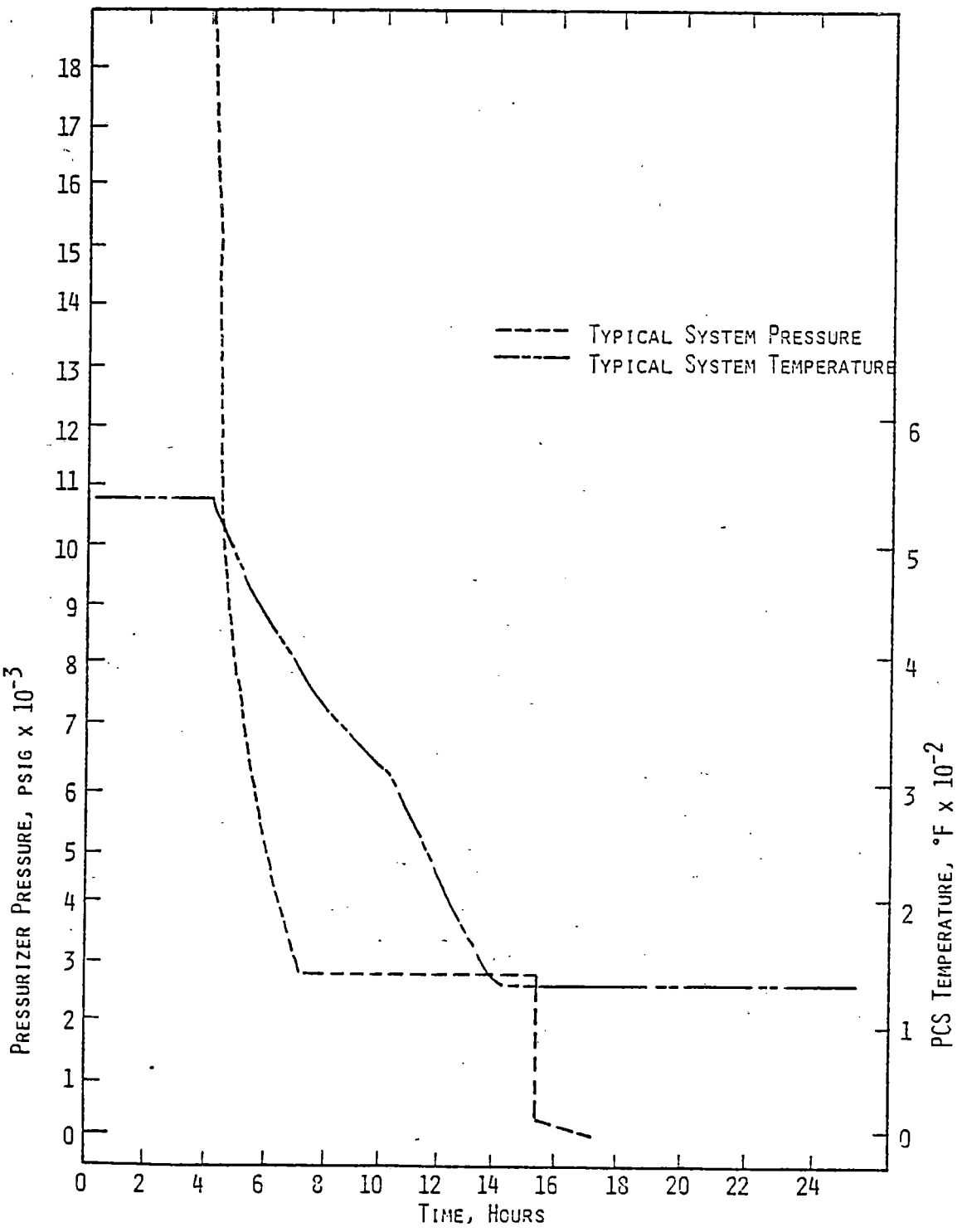

FIGURE B.1. PALISADES PLANT - PRESSURE-TEMPERATURE RELATIONSHIP DURING NORMAL SHUTDOWN.