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SHEARON HARRIS NUCLEAR PLANT
NATURAL CIRCULATION COOLDOWN EVALUATION
PROGRAM REPORT

BY

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1.0 INTRODUCTION

Nuclear power plants were originally designed with a safe shutdown design basis of hot standby. In late 1979, the NRC issued Branch Technical Position (BTP) RSB 5-1 (Reference 1), Design Requirements of the Residual Heat Removal System (RHR), which required plants in the licensing process to evaluate their capability to go from normal operating conditions to cold shutdown under functional requirements that included:

- Use of only safety-grade systems
- Single failure in safety-grade systems
- With or without offsite power
- Operation from the control room with limited operator action outside control room if suitably justified
- Within a reasonable period of time

In order to comply with RSB 5-1, a utility was permitted to satisfy the functional requirements of the branch technical position through a comparison of test results of previously tested plants of a similar design along with a supporting thermal/hydraulic analysis of a plant specific cold shutdown scenario.

1.1 Program Description

This Natural Circulation Cooldown Evaluation program satisfies the test requirement of BTP RSP 5-1 for Shearon Harris through a comparison and evaluation of the results from the Diablo Canyon Natural Circulation/Boron Mixing/Cooldown Test (Reference 2). The program includes a qualitative comparison and evaluation of the Shearon Harris design features and discusses the applicability of the Diablo Canyon Unit 1 test results to Shearon Harris. This comparison is then used to develop the cold shutdown scenario for Shearon Harris that addresses the requirements and assumptions in BTP RSB 5-1. Finally, the program performs a thermal/hydraulic computer code analysis that evaluates and justifies the specific Shearon Harris design cold shutdown capabilities under the requirements of RSB 5-1.

1.2 Background Information

Circulation of reactor coolant is a key function in the operation of the Shearon Harris plant, including operations to place and maintain the plant in the hot standby operational mode and in performing operations to take the plant to cold shutdown. During normal plant operations, at least one Reactor Coolant Pump (RCP) is operating to ensure forced circulation of reactor coolant for boron mixing, heat removal and pressure control considerations.

The loss of forced circulation constitutes an emergency plant condition. Under this plant condition, the plant protection systems will automatically trip the reactor and the plant will be placed in the hot standby operational mode under natural circulation conditions. The plant is designed to be maintained in this condition until forced circulation is restored and normal plant operations can be resumed. Natural circulation of reactor coolant is provided with the reactor core as the heat source and the steam generators as the heat sink. Steam release to maintain the reactor at hot standby is accomplished via the main steam power-operated atmospheric relief valves, or the safety valves if needed.

The Shearon Harris systems' capabilities needed to support compliance with Reactor Systems Branch (RSB) BTP 5-1 are provided in Section 5.4.7.2.8 of the Shearon Harris Nuclear Plant Final Safety Analysis Report (Reference 3).

1.3 Description of Diablo Canyon Natural Circulation Test

On March 28 and 29, 1985, a boron mixing and cooldown test was performed at Diablo Canyon Unit 1. The test began with a trip from hot full power conditions at 2130 hours on March 28, and continued until 2245 hours on March 29 when cold shutdown conditions were achieved. Details of the test are provided in Reference 2. In general, the test consisted of four basic periods as described below:

1) An initial period of approximately three hours during which the plant was stabilized at hot standby conditions prior to initiation of natural circulation.

2) A period of approximately four hours during which the plant was maintained at hot standby under natural circulation conditions. During this period, natural circulation was established and the boron mixing test was performed.

3) A period of approximately thirteen hours during which the plant was cooled down and depressurized from hot standby conditions to RHR system initiation conditions. During this period, plant cooldown and depressurization testing was performed.

4) A final period of approximately four and one-half hours during which the plant was cooled from RHR initiation conditions to cold shutdown conditions.

1.4 Report Structure

This report is structured in three major sections to comply with the requirements of BTP RSB 5-1:

Section 2.0 provides a qualitative comparison between the systems and equipment of Shearon Harris and Diablo Canyon and provides justification of the applicability of the Diablo Canyon test results to Shearon Harris.

Section 3.0 provides a description of the plant specific natural circulation cold shutdown scenario developed for Shearon Harris that addresses the functional requirements and assumptions of BTP RSB 5-1.

Section 4.0 provides a detailed description of the thermal/hydraulic transient analysis for the Shearon Harris natural circulation cold shutdown scenario developed in Section 3.0.

2.0 QUALITATIVE PLANT COMPARISON OF SHEARON HARRIS TO DIABLO CANYON UNIT 1

2.1 Plant System Comparison

This section qualitatively compares the systems and equipment that affect natural circulation of the Shearon Harris Nuclear Plant to those of Diablo Canyon Unit 1 in sufficient detail to evaluate the systems' natural circulation, boration, cooldown and depressurization capabilities.

2.1.1 Reactor Coolant System

The general configuration of the piping and components in the reactor coolant loops is the same in both Shearon Harris and Diablo Canyon. However, Shearon Harris has three heat transfer loops while Diablo Canyon has four. Each heat transfer loop contains a steam generator (SG) and a reactor coolant pump (RCP). The Diablo Canyon design incorporates a Model 51 SG and a Model 93A, 6000 horsepower RCP while the Shearon Harris design utilizes a Model D4 SG and a model 93A1, 7000 horsepower RCP. Also, one loop at each plant is equipped with a pressurizer. With respect to natural circulation conditions, the design differences between the RCP models are minimal since the pump design features are nearly identical. The Model D4 steam generator has a shorter tube bundle elevation and incorporates a preheater in the lower tube bundle region in comparison to the Model 51 steam generator. The only steam generator or reactor coolant pump design difference between the two plants that may influence the actual natural circulation flow rates is the variance in the steam generator tube bundle elevation. An applicability study is performed in Section 2.2.1 to show that the SG tube bundle elevation differences have minimal effect on the natural circulation flow capabilities for Shearon Harris.

Pressure control is available at both Diablo Canyon and Shearon Harris using the normal pressurizer spray valves if the RCPs are running or the pressurizer auxiliary spray systems if the RCPs are not available. If both the normal and auxiliary spray capabilities are unavailable, the pressurizer Power Operated Relief Valves (PORVs) are normally available at each plant for RCS depressurization. At Shearon Harris, the pressurizer PORV controls are not qualified and thus the PORVs are not available for RCS depressurization under the assumptions of BTP RSB 5-1. However, while the pressurizer auxiliary spray valve at Shearon Harris is designed to fail closed upon a loss of air, the valve can be operated by utilizing a pressure regulated portable compressed gas supply. Credit can be taken for operator action in providing a local hook-up of this system. This portable setup then provides a qualified means for RCS depressurization.

2.1.2 Auxiliary Feedwater System

The auxiliary feedwater systems at both Diablo Canyon and Shearon Harris are capable of supplying cooling to all steam generators using the auxiliary feedwater pumps during the natural circulation cooldown. Each plant incorporates two motor driven pumps and one turbine driven pump. With Diablo Canyon having four heat transfer loops, each motor driven pump is capable of supplying auxiliary feedwater to two steam generators. In comparison, Shearon Harris has the capability to feed all three steam generators from either motor driven pump. At both plants, the turbine driven pump has the capability of supplying water to all steam generators. Throttling capability is available at both plants to maintain adequate secondary inventory control.

The primary auxiliary feedwater supply to the steam generators is provided by the Condensate Storage Tank (CST) at both Diablo Canyon and Shearon Harris. The auxiliary feedwater system at Shearon Harris is capable of supplying a deaerated water source from the seismic Category 1 CST (415,000 gallon working capacity) to permit 4 hours of operation at hot standby plus cooldown to RHR initiation conditions. A backup seismic Category 1 source for the Auxiliary Feedwater System is also available at Shearon Harris from the Emergency Service Water System.

2.1.3 Main Steam System

Each steam generator at both plants have pressure relief valves which are utilized for the plant cooldown. The Diablo Canyon steam generator PORVs are air operated valves. At Shearon Harris, the Main Steam power-operated atmospheric relief valves are hydraulically operated valves which are Safety Class 2, seismic Category 1 and environmentally qualified. Therefore, these relief valves provide a qualified means of controlling steam release.

2.1.4 Chemical and Volume Control System (CVCS)

Injection of boric acid into the RCS is required to offset xenon decay and the reactivity change which occurs during plant cooldown. The Diablo Canyon natural circulation cooldown test utilized the charging pumps to charge through the Safety Injection System (SIS) boron injection tank (at 20,000 ppm boron) into the Reactor Coolant System. Subsequent charging was aligned from the volume control tank in the CVCS. The boron concentration in the volume control tank was adjusted to 2000 ppm to simulate charging from the Refueling Water Storage Tank (RWST).

At Shearon Harris, four weight percent boric acid is normally pumped from the boric acid tank (at a minimum of 7000 ppm boron) by the boric acid transfer pumps to the suction of the centrifugal charging pumps. Each train of pumps is powered from a different emergency bus. A backup source of boric acid is available from the RWST (at a minimum of 2000 ppm boron). The borated water is then injected into the RCS via the normal charging line and the RCP seal injection flow path. A backup injection path to the RCS is also available through the SIS injection lines using the centrifugal charging pumps.

To accommodate the borated water addition to the RCS, letdown capability is normally provided by the normal and excess letdown lines to the CVCS at both the Diablo Canyon and Shearon Harris plants. However, the normal and excess letdown lines at both plants are not qualified lines and do not meet the requirements of RSB

5-1. The Diablo Canyon test did utilize letdown as a demonstration of RCS inventory control. To comply with BTP RSB 5-1, Shearon Harris can take credit for a qualified letdown path that can be established through the reactor vessel head vent line to either containment or the pressurizer relief tank (PRT). This line is equipped with redundant solenoid-operated vent line isolation valves powered from the safety grade 120 AC power supplies.

2.1.5 <u>Residual Heat Removal (RHR) System</u>

The RHR systems at both Diablo Canyon and Shearon Harris are low pressure heat removal systems consisting of RHR pumps and heat exchangers. They are designed to lower the temperature of the RCS from 350°F to cold shutdown conditions at a controlled rate. Residual heat is transferred during this stage from the reactor core through the RHR system to the component cooling water circulating through the shell side of the RHR heat exchangers.

Following cooldown to RHR initiation conditions, the RHR system is brought into operation by accessing one or both of the redundant RHR trains. Start-up of the RHR system includes a warmup period during which time reactor coolant flow through the heat exchangers is limited to minimize thermal shock on the RCS components. This flow is regulated by flow control valves downstream of the residual heat exchangers. A bypass line around the residual heat exchanger contains a flow control valve which maintains a constant total return flow to the RCS. Should any of these flow control valves fail, adequate RHR flow can be provided by manual operator control of the RHR pumps.

2.2 <u>Applicability of Diablo Canyon Test Results To Shearon Harris</u>

This section provides qualitative justification of the applicability of the Diablo Canyon test results to Shearon Harris by evaluating the phenomena of natural circulation, boron mixing, cooldown and depressurization through a systems comparison.

2.2.1 Natural Circulation

The Diablo Canyon natural circulation test evaluation verified that RCS natural circulation flow could be established, thereby permitting boron mixing, RCS cooldown and RCS depressurization to RHR system initiation conditions. This phase of the test had no specific acceptance criteria and it was evaluated based on the results of the boron mixing and cooldown/depressurization phases of the natural circulation cooldown test.

The Diablo Canyon test results indicated that natural circulation flowrates were adequate to ensure that core decay heat removal, boron mixing and plant cooldown/depressurization were maintained throughout the test. The response of the RCS temperatures indicated stable natural circulation conditions existed throughout the test.

The Shearon Harris plant and Diablo Canyon Unit 1 have been compared (Section 2.1) to ascertain any system differences between the two plants that could potentially affect natural circulation flow. The general configuration of the piping and components in each reactor coolant loop is the same in both Shearon Harris and Diablo Canyon Unit 1 even though Shearon Harris has one less heat transfer loop. The elevation head represented by these components and the system piping is similar in both plants. Steam generator units (Model 51 for Diablo Canyon vs. Model D4 for Shearon Harris) were also compared to ascertain any variation that could affect natural circulation capability by changing the effective elevation of the heat sink or the hydraulic resistance seen by the primary coolant. The primary design difference affecting natural circulation flow rates between the two steam generator models is that the Model D4 has a shorter tube bundle length than that of the Model 51. The length of the tube bundle region has an effect on the natural circulation driving head established by the system. The longer tube bundle in the Model 51 SG for Diablo Canyon Unit 1 would result in approximately a 9.5 ± 2.5% or (7 to 12%) higher driving head when compared to the Model D4 SG installed at Shearon Harris. This variance in net driving head is relatively small and should not effect the natural circulation flow rate. Therefore, it can be concluded that there are no significant differences in the steam generator units between the two plants that would adversely affect the natural circulation flow characteristics for Shearon Harris.

To further compare the natural circulation flow capabilities of Shearon Harris and Diablo Canyon, the hydraulic resistance coefficients of system piping were also compared. The coefficients were generated on a per loop basis. The hydraulic resistance coefficients applicable to normal flow conditions are shown in Table 2-1.

The general configuration of the reactor core and internals for Diablo Canyon is similar to Shearon Harris. The slight variation in the hydraulic resistance coefficient is primarily due to the specific design details of the vessel and internals (i.e., flow area, upper/lower support plate designs, thermal design flow, elevations, etc.).

The reactor nozzles at Shearon Harris have a lower resistance coefficient than those of Diablo Canyon due to the design of the reactor vessel inlet nozzle. The Diablo Canyon vessel inlet nozzle radius is significantly smaller than that of Shearon Harris, as reflected by the higher coefficient for Diablo Canyon. The "vessel inlet nozzle radius" refers to the bend or curvature of the nozzle at the maximum diameter of the nozzle (i.e., at the point where the nozzles and the vessel wall intersect).

The flow losses in the reactor coolant loop piping and the steam generators are very similar for the two plants. This similarity is reflected in the resistance coefficients calculated in Table 2-1.

The coefficients in Table 2-1 represent the resistance in one loop, excluding the resistance through the reactor coolant pump. Since the RCP impeller designs for Diablo Canyon and Shearon Harris are nearly identical, the flow ratio reported in Table 2-1 would not be

TABLE 2-1

DIABLO CANYON VS. SHEARON HARRIS
HYDRAULIC RESISTANCE COEFFICIENTS FOR NORMAL FLOW CONDITIONS

	Diablo Canyon $[ft/(gpm)^2]$	Shearon Harris $[ft/(gpm)^2]$
Reactor Core & Internals	129.0×10^{-10}	101.1×10^{-10}
Reactor Nozzles	36.1×10^{-10}	27.6×10^{-10}
R.C. Loop Piping	20.9×10^{-10}	24.0×10^{-10}
Steam Generator	112.0×10^{-10}	112.4×10^{-10}
Total Hydraulic Flow Coefficient (HFC_{tot})	298.0×10^{-10}	265.1×10^{-10}

$$\text{Flow Ratio Per Loop} = \left[\frac{HFC_{tot} \text{ for Diablo Canyon}}{HFC_{tot} \text{ for Shearon Harris}}\right]^{1/2} = 1.06$$

affected by the RCP flow resistance. The overall hydraulic flow coefficient for Shearon Harris is lower than that of Diablo Canyon resulting in an increased natural circulation flow rate capability.

If the effect of the increased natural circulation driving head (7 to 12%) for Diablo Canyon Unit 1 and the lower overall piping resistances for Shearon Harris are factored together, the total hydraulic flow ratio would decrease to approximately 1.01. Therefore, the natural circulation loop flowrate for Shearon Harris is expected to be nearly the same as that for Diablo Canyon. The differences in reactor power and decay heat levels between the two plants are not expected to alter this conclusion.

2.2.2 Boron Mixing

The Diablo Canyon boron mixing test evaluation demonstrated adequate boron mixing under natural circulation conditions when highly borated water at low temperatures and low flowrates (relative to RCS temperature and flowrate) was injected into the RCS. It also evaluated the time delay associated with boron mixing under these conditions.

The acceptance criterion for this phase of the Diablo Canyon test was that RCS hot legs (loops 1 & 4) indicate that the active portions of the RCS were borated such that the boron concentration had increased by 250 ppm or more.

Boron injection was conducted at the Diablo Canyon test using the 20,000 ppm boron solution contained in the boron injection tank (BIT). The BIT's contents were flushed into the RCS and, within 12 minutes, natural circulation had provided adequate mixing to increase the boron concentration in the RCS by 340 ppm. Following injection, makeup to the Volume Control Tank (VCT) was set to provide 2000 ppm boron. This simulated suction of the charging pumps aligned to the RWST. The charging pump discharge was aligned to provide seal injection flow to each RCP and charging flow to one RCS loop. This alignment was continued throughout the remainder of the test causing the boron concentration to further increase.

For Shearon Harris, boron will normally be supplied from the 7000 ppm (minimum) boron solution of the boric acid tanks to the suction of the centrifugal charging pumps by the boric acid transfer pumps. Makeup in excess of that needed for boration can be provided from the RWST. The BAT boron concentration (7000 ppm minimum) at Shearon Harris is less than that used for the successful Diablo Canyon test, therefore, the addition of a larger quantity of borated water over a longer period of time will be required to achieve a similar change in boron concentration. However, because natural circulation flow at Shearon Harris is expected to be very similar to the flow obtained at Diablo Canyon (See Section 2.2.1), adequate mixing of the boron would also be provided for Shearon Harris. The ability to borate to the required concentration with the BAT will be discussed in the analysis presented in Section 4.0.

2.2.3 Reactor Coolant System Cooldown

The cooldown portion of the Diablo Canyon test demonstrated the capability to cool down the RCS to RHR system initiating conditions at approximately 25°F/hour using all four steam generators for natural circulation. The RHR system was then used to cool the RCS to cold shutdown conditions. Plant cooldown was controlled within Technical Specification limits. All active portions of the RCS remained within 100°F of the average core exit temperature. Also, both the steam generators and reactor vessel upper head were cooled to below 450°F when the core exit temperature was 350°F.

For Shearon Harris, cooldown capability will be similar to Diablo Canyon due to similarities in the design of the RCS, AFW, main steam and RHR systems. Initial plant cooldown will be accomplished via steam release from the main steam power-operated atmospheric relief valves. After RHR system initiation, the RHR system will be used to cool the plant down to cold shutdown temperatures. In terms of the upper head cooldown for Shearon Harris, the upper head region for

Shearon Harris is expected to cool at a rate comparable to or exceeding that of Diablo Canyon Unit 1. The upper head volume for Shearon Harris is slightly smaller than that of Diablo Canyon. However, the reactor vessel spray nozzle between the downcomer and the upper head region has a flow area nearly 9 times larger for Shearon Harris thereby allowing better flow communication and mixing in the upper head during natural circulation cooldown. In fact, due to the enhanced flow mixing capability of a T-cold upper head design plant such as Shearon Harris (Reference 4), a maximum RCS natural circulation cooldown rate of 50°F/hr may be employed under normal conditions. This rate is twice as fast as the recommended natural circulation cooldown rate of 25°F/hr for T-hot upper head design plants such as Diablo Canyon. Also, Shearon Harris is not required to perform an upper head soak (Reference 4) prior to placing the RHR system in service as opposed to the soak requirements for Diablo Canyon. The ability of Shearon Harris to achieve cold shutdown while maintaining adequate subcooling in the upper head will be discussed further in Section 4.0.

2.2.4 Reactor Coolant System Depressurization

The depressurization portion of the Diablo Canyon test demonstrated the capability to control pressure in the RCS under natural circulation conditions. Pressure control capability included the ability to maintain adequate RCS pressure and the ability to significantly reduce RCS pressure when needed to initiate RHR system operation. Three methods of reducing pressure were demonstrated. During the RCS cooldown, pressurizer pressure exhibited a downward trend due to fluid shrinkage and ambient heat losses from the pressurizer. This was followed by operator initiated RCS depressurization using the auxiliary spray. For auxiliary spray to be effective, the charging lines to the RCS loops must be isolated. Finally, depressurization was completed using a pressurizer PORV. Each method was determined to be effective in reducing RCS pressure.

For Shearon Harris, pressure control and depressurization capability will be similar to Diablo Canyon due to similarities in the design of the RCS and CVCS. Ambient heat losses will gradually reduce RCS pressure. The pressurizer auxiliary spray line will be available at Shearon Harris for RCS depressurization following the installation of a pressure regulated, portable compressed gas bottle to the pneumatic controls of the auxiliary spray valve.

2.3 Summary

The Diablo Canyon Unit 1 Natural Circulation/Boron Mixing/Cooldown Test (Reference 2) demonstrated that the plant can safely be taken to cold shutdown under natural circulation conditions.

In order to apply the test results to Shearon Harris, a qualitative comparison (Section 2.1) of the plant systems and equipment that affect natural circulation, boron mixing, cooldown and depressurization capabilities has been made between the Shearon Harris and Diablo Canyon Unit 1 plants. The Section 2.2 evaluation qualitatively demonstrates that the Shearon Harris capabilities are comparable to those of Diablo Canyon Unit 1. Sections 3.0 and 4.0 provide the quantitative evaluation of the Shearon Harris plant's capability to borate, cooldown and depressurize under the requirements of BTP RSB 5-1 by developing a plant specific cold shutdown scenario and performing the associated thermal/hydraulic analysis.

3.0 NATURAL CIRCULATION COLD SHUTDOWN SCENARIO

To address the requirements of BTP RSB 5-1, the systems required to go from hot standby to cold shutdown have been evaluated for Shearon Harris in this section. As noted previously, the following functional requirements are included in BTP RSB 5-1:

- Use of only safety-grade systems
- Single failure in safety-grade systems
- With or without offsite power
- Operation from the control room with limited operator action outside control room if suitably justified
- Within a reasonable period of time

An evaluation of operator functions has been performed to scope the operational strategies needed to achieve cold shutdown if certain normal operational systems are unavailable due to the BTP RSB 5-1 assumptions. The following operator functions have been evaluated:

- RCS Boron Concentration Control
- RCS Inventory Control
- RCS Pressure Control
- RCS Temperature Control
- Secondary Inventory Control
- Secondary Pressure Control

The worst case cold shutdown scenario has been defined based on the limiting set of plant equipment available under the requirements of BTP RSB 5-1. The minimum equipment available to support each operator function under the BTP RSB 5-1 requirements has been determined for Shearon Harris and are itemized on Table 3-1. In addition to the requirement to use only qualified systems, BTP RSB 5-1 also requires that systems used to achieve cold shutdown be capable of tolerating the most limiting single failure. Based on an evaluation of the operator functions described above, the most limiting single failure would result from the operator functions of RCS temperature control, secondary pressure control and secondary inventory control. Addressing a single failure in these systems results in one steam generator not being available for plant cooldown since steam release from the steam generator may not be available. The unavailability of one SG will maximize the time required to cool the RCS to RHR cut-in temperature. The unavailability of one of the three steam generators due to a single failure is also reflected in Table 3-1.

To define appropriate operator strategies necessary to achieve safe shutdown using only the systems available under the BTP RSB 5-1 assumptions, the above operator functions have been assessed to determine how they are performed. A review of Table 3-1 indicates that the functions of secondary inventory and secondary pressure control can be performed by the operator using available equipment in a manner similar to a normal natural circulation cooldown. However, the operator functions of controlling RCS boron concentration, RCS inventory, RCS pressure and RCS temperature must differ to various extents from a normal natural circulation cooldown due to the unavailability of normal operational systems and equipment (e.g., letdown and charging, reactor makeup control system, pressurizer heaters, Control Rod Drive Mechanism (CRDM) fans, etc.).

The initiating event for the cold shutdown scenario is assumed to be a reactor trip with concurrent loss of offsite power and associated RCP trip. To establish the worst case scenario, the reactor core is assumed to be operating at 102% power with BOL equilibrium xenon conditions prior to the initiating event. These conditions were chosen as being conservative as a result of the larger heat removal requirements, greater boron concentration increase needed for cold shutdown conditions and their subsequent impact on the hot standby and cooldown periods. The operator will respond to the reactor trip by establishing hot standby conditions. Having accomplished this, the operator will determine when a natural circulation cooldown can be performed. For the worst case scenario, a natural circulation cooldown will be initiated at four hours (assuming a four-hour hot standby period prior to cooldown initiation as described in the Shearon Harris FSAR) after reactor trip. The operator response strategy to achieve cold shutdown conditions for the worst case cold shutdown scenario with the minimum set of available systems and equipment is discussed below on an operator function basis. As required by BTP RSB 5-1, this operator response strategy addresses single failures and the unavailability of normal operational systems and equipment, such as letdown and excess letdown, normal charging, the reactor makeup control system, pressurizer heaters and CRDM fans.

3.1 Secondary Pressure Control

Plant and operator response to control secondary pressure will be similar to a normal reactor trip with natural circulation cooldown. Following the trip, the steam generator PORVs or safety valves will open upon demand to relieve steam and dissipate reactor core decay heat. Immediately following the trip, secondary pressure will be controlled by the steam generator PORVs or safety valves.

Upon initiating natural circulation cooldown, the operator will control the available steam generator PORVs to reduce SG pressures and RCS temperatures. By controlling the SG PORVs, RCS temperatures will be reduced to Residual Heat Removal (RHR) system initiation temperatures. Following RHR system initiation, the SG PORVs will be used periodically to cool the U-tube portion of the steam generators.

3.2 Secondary Inventory Control

Plant and operator response to control secondary inventory will be similar to a normal reactor trip with natural circulation cooldown. Immediately following the trip, steam voids in the secondary side of the steam generators will collapse and the SG inventory will shrink. The Auxiliary Feedwater (AFW) system will be automatically started to provide makeup to the steam generators. The operator will control auxiliary feedwater to ensure that total AFW flow is greater than the minimum required for heat removal or that steam generator inventory is above a minimum level. Once minimum level is established, the operator will control inventory to maintain SG levels throughout the hot standby and cooldown operations to cold shutdown conditions.

TABLE 3-1

OPERATOR FUNCTIONS AND MINIMUM EQUIPMENT AVAILABLE UNDER BTP RSB 5-1 ASSUMPTIONS

RCS BORON CONCENTRATION CONTROL

1. Boric Acid Tank (available after 1 hour)
2. Refueling Water Storage Tank (Backup)

RCS INVENTORY CONTROL

1. Charging (using one centrifugal charging pump)
    a) Seal Injection Flow Path
2. Letdown
    a) Seal Return Flow Path
    b) Head vent path to containment or PRT (for inventory control)
3. Water Supply
    a) Refueling Water Storage Tank

RCS PRESSURE CONTROL

1. Auxiliary Spray Valve (available after 6 hours)
2. Pressurizer Safety Valves

RCS TEMPERATURE CONTROL

1. SG PORVs (2 out of 3 SGs available)
2. RHR System (one pump and flowpath)
3. Head vent path to containment (for upper head cooling)

SECONDARY INVENTORY CONTROL

1. One motor-driven or the turbine-driven AFW pump and flow paths
2. Water Supply
    a) Condensate Storage Tank
    b) Emergency Service Water (Backup)

SECONDARY PRESSURE CONTROL

1. SG PORVs (2 out of 3 SGs available)
2. SG Safety Valves

During cold shutdown operations, makeup to the steam generators will come from the condensate storage tank (CST). The water in this tank will be used to maintain the plant at hot standby for up to 4 hours, followed by the cooldown to RHR initiation. A backup source of auxiliary feedwater is provided by the Emergency Service Water System. After RHR initiation, periodic steam release to cool the steam generator U-tubes will require an additional small amount of CST inventory prior to final RCS depressurization after the RCS is cooled to 200°F. Alternatively, water already existing in the SGs can be utilized for this additional SG cooling.

3.3 RCS Boron Concentration Control

Operator response to control RCS boron concentration will differ from a normal reactor trip with natural circulation cooldown. This difference will be in part due to the unavailability of the reactor makeup control system which is normally used to provide makeup to the suction of the charging pumps at the desired makeup boron concentration. However, the major reason that RCS boron concentration control will differ is the unavailability of normal or excess letdown to serve as an RCS letdown path. Since letdown is not available, RCS letdown and makeup cannot be used to adjust RCS boron concentration while permitting RCS inventory to be controlled independently.

Initial plant response to the reactor trip will result in a core subcritical condition as the control rods drop into the core. The negative reactivity resulting from insertion of the control rods will initially shut down the core. The cold shutdown scenario assumes the reactor trip occurred with the plant operating at a 102% steady state power condition, therefore, xenon will increase in the time period immediately following reactor trip. This will further increase shutdown margin until xenon starts to decay approximately 8-10 hours after trip. Consequently, boration to maintain subcriticality is not an immediate concern following reactor trip. However, boration will be required during plant cooldown to cold shutdown conditions to compensate for cooldown positive reactivity insertion and to eventually compensate for xenon decay. This boration will be provided via RCS makeup from the boric acid tank. The four weight percent boric acid is pumped from the boric acid tank by the boric acid transfer pumps to the suction of the centrifugal charging pumps. One hour is the time assumed for any local valve operations that may be required by the operator to establish one of the redundant flowpaths from the discharge of the boric acid transfer pumps to the suction of the centrifugal charging pumps.

3.4 RCS Inventory Control

Operator response to control RCS inventory will differ from a normal reactor trip with natural circulation cooldown since normal and excess letdown will not be available. Consequently, the operator will not be able to control RCS makeup and letdown to control pressurizer level. Any makeup to the RCS will result in a net increase in RCS inventory. The operator will, therefore, have to minimize RCS makeup, subject to other operational requirements such as RCS boration and RCP seal cooling. For Shearon Harris the upper head vent path is qualified and can be used as an alternate letdown path for RCS inventory control. During the cooldown period, the operator will also utilize the RCS cooldown rate (RCS shrink) to reduce the RCS water volume in order to accommodate the needed makeup requirements.

Initial plant response to the reactor trip will result in a small pressurizer level decrease from the full power level to the post-trip level. Following the trip, it is assumed that the letdown and excess letdown paths are unavailable for the worst case scenario. The normal charging path is not available as a RCS makeup source since the flow control valve fails open on the loss of air resulting in no charging flow control capability. Therefore, the charging flow path is isolated by operator action in order to reduce RCS makeup flow to only that being added for RCP seal cooling via the RCP seal injection flow path. A nominal seal injection flow of 8 gpm per RCP is established with approximately 5 gpm per pump entering the RCS and 3 gpm returning through the No. 1 seal leakoff line. This results in a net RCS inventory addition of 15 gpm. Over a one hour time period without RCS contraction, this nominal RCP seal injection flow into the RCS will increase pressurizer level by approximately 10%. RCS cooldown and contraction will be utilized to control RCS inventory while permitting RCP seal injection to be continued for RCS boration and RCP seal cooling purposes.

3.5 RCS Pressure Control

Operator response to control RCS pressure will differ from a normal reactor trip with natural circulation cooldown due to the unavailability of pressurizer heaters to increase RCS pressure. The pressurizer PORVs are also unavailable. However, operator response to decrease RCS pressure for the worst case scenario will be similar to normal natural circulation cooldown since the pressurizer auxiliary spray valve will be available to depressurize the RCS at the end of the cooldown period. Credit is taken for local operator action to hook up a portable compressed gas supply to the auxiliary spray valve in 6 hours assuming the normal air supply is lost to the valve. Therefore, the auxiliary spray valve is assumed available for depressurization in 6 hours.

Since the capability to increase RCS pressure is not available whereas the capability to decrease RCS pressure is available, operator actions will maximize RCS pressure throughout the worst case scenario. This will be accomplished through avoiding RCS depressurization except due to unavoidable ambient heat losses from the pressurizer. Also, RCS inventory (i.e., pressurizer level) control will be used to provide partial control of the RCS pressure through compression and expansion of the pressurizer steam space. The objective of RCS pressure control will be to prevent void formation in the reactor vessel upper head and to maintain RCS subcooling.

For the worst case scenario, RCS pressure will initially decrease following reactor trip due to decreasing RCS temperatures and pressurizer level following the trip but will rapidly increase as natural circulation conditions are established at RCS temperatures above no-load values. Since the pressurizer PORVs are assumed not to be available, RCS pressure will increase to the pressurizer safety valve set pressure. The RCS pressure will then be maintained around the valve set pressure through periodic releases through the pressurizer safety valves.

During plant natural circulation cooldown, RCS pressure will decrease from the pressurizer safety valve setpoint pressure due to decreased core decay heat generation and increased heat transfer to the active steam generators. RCS pressure will also gradually decrease due to the pressurizer ambient heat loss. Operator control of pressurizer level will be used to compress or expand the pressurizer steam space to partially control RCS pressure. At the completion of RCS cooldown to RHR initiation temperature, the pressurizer auxiliary spray valve will be used to depressurize the RCS to RHR initiation pressure.

3.6 RCS Temperature Control

Operator response to control temperatures in the active portions of the RCS will be similar to a normal reactor trip with natural circulation cooldown. For Shearon Harris, which is a T-cold upper head plant, the Westinghouse Owners Group (WOG) Emergency Response Guideline (ERG) ES-0.2 allows a 50°F/hour natural circulation cooldown rate (Reference 4). However, a limited cooldown rate of 25°F/hour has been selected for use in the worst case scenario since the unavailability of certain plant equipment (i.e., RCS normal letdown and makeup capabilities, PRZR heaters and one steam generator for steam release) limits the maximum cooldown rate achievable. The operator will use secondary steam release to atmosphere to cool down the RCS from post-trip temperatures to RHR initiation temperatures. RHR system operation will then be initiated to cool the plant to cold shutdown conditions.

Operator response to control temperatures in the inactive portions of the RCS will differ from normal reactor trip with natural circulation cooldown. Normal heat removal from the reactor vessel upper head will not be available since the CRDM fans are not available. The head vent path is available to ensure adequate mixing of the upper head fluid to enhance heat removal from the upper head. Normal heat addition to the pressurizer will not be available since the pressurizer heaters are not available. Although this inability to control temperatures in the pressurizer and reactor vessel upper head are temperature control problems, their operational impact is more on RCS pressure control than RCS temperature control since the operator will be restricted relative to RCS depressurization.

Initial plant response to the reactor trip will result in the establishment of natural circulation flow in the RCS. Following the trip, RCS cold leg temperatures will stabilize at values that approximate the saturation temperature corresponding to the pressure in the steam generators. RCS hot leg temperatures in the active loops will be greater than the cold leg temperature by a value dependent upon core decay heat. As long as subcooled natural circulation conditions exist during hot standby and subsequent RCS natural circulation cooldown, these basic relationships will continue to exist.

3.7 Summary

Based upon the operator functions described in Sections 3.1 through 3.6, a plant specific cold shutdown scenario for Shearon Harris has been developed that addresses the requirements of BTP RSB 5-1. A quantitative thermal/hydraulic analysis of this Shearon Harris cold shutdown scenario is performed in Section 4.0.

4.0 THERMAL/HYDRAULIC ANALYSIS OF COLD SHUTDOWN SCENARIO

As part of the requirements of BTP RSB 5-1, all Class 2 plants must demonstrate the ability to achieve cold shutdown conditions from full power operation by utilizing only safety-grade equipment and assuming credible single failures. This may be demonstrated via actual plant testing or through comparison with previously performed tests for similar plants (i.e., the Diablo Canyon natural circulation cooldown and boron mixing test). For Shearon Harris, a two part approach will be utilized to demonstrate compliance with BTP RSB 5-1. First, Section 2.0 details a Shearon Harris plant comparison to Diablo Canyon. This portion qualitatively demonstrates the similarity of key plant parameters such that the conclusions of the Diablo Canyon natural circulation test are applicable to Shearon Harris. Second, this section details an actual analysis simulation which demonstrates the capability of the Shearon Harris plant to attain cold shutdown conditions in a worst case scenario. This two part approach will demonstrate Shearon Harris compliance with BTP RSB 5-1 via plant comparison and transient simulation in lieu of an actual plant test.

The Westinghouse proprietary Transient Real-Time Engineering Analysis Tool (TREAT) computer code was used to perform the thermal hydraulic analysis of the Shearon Harris natural circulation cold shutdown scenario. The worst-case scenario to be simulated was defined in Section 3.0. The transient simulation will be discussed in this section.

4.1 TREAT Model Description

TREAT is a real-time, interactive, two-phase, nonequilibrium, nonhomogeneous, thermal-hydraulic network code. The network consists of a system of nodes connected by flow links. Each node may contain two separate regions: a steam region and a mixture region. The regions are separated by a moving interface. Properties in each region are solved independently by using two mass and two energy conservation equations. The mass equations are solved explicitly, and the energy equations are solved using a predictor/corrector method. In conjunction with the corrector part of the solution, a global pressure is found which conserves global volume. Although overall system volume is conserved, the fluid in an individual node might not occupy the same volume as the physical node. This local volume error is coupled to the momentum equation using the dual-variable method to obtain the volumetric flow in each flow link. By applying drift flux correlations, the total volumetric flow is separated into vapor and liquid flows.

The TREAT pressurized water reactor (PWR) system includes models for neutronics, heat transfer, automatic controllers, plant protection systems, boundary flows, and reactor coolant pumps (RCPs). The neutronic models compute the axial flux, power, and fission product distributions in the core. The heat transfer models compute core and steam generator (SG) heat transfer, as well as conduction-limited, thick metal heat transfer. The simulated controllers for reactor power, pressurizer pressure, pressurizer level, steam/feed flow, and SG level all operate automatically in response to changes in load demand; they may also be placed under manual control. The Reactor Protection System (RPS) monitors the reactor trip, SI actuation, turbine trip, steamline isolation, feedwater isolation, letdown isolation, and auxiliary feedwater actuation setpoints. The RCP model uses a four-quadrant homologous curve to compute the pump head. The boundary flow models either automatically control or allow the user to manually adjust the SI, charging, letdown, pressurizer or SG power-operated relief valve (PORV), and spray flows. Detailed descriptions of the TREAT model are provided in Reference 5.

TREAT has been used extensively in the development of the Westinghouse Owners Group (WOG) Emergency Response Guidelines (ERGs) as well as plant specific Emergency Operating Procedures (EOPs). TREAT was also used to perform a safety grade cold shutdown and long term cooling scenario simulation for the South Texas plant. The results of these simulations were submitted to the NRC staff for review. Subsequently, the staff has approved the use of the TREAT cold shutdown simulation in the resolution of the RSB 5-1 issue for the South Texas project (Reference 6). The same methodology is used in the analysis of the Shearon Harris natural circulation cold shutdown simulation.

Also, note that as part of the validation of TREAT for such a cooldown scenario, a benchmark analysis (Reference 7) was made for the Diablo Canyon natural circulation cooldown and boron mixing test of March 28-29, 1985 (using a Diablo Canyon specific TREAT model). This analysis demonstrated that TREAT adequately predicted the key elements that are important for the natural circulation cooldown scenario. These include proper mixing of boron in the RCS, cooldown of the upper head metal and fluid, and the correct natural circulation delta-T (i.e., Thot-Tcold). TREAT has been determined to be an appropriate code to accurately predict the thermal hydraulic response of such cooldown scenarios.

For the Shearon Harris natural circulation cold shutdown scenario, a plant-specific TREAT input deck that explicitly models each of the three Shearon Harris loops was set up. Also, Shearon Harris specific core power, RCP model, temperatures, reactor protection system, charging flow and steam generators were modeled. The control systems modeled include pressurizer level, pressurizer pressure, SG level and SG pressure. Table 4.3-1 summarizes the important parameters simulated in the Shearon Harris TREAT model.

4.2 Operational Input to Transient Analysis

A worst case cold shutdown scenario that complies with the guidelines set forth in Branch Technical Position RSB 5-1 was defined in Section 3.0 by careful evaluation of operator functions and plant equipment availability status. The analysis of this natural circulation cold shutdown scenario requires a number of unique analysis requirements. These are identified in Table 4.2-1 and result from the unavailability of pressurizer heaters, pressurizer PORVs, CRDM fans, letdown, charging and 1 of 3 steam generators for cooldown operations. This worst case cold shutdown scenario was simulated with the TREAT code described in the previous section using the Shearon Harris input model. A listing of the important analysis assumptions for the transient analysis is provided in Table 4.2-2.

Operation of the plant during the time from transient initiation until the attainment of cold shutdown conditions will consist of four (4) major operational periods. Operator response to the initiating transient will stabilize and control the plant in the hot standby mode of operation. Following plant stabilization during the hot standby period, the operator will initiate a natural circulation cooldown to RHR system initiation temperature. Having achieved RHR system initiation temperature, the next step is to depressurize the RCS to the RHR cut-in pressure. However, prior to beginning the RCS depressurization, the reactor vessel upper head vent may be opened to assure adequate mixing and subcooling in the upper head thereby precluding steam bubble formation during RCS depressurization. Upper head cooling will be discussed in detail in Section 4.3.4. Following the operation of the upper head vent the RCS may then be depressurized. Finally, RHR system operation will be initiated and RCS cooldown continued to cold shutdown conditions.

The four (4) major operational periods are itemized below:

- Hot Standby
- RCS Cooldown to RHR System Initiation Temperature
- RCS Depressurization to RHR System Initiation Pressure
- RHR System Initiation and RCS Cooldown/Depressurization to Cold Shutdown

For each of these periods, there are various operational considerations necessary to maintain the plant within appropriate limits. Operator actions applicable to the Shearon Harris plant in order to accomplish this goal are discussed in the following subsections.

4.2.1 Hot Standby Period

This period includes the transient initiation and the subsequent operator response to plant trip. Operator actions are necessary to maintain the plant in hot standby mode while preparations are made to initiate the RCS cooldown. Per the requirements of BTP RSB 5-1, the hot standby period will be maintained for four (4) hours.

To control the plant in the hot standby mode, the operator will monitor plant parameters and perform actions to maintain plant parameters within acceptable limits. Due to the loss of offsite power, the main feedwater pumps are tripped and a motor-driven auxiliary feedwater pump is automatically sequenced on to the diesel generators. The turbine-driven AFW pump also receives a start signal and has the capability of supplying AFW flow to the steam generators. However, only the flow from one motor driven auxiliary pump was assumed to be available since this represents the bounding scenario with respect to secondary decay heat removal. Once the operator has verified that auxiliary feed flow from the motor driven pump has been initiated, the flow should be controlled to maintain the secondary narrow range levels in the 10-50% range. Steam generator isolation will be accomplished by main steam isolation valve(s) closure.

Primary parameters to be monitored during the hot standby period include RCS pressure, pressurizer level, RCS subcooling and RCS shutdown margin. The RCS pressure should be controlled such that the low pressurizer pressure safety injection setpoint is not reached. Also, the pressurizer level should be maintained in an appropriate range to avoid uncovering the heater banks or filling the pressurizer with water. Adequate RCS subcooling should be verified during the hot standby period to avoid any unwanted hot spots in the RCS. Finally, although the RCS shutdown margin is adequate at this time and throughout the early portion of the transient, action should be taken to verify the operability of the Boric Acid Tank (BAT). Boration should be initiated an the end of the hot standby period (before the RCS cooldown) if normal charging is available. Should only the RCP seal injection paths be used, boration should be initiated as soon as possible during the hot standby period.

4.2.2 RCS Cooldown Period

Following the 4-hour hot standby period, the RCS cooldown should be started. This will be accomplished by relieving steam through the PORVs on the two intact steam generators. Based on the RCS conditions and available equipment, the operator must choose an initial RCS cooldown rate. For a Tcold plant such as Shearon Harris, the maximum cooldown rate is 50°F/hr (see Section 3.6). However, constraints on RCS makeup may limit the RCS cooldown rate to less than 50°F/hr. Also, the constant RCS makeup rate (seal injection) and the RCS shrink due to the cooldown are competing effects with respect to RCS inventory. Since the seal injection rate is constant throughout the transient, the RCS cooldown rate (i.e., shrink) may be varied, if necessary, during the cooldown period to control pressurizer level and RCS pressure (RCS subcooling).

The safety injection signal should be blocked sometime in the early stages of the cooldown period. Therefore care should be taken so as not to have the RCS pressure decrease below the low pressurizer pressure safety injection setpoint while attaining appropriate hot leg temperatures. The combination of decreased hot leg temperatures and RCS pressure near 2000 psia will assure adequate RCS subcooling prior to blocking SI. Once SI is blocked, the RCS pressure will not be bounded by the low pressurizer pressure SI setpoint and the cooldown should be continued to the RHR cut-in temperature. As mentioned previously, the RCS cooldown and seal injection are competing effects with respect to RCS inventory. Therefore, the cooldown rate should be balanced such that pressurizer level is maintained in an operable range (i.e., between full and uncovering the heater banks) during the cooldown period.

Boration should be started or continued during this period to ensure that the RCS boron requirements (as a function of RCS temperature) are maintained during the cooldown period. Should there be difficulty in maintaining adequate RCS boron requirements, the cooldown may have to be stopped and the RCS borated to attain adequate shutdown margin. RCS shutdown margin should be monitored throughout this period to ensure adequate boration and to determine when the cold shutdown boron requirements are attained.

The RCS subcooling margin should be monitored to assure that no hot spots develop in the RCS. Also, since no thermocouple is located in the top part of the upper head region, RCS pressure must be used as an indicator of the potential to draw a bubble in the reactor vessel upper head region. To preclude this possibility, the upper head vent should be opened during this cooldown period (when CRDM fans are not operable) if the RCS pressure decreases to the saturation pressure of the reactor vessel upper head temperature at the end of hot standby. Should the RCS pressure not decrease to this value, consideration should be given to opening the head vent prior to RCS depressurization to assure good fluid mixing in the upper head region.

During the cooldown period, the steam generator levels should continue to be monitored and controlled in the appropriate range. The pressure differential between the active and inactive steam generators should be maintained less than 400 psi, if possible, during the cooldown period. This will ensure that the cooldown rate will not be unduly retarded due to heat transfer degradation in the inactive SG.

The RCS cooldown period and associated operator actions for the Shearon Harris cold shutdown scenario are discussed in detail in Section 4.3.3. Parameter-dependent operator actions for the RCS cooldown period are summarized in Table 4.2-3.

4.2.3 RCS Depressurization Period

Following cooldown to RHR system initiation temperature, and an upper head mixing period (if necessary), the RCS is depressurized to the RHR system initiation pressure. Since the pressurizer PORVs are unavailable, the pressurizer auxiliary spray will be utilized to accomplish the RCS depressurization. As the RCS pressure decreases to the RHR cut-in pressure, the operator should block the SI accumulators at approximately 1000 psia. Also, the addition of the pressurizer auxiliary spray will cause the pressurizer level to increase during this period. Therefore, the upper head vent may have to be utilized as a letdown path during this period to prevent the pressurizer from becoming water solid.

The RCS depressurization period and associated operator actions for the Shearon Harris cold shutdown scenario are discussed in detail in Section 4.3.5. Parameter-dependent operator actions for the RCS depressurization period are summarized in Table 4.2-3.

4.2.4 RCS Cooldown to Cold Shutdown Period

This period consists of RHR system operation to cool the plant to cold shutdown conditions. This period is similar to a normal plant cooldown using a single train of the RHR system. This period is not included in the transient analysis performed for the natural circulation cooldown scenario since the capability and time required to attain cold shutdown conditions by utilizing one train of the RHR system have been previously demonstrated (Reference 3).

TABLE 4.2-1

UNIQUE ANALYSIS REQUIREMENTS FOR NATURAL CIRCULATION COLD SHUTDOWN SCENARIO

1) Ambient heat loss from pressurizer

2) Natural circulation cooling of the reactor vessel upper head

3) Natural circulation cooldown utilizing 2 of 3 steam generators

TABLE 4.2-2

ANALYSIS ASSUMPTIONS FOR NATURAL CIRCULATION COLD SHUTDOWN SCENARIO

1) 102% power, BOL equilibrium xenon condition

2) Initiating Transient - reactor trip at time = 0 minutes (with subsequent turbine trip, loss of offsite power and RCP trip)

3) Pressurizer heaters do not function after reactor trip

4) Reactor vessel upper head CRDM fans do not function after reactor trip

5) SG 3 PORV does not function after reactor trip

6) Letdown isolated on loss of offsite power (all air-operated letdown isolation valves fail closed due to loss of instrument air)

7) One (1) charging pump available for seal injection

8) Pressurizer PORVs unavailable

9) One (1) motor-driven auxiliary feedwater pump available

10) AFW temperature - 120°F

TABLE 4.2-3

PARAMETER DEPENDENT OPERATOR ACTIONS FOR NATURAL CIRCULATION COLD SHUTDOWN SCENARIO

Limit	Operator Action Required When Limit Satisfied
Cooldown Period (Begin at 4 Hours)	
RCS Hot Leg Temperatures - All less than 580°F AND RCS Pressure - 1865 psia ≤ P ≤ 2015 psia	Block Safety Injection
RCS Pressure - at (1500) psia (or End of Cooldown Period)	Open RV Upper Head Vent
RCS Pressure - at (1000) psia	Isolate SI Accumulators
Depressurization Period (Begin at 14.3 Hours)	
RCS Pressure - at (1000) psia	Isolate SI Accumulators
RCS Hot Leg Temperatures - All less than (350)°F AND - RV Head Vent Closed	Depressurize RCS to RHR system initiation pressure
RCS Pressure - less than (360) psig	Initiate RHR system operation

( ) - Setpoint in parenthesis are approximate values

4.3 Transient Analysis of Natural Circulation Cold Shutdown Scenario

4.3.1 Description of the Analysis

The Shearon Harris natural circulation cold shutdown scenario is described in Section 3.0. The TREAT computer code was used to simulate this scenario. The major periods covered by this analysis include: 1) transient initiation/hot standby, 2) RCS cooldown and 3) RCS depressurization. RCS cooldown to cold shutdown temperature from RHR initiation conditions was not simulated because the process will be similar to normal plant cooldown. The subsequent sections discuss each period, the specific operator actions simulated, the various system responses and a final results summary for each period.

Table 4.3-1 lists the plant data used in the TREAT analysis for the primary and secondary systems. Table 4.3-2 presents the chronological sequence of events for the Shearon Harris natural circulation cold shutdown simulation.

4.3.2 Transient Initiation/Hot Standby Period (0-4 Hours)

The Shearon Harris transient was initiated with the plant at 102% power and BOL equilibrium xenon conditions. (See also Table 4.2-2 for a list of analysis assumptions). The initiating event was assumed to be a manual reactor trip followed by turbine trip. Loss of offsite power was also assumed coincident with reactor trip thereby tripping the RCPs and main feedwater pumps. The steam dump, pressurizer heaters, pressurizer PORVs, letdown and normal charging were all assumed to be unavailable for this scenario. Additionally, due to the postulated single failure, the PORV on SG 3 was unavailable throughout the entire transient. The normal 5 GPM/RCP seal injection was not affected by the initiating transient and served as a source of RCS makeup during the entire scenario. The transient results for the hot standby period are presented in Figures 4.3-1 through 4.3-6.

Following the postulated initiating event, the operator is instructed to bring the plant to hot standby conditions. At one (1) minute following reactor trip, it was assumed that one motor driven auxiliary feedwater pump was sequentially loaded onto the diesel generators and 400 GPM of auxiliary feed flow was divided amongst the three (3) steam generators at this time. At five (5) minutes it was assumed that the operator terminated flow to SG 3 to minimize cycling of the safety valve. Thus 400 gpm would be divided between SGs 1 and 2 at this time. This operator action was modeled to create a bounding scenario with respect to secondary heat removal. Specifically, the lack of auxiliary feed flow to SG 3 will result in dry out of this steam generator thereby degrading heat transfer via this loop and potentially leading to reverse heat transfer. This phenomenon will maximize RCS pressure during the hot standby period and also prolong the RCS cooldown (via the SG PORVs) to RHR cut-in temperature resulting in a conservative estimate of the time to attain RHR initiating conditions.

Following reactor trip and the coast down of the RCPs, natural circulation flow was established in all three loops. The natural circulation flow in loops 1 and 2 was approximately 400 lb/sec while the loop 3 natural circulation flow decreased to approximately 225 lb/sec due to the degraded heat removal of SG 3. According to the results of the Diablo Canyon natural circulation and boron mixing test, these magnitudes of loop natural circulation flows are capable of providing adequate mixing of the boron injected to the RCS.

At approximately 57 minutes the wide range level indication for SGs 1 and 2 had reached 75% (Figure 4.3-5). Since this corresponds to the narrow range level in the 30% range, it was assumed that the operator would throttle the auxiliary feed flow to these SGs to maintain narrow range level in the 10-50% range per guidance in the Shearon Harris Emergency Operating Procedures. The auxiliary feed flow to SGs 1 and 2 were controlled in this manner (i.e., to maintain level between 10 and 50% narrow range) for the remainder of the transient. Note from Figure 4.3-5 that SG 3 is predicted to dry out at approximately 3800 seconds due to the lack of auxiliary feed flow. This minimized the cycling of the SG 3 safety valve.

The initial boron concentration in the RCS combined with the xenon build-up provided sufficient core shutdown margin during the hot standby period even without additional boration. However, as discussed in Section 4.2.1, boration will be needed later in the cold shutdown scenario to maintain adequate shutdown margin. To facilitate the necessary boron increase during the subsequent cooldown, boration from the BAT should be made available as soon as possible. Up to a one hour time period may be required for local operator actions to restore a flow path from the boric acid tank (BAT). At that time, the seal injection alignment was switched from the 2000 ppm (minimum) RWST to the 7000 ppm (minimum) BAT. Due to the addition of 7000 ppm (minimum) boric acid for the final 3 hours of the hot standby period and the mixing of the borated water by the natural circulation flow, the RCS boron concentration increased by approximately 350 ppm at the end of the hot standby period. However, the boron concentration requirement for cold shutdown conditions (i.e., to conservatively bound all core conditions, an increase of 688 ppm boron concentration was determined to be sufficient) had still not been attained. Therefore, boration via the BAT must be continued during the cooldown and the shutdown margin should be monitored to assure that the shutdown margin requirements are maintained during the cooldown. The cold shutdown RCS boron requirement is expected to be met at some time during the cooldown and will be discussed further in Section 4.3.3.

Figures 4.3-1 through 4.3-6 may be referred to in the following discussion of some relevant primary and secondary responses during the hot standby period.

Immediately following reactor trip the secondary pressure increases such that the SG PORV and safety valves (with the exception of SG 3 PORV) lift to relieve this energy. Shortly thereafter (i.e., after SG isolation) the PORVs in SG 1 and 2 lifted sufficiently to relieve the energy transferred to the secondary side of these loops, while the safety valve on SG 3 cycles to relieve the energy of this loop. After SG 3 dries out, the safety valve on this loop ceases to cycle and the SG 1 and 2 PORVs attain a relatively steady flow to maintain adequate energy removal at the PORV set pressure of 1121 psia.

RCS pressure is seen to initially decrease following reactor trip. However, due to the post-trip decrease in primary to secondary heat removal by only two steam generators and the addition of 15 GPM total seal injection in conjunction with no letdown path, the RCS depressurization trend ceases and the RCS pressure steadily increases. Since the pressurizer PORVs are assumed unavailable, the RCS pressure continues to increase to the pressurizer safety valve setpoint (2500 psia) at approximately 7200 seconds. Following the lifting and subsequent shutting of the pressurizer safety valve, the RCS pressure is maintained between the open pressure of 2500 psia and the approximate blowdown pressure of 2375 psia.

During the RCS pressure increase, the pressurizer level also exhibits the same trend since there is a net addition of inventory to the RCS system due to the 15 GPM seal injection and the lack of a letdown path. While the RCS pressure is being maintained in an approximate 125 psi band by the pressurizer safety valve, the pressurizer level continues to increase. To avoid a water solid pressurizer, it is assumed that the operator takes action to alleviate the pressurizer fill by using the qualified reactor vessel upper head vent as a letdown path. Since the pressurizer level instrumentation error is approximately 10%, the operator should take action to utilize this letdown path prior to the pressurizer level indication reaching 90%. For this scenario, the head vent was opened when the pressurizer level reached 88%. However, to prevent the initiation of safety injection (SI), the head vent was closed before the low pressurizer pressure SI setpoint (1865 psia) was reached. Also, 100 psi uncertainty was added to the low pressurizer pressure SI setpoint for conservatism; therefore the pressure was maintained above 1965 psia. For the remainder of the hot standby period, the head vent was operated three (3) times to maintain the pressurizer level below 90% and the pressurizer pressure above 1965 psia.

The loop 1 temperatures, which are also representative of the other active loop (2) temperatures, show an initial increase in Thot followed by a gradual decline. Loop 1 Tcold is relatively stable at 560°F which corresponds to the saturation temperature of the steam pressure in the secondary side of the steam generators. The loop 3 Thot exhibits similar behavior to the loop 1 and 2 Thot; however, the loop 3 Tcold approaches Thot due to the drying out phenomenon and heat transfer degradation of SG 3. The plant auctioneered average temperature is representative of the loop 3 temperatures.

Since Shearon Harris has a Tcold upper head design (versus Thot upper head design for Diablo Canyon), the initial upper head fluid temperature is close to the cold leg temperature (557°F). The TREAT predicted temperature for the upper head at the end of the hot standby period is 584°F. There is still at least 50°F subcooling in the upper head at this time. To assure adequate subcooling in the upper head during the cooldown period, the operators should open the head vent for upper head fluid mixing at the RCS pressure corresponding to a 584°F saturation temperature plus some degree of pressure uncertainty (i.e., 1368 psia + 100 psi Uncertainty = 1468, say 1500 psia).

4.3.3 RCS Cooldown Period (4-14.1 Hours)

Following the hot standby period, RCS cooldown was initiated utilizing the secondary PORVs on the two active SGs (1 and 2). Although the maximum cooldown rate for a Tcold upper head design plant such as Shearon Harris is 50°F/hr, the cooldown rate for this case was initialized at 25°F/hr due to the assumed minimal makeup of the 15 GPM total seal injection flow. Per EOP guidance, a key operator action during the initial stages of the cooldown is the blocking of the SI signal. To initiate the blocking of the SI signal, it is necessary to decrease the RCS pressure below an unblock pressure while maintaining sufficient RCS subcooling. For this scenario, the combination of the 15 GPM seal injection and 25°F/hr RCS cooldown is sufficient to decrease the RCS pressure below the SI unblock pressure of 2015 psia but maintain the RCS pressure above the low pressurizer pressure SI setpoint of 1865 psia while cooling the RCS hot leg temperatures to 580°F. Cooling the RCS hot legs to a temperature of less than or equal to 580°F while maintaining the

RCS pressure in the aforementioned range will assure adequate subcooling to block SI. Therefore, SI is blocked at approximately 30 minutes into the cooldown.

Figures 4.3-7 through 4.3-16 show the relevant data for the entire transient scenario, including the cooldown period. The RCS pressure is seen to decrease initially at a relatively fast rate until the pressurizer becomes saturated again at which time the depressurization rate slows. Note the depressurization rate slows considerably prior to the end of the RCS cooldown period as the 25°F/hr cooldown rate was unattainable with two steam generators due to the secondary PORVs reaching their maximum relief capacity at the existing conditions. Near the end of the RCS cooldown period, the RCS pressure stabilizes and eventually begins to increase since the less than 25°F/hr cooldown shrink could not offset the mass addition from the seal injection. Note that the approximate 25°F/hr cooldown rate did maintain the subcooling at greater than 50°F for the entire RCS cooldown period.

The pressurizer level shows a steady decrease during the RCS cooldown period. The pressurizer level should be maintained during the RCS cooldown period between 90% (to avoid a solid pressurizer) and 25% (to avoid uncovering the heater banks). The upper head vent and/or cooldown rate may be used to control pressurizer level in this range. For this scenario, it is shown that the competing RCS cooldown shrink and seal injection can stabilize the pressurizer level at approximately 47%. Examination of RCS shutdown margin indicates that the cold shutdown boron requirement is met approximately 3 hours into the cooldown.

The inactive steam generator (SG 3) depressurized due to secondary to primary (reverse) heat transfer with an approximate 1.5 hour lag time behind the active steam generator response. There was no need to manually depressurize the inactive steam generator during the cooldown as the pressure differential between SG 3 and SGs 1/2 remained below 400 psid. The active and inactive steam generator pressures at the RHR cut-in temperature of 350°F were 81 and 135 psia, respectively. Note that the inactive loop steam generator wide range level was predicted to return at approximately 6.1 hours due to vapor condensation effects caused by secondary to primary (reverse) heat transfer. This reverse heat transfer was directly attributable to the RCS cooldown resulting from the active loop steam generator depressurization.

Finally, it is seen that the desired upper head subcooling margin of 50°F was maintained throughout the entire cooldown period. This demonstrates that for Shearon Harris, with a cooldown rate of 25°F/hr, adequate subcooling can be maintained throughout the RCS. However, since the pressure corresponding to the upper head mixture temperature at the end of hot standby was not reached, consideration should be given to mixing upper head fluid prior to RCS depressurization.

4.3.4 Upper Head Mixing Period (14.1-14.3 Hours)

Since Shearon Harris is a Tcold upper head design plant, the initial reactor vessel upper head fluid temperature is approximately equal to the cold leg temperature of 557°F. At the end of the RCS cooldown period, the RCS pressure is approximately 1530 psia which corresponds to a saturation temperature of 599°F. The predicted upper head temperature at the end of the hot standby period was 584°F while the predicted upper head temperature at the end of the RCS cooldown was 420°F (a predicted 170+°F subcooling in the upper head at the end of the RCS cooldown). The TREAT calculations assume complete mixing of the bypass flow with the fluid in the upper head. This is believed to be a reasonable assumption particularly for a Tcold plant such as Shearon Harris. However the NRC consultant, in their evaluation of the Diablo Canyon test (Reference 8), postulated that the upper head fluid could be fully stratified with no mixing occurring between the cold bypass flow and the hottest fluid in the upper head. Due to lack of appropriate temperature measurements from the Diablo Canyon test, the NRC suggested this issue should be addressed in each individual submittal (Reference 8). Since the predicted upper head temperature for Shearon Harris at the end of hot standby (584°F, which is greater than the initial condition) is expected to be accurate and since there are no mechanisms for the upper head to heat up during cooldown, the maximum temperature in the upper head at the end of RCS cooldown could be conservatively postulated to be 584°F. This temperature still corresponds to 15°F subcooling in the upper head.

Because of the potential stratification concern, steps should be taken to preclude upper head voiding during the RCS depressurization. For the Shearon Harris cold shutdown scenario, the upper head vent was opened for 10 minutes prior to RCS depressurization to assure adequate mixing in the upper head. When performing this action, the pressurizer level should not be allowed to fall below 25%. Note that the 10 minute mixing period was considered sufficient for this analysis to simulate adequate mixing; a longer mixing time (i.e., up to 30 minutes) may be used in actual conditions without causing the pressurizer level to fall below 25%. Since there would be good mixing due to the relief path in the upper head, the TREAT predicted temperature at the end of this 10 minute period is expected to be accurate. The upper head temperature at the end of 10 minutes is predicted to be 400°F thereby yielding an upper head subcooling margin of approximately 200°F. The use of the head vent in the proposed increment to induce upper head mixing will ensure adequate subcooling in the upper head prior to RCS depressurization. Therefore, no upper head soak would be required prior to RCS depressurization as would be expected for a Tcold upper head design such as Shearon Harris.

4.3.5 RCS Depressurization Period (14.3-15.1 Hours)

The RCS depressurization to the RHR cut-in pressure of 375 psia was performed by using the pressurizer auxiliary spray system. The auxiliary spray system is assumed available at 6 hours from transient initiation by the installation of a pressure regulated, portable compressed gas bottle to the pneumatic controls of the auxiliary spray valve. An auxiliary spray flow of 50 GPM was used to depressurize the RCS at a rate of approximately 0.4 psi/sec. The pressurizer level swelled to nearly 90% during this period. Should a faster depressurization rate be desired, the upper head vent may have to be opened to avoid filling the pressurizer. The SG 1 and 2 PORVs were controlled to maintain the RHR cut-in temperature of 350°F. At the end of the RCS depressurization period, the RCS pressure is 375 psia and the RHR system may be placed in service and the cooldown to cold shutdown conditions continued. Per Reference 3, the cooldown to cold shutdown temperature using one train of RHR has been studied before and is, therefore, not modeled in this analysis. The previous reference also notes that a time of less than 30 hours is required for one train of RHR to bring the plant to cold shutdown conditions.

4.3.6 Summary of the Results

A summary of the sequence of events for this TREAT analysis is provided in Table 4.3-2. Figures 4.3-1 through 4.3-6 show key parameter plots of the 4-hour hot standby period while Figures 4.3-7 through 4.3-16 provide plots of key variables for the entire transient.

RCS steady state natural circulation conditions were established soon after the RCP trip during the initial stage of the hot standby period. The results of the analysis indicate a natural circulation core flow of approximately 1000 lb/sec.

Boration for this scenario was achieved through the RCP seal injection paths. Note the alignment of the BAT at one (1) hour was key in the attainment of the cold shutdown boron requirements (i.e., a boron increase of 688 ppm). Based on the Diablo Canyon test results, the 1000 lb/sec magnitude of natural circulation flow is adequate to ensure boron mixing. During the natural circulation hot standby period, the RCS boron concentration increased by approximately 350 ppm. The cold shutdown boron concentration was attained at approximately 7 hours following transient initiation thereby demonstrating the attainment of the cold shutdown boron requirement with 15 gpm RCS makeup from the BAT. Also, approximately 6005 gal of the 36000 gal BAT was used during the boration to attain the cold shutdown boron requirement and a total of approximately 13000 gal of the 36000 gal BAT was injected to the RCS up to the time of RHR cut-in conditions.

The TREAT simulation shows that Shearon Harris can attain the RHR cut-in temperature via a natural circulation cooldown of 25°F/hr, and utilizing only 2 of 3 steam generators in approximately 10 hours. An additional hour is required to attain the RHR cut-in pressure. Calculations show that approximately 220000 gal of auxiliary feed water was needed throughout the natural circulation cooldown scenario to RHR initiation. However, this estimate was based on the analysis assumption of controlling the auxiliary feedwater to maintain secondary level near 50% during the cooldown and depressurization to RHR initiating conditions. Should the secondary level be controlled to near 66% for the cooldown and depressurization to RHR cut-in conditions (as advised in the present Shearon Harris natural circulation cooldown Emergency Operating Procedure), the amount of auxiliary feedwater needed has been conservatively calculated to be 230000 gal. Since the Shearon Harris Technical Specifications require a minimum of 270000 gal of water in the CST, there is an adequate Seismic 1 source of auxiliary feedwater to attain RHR initiating conditions. A small amount of additional water is expected to be needed during RHR operation to cold shutdown conditions, however the remainder of the CST and the backup water source (Emergency Service Water System) will be more than adequate to supply any additional water.

Shearon Harris is a Tcold upper head design plant; the upper head temperature is representative of the cold leg temperature during normal operations. This is a result of enhanced flow communication between the upper head and the annulus of the downcomer as opposed to limited flow for a Thot upper head design plant (i.e., Diablo Canyon). This enhanced flow communication will remain true for natural circulation conditions also. Therefore, the Shearon Harris reactor vessel upper head temperature should remain adequately subcooled throughout the natural circulation cooldown scenario. As expected, the reactor vessel upper head is predicted by TREAT to remain greater than 50°F subcooled during the entire natural circulation cooldown scenario. The upper head cooldown rate during the 25°F/hr RCS cooldown to RHR cut-in temperature is predicted to be approximately 17°F/hr. Although sufficient subcooling is expected, the upper head vent was opened prior to RCS depressurization to induce sufficient mixing of the upper head fluid to preclude steam voids during depressurization for the unlikely situation of a totally stratified upper head as postulated by the NRC consultant. At the end of the RCS depressurization, at least 50°F subcooling was still observed in the upper head. The TREAT simulation shows that the Shearon Harris plant can be depressurized to the RHR cut-in pressure of 375 psia using the auxiliary spray in approximately 0.8 hours.

For the TREAT simulation, several "boundary" flows were tabulated for the entire transient scenario. The head vent was operated 3 times during the hot standby period to control RCS pressure and pressurizer level plus once again prior to RCS depressurization to ensure good upper head fluid mixing; approximately 15000 lbs of fluid was relieved via this path during the 15 hour simulation. The seal return was estimated to be 3 GPM for this scenario thereby yielding an integrated seal return flow of 22725 lbs per loop. Finally, the pressurizer safety valve lifted twice during the hot standby period as the RCS pressure had increased to the 2500 psia safety valve setpoint; approximately 945 lbs of steam were relieved from the pressurizer to control the RCS pressure.

The TREAT simulation demonstrates that with the limited qualified equipment available for this worst-case scenario, the Shearon Harris plant can attain RHR initiation conditions (primary pressure=375 psia, Thot=350°F) in approximately 15 hours including a 4 hour hot standby period. The one train of RHR may then be initiated to bring the plant to cold shutdown conditions (Reference 3).

TABLE 4.3-1

SHEARON HARRIS PLANT DATA USED IN TREAT ANALYSIS

Reactor Coolant System:

Core Power	2785 MWt
Number of Coolant Loops and RCPs	3
RCS Thermal Design Flow Rate	30278 lbm/sec
Total RCS Volume (excluding pressurizer)	8040 ft^3
Core Tavg - 100% Power	588.8^OF
Tavg - No Load	557^OF
Upper Head Flow - 100% Power	520 lbm/sec
Initial Boron Concentration	1248 ppm

Pressurizer:

Volume	1442 ft^3 (including surge line)
Total Heater Capacity	1400 kW
Level - 100% Power	60.0%
Level - No Load	25%
Nominal Pressurizer Pressure	2235 psig
Pressurizer Heat Loss	25 BTU/sec
Number of PORVs	3
Rated Flow at 2335 psig Setpoint	58.3 lbm/sec/valve
Number of Safety Valves	3
Rated Flow at 2485 psig Setpoint	105.6 lbm/sec/valve

Reactor Protection System:

Low Compensated Pressurizer Pressure Trip	1960 psig
Low Pressurizer Pressure SI Actuation	1850 psig
Turbine Trip on Reactor Trip	Yes

Secondary System:

Number/Type of Steam Generators	3/U-Tube Model D4-1
Steam Pressure - 100% Power	949 psig
Volume, each SG	5949 ft^3
Narrow Range Level - 100% Power	66.0%
Steam Flow Rate/SG - 100% Power	1130 lbm/sec
Number of U-Tubes - Each SG	4578
Tube I.D.	0.0553 ft
Number ASD per Steam Line	1
Capacity ASD at 1106 psig	120.36 lbm/sec/valve
Number Safety Valves	5
Lowest to Highest Setpoints	1170-1230 psig
Flow Rate at 1170 psig	245.0 lbm/sec/valve

TABLE 4.3-2

SHEARON HARRIS NATURAL CIRCULATION COOLDOWN SEQUENCE OF EVENTS

Time (sec)	Event(s)
0	-Reactor Trip (Manual) -Turbine Trip -Loss of Offsite Power -All RCPs Trip -Main Feedwater Pumps Trip -Single Failure Assumption; SG 3 PORV Unavailable
0-End	-Seal Injection Maintained at Constant 15 GPM to RCS [(24-9) GPM]
60	-One (1) Motor-Driven Auxiliary Feedwater Pump Loaded onto Diesel; 400/3 GPM Flow to Three (3) SGs
300	-Terminate Aux Feed Flow to SG 3; SGs 1 and 2 divide 400 GPM Aux Feed Flow
3400-End	-Aux Feed Control to Maintain SG 1 and 2 Levels
3600	-Switch Seal Injection Pump Suction from 2000 ppm RWST to 7000 ppm BAT
3800	-SG 3 Dries Out
7200-10000	-RCS Pressure Maintained by Pressurizer Safety Valve(s)
10000-14400	-Upper Head Vent Operated 3 Times to Maintain PRZR Level Below 90% and RCS Pressure Above 1965 psia
14400	-End 4-Hour Hot Standby Period
14401	-Begin 25°F/hr Cooldown Using SG 1 and 2 PORVs
50920	-All Loop Temperatures Less Than RHR Cut-in of 350°F

TABLE 4.3-2 (cont)

Time (sec)	Event(s)
50920	-Open Upper Head Vent Prior to Depressurization to Assure Adequate Upper Head Mixing
51520	-Close Upper Head Vent -Initiate RCS Depress. via Pressurizer Auxiliary Spray (50 GPM)
54390	-Terminate Aux Spray; RCS Pressure at RHR Cut-in of 375 psia
54390 (15.1 hours)	-Transient Termination -One (1) Train RHR Placed in Service
≤ 45.1 hours	-RCS at or below Cold Shutdown Temperature of 200°F

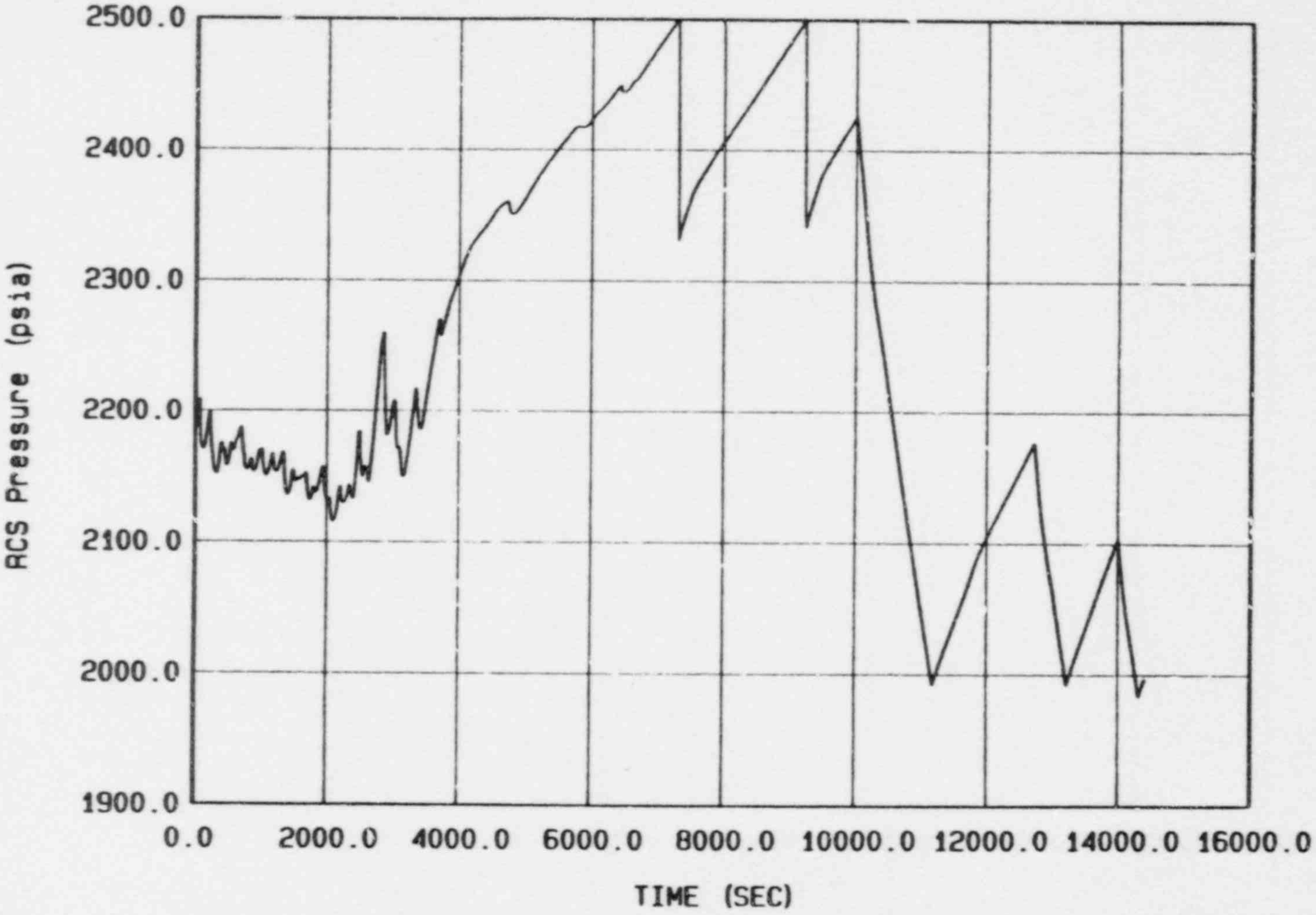

Figure 4.3-1 RCS Pressure for Hot Standby Period

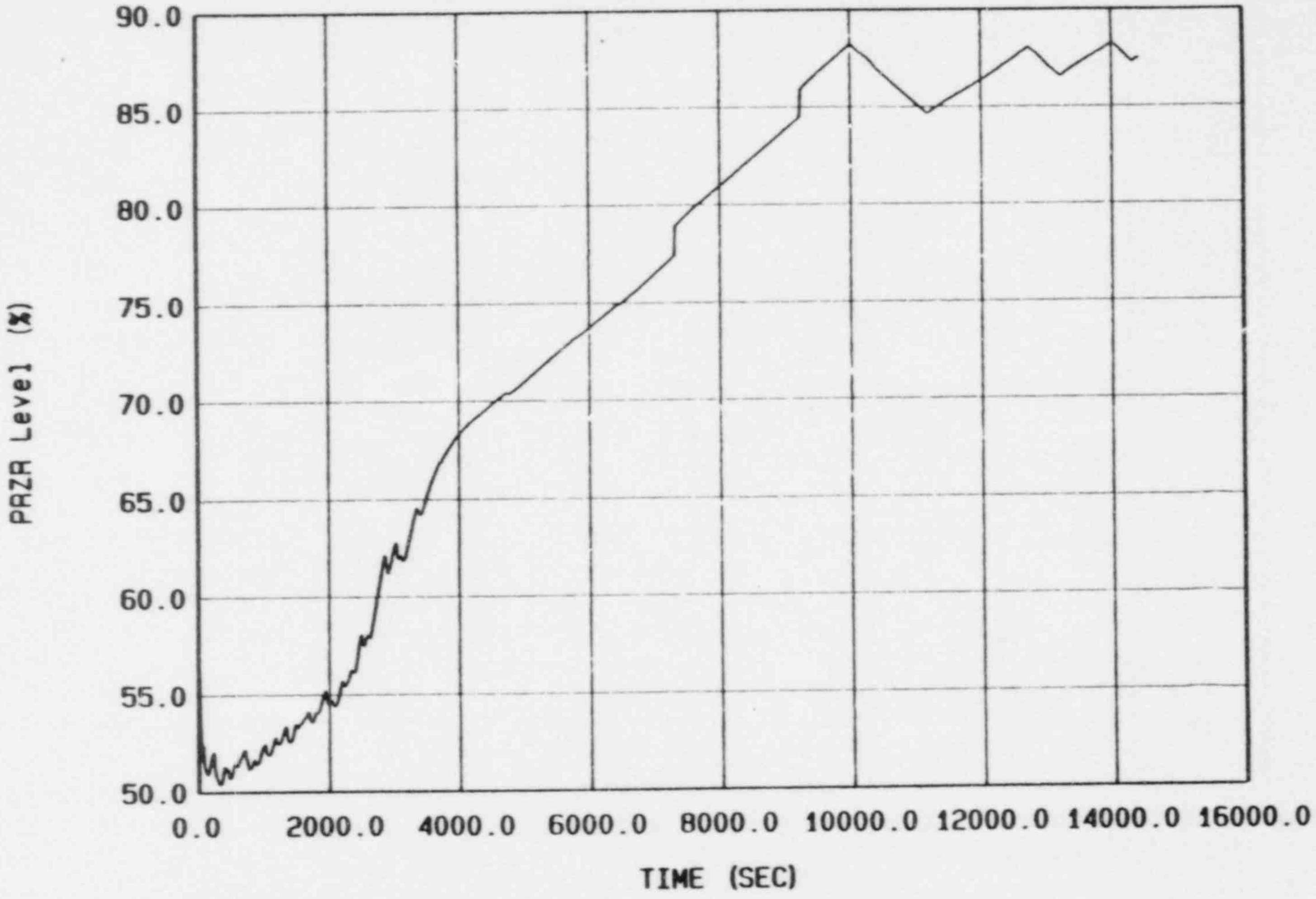

Figure 4.3-2 Pressurizer Level for Hot Standby Period

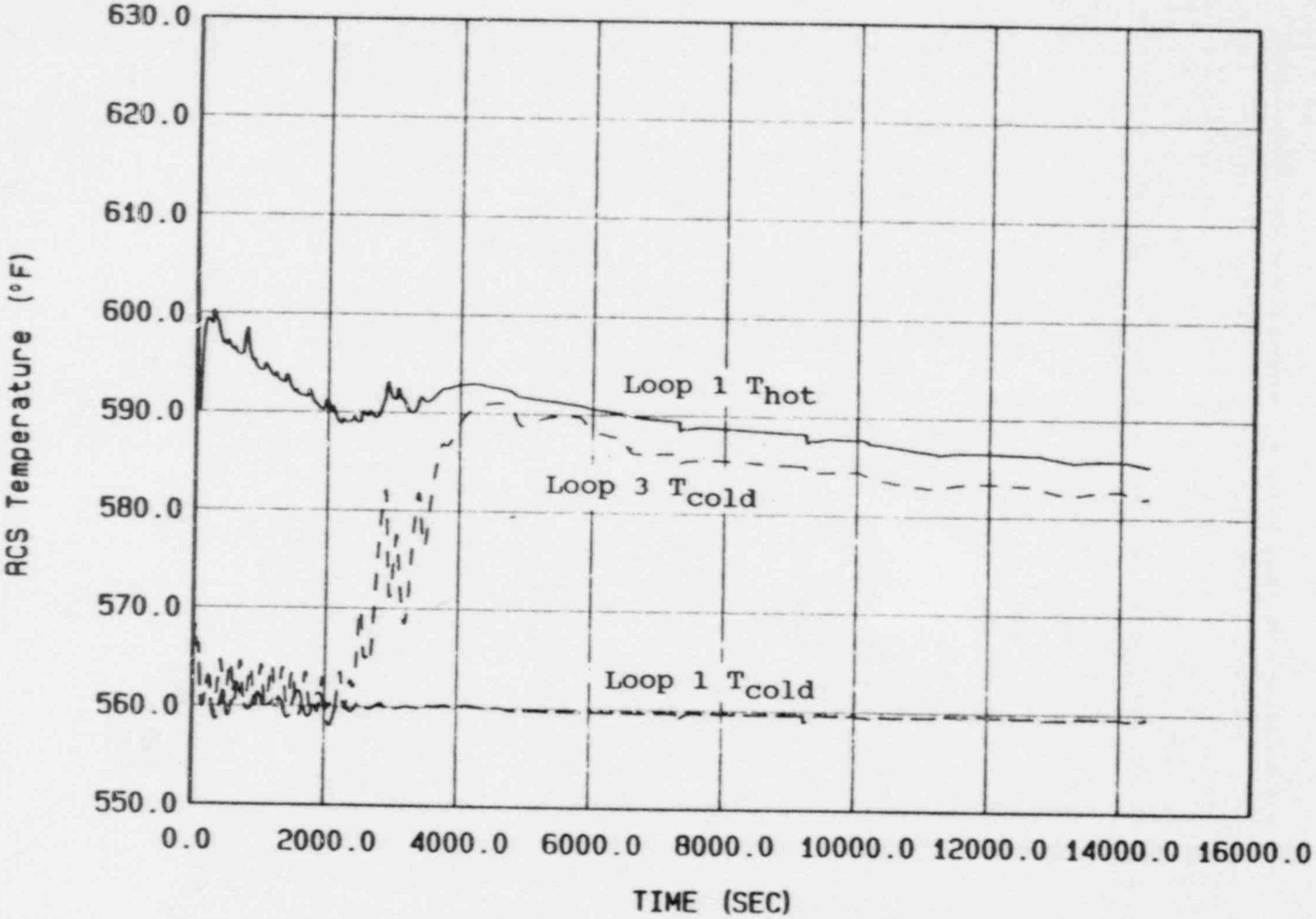

Figure 4.3-3 RCS Temperatures for Hot Standby Period

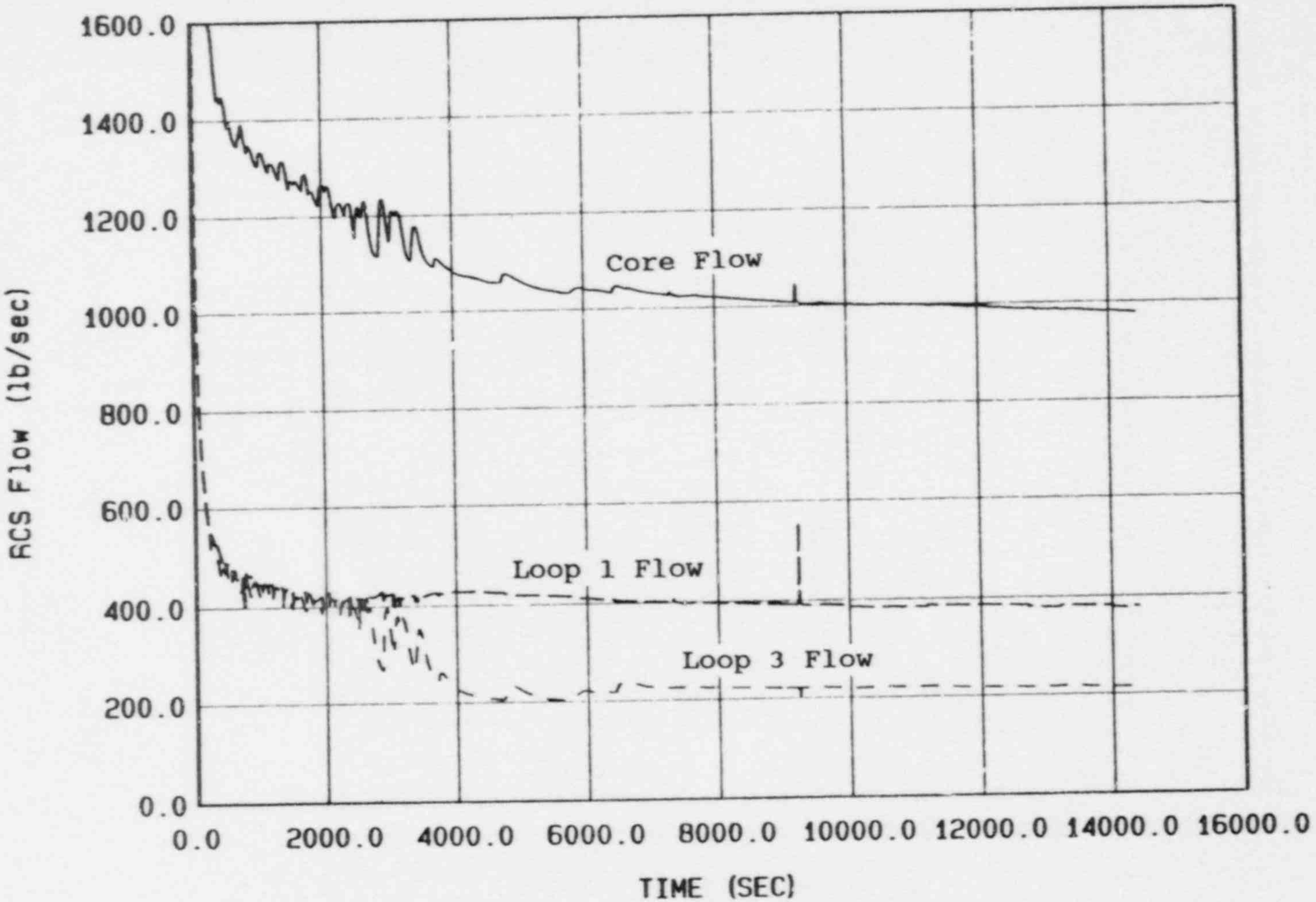

Figure 4.3-4 RCS Flows for Hot Standby Period

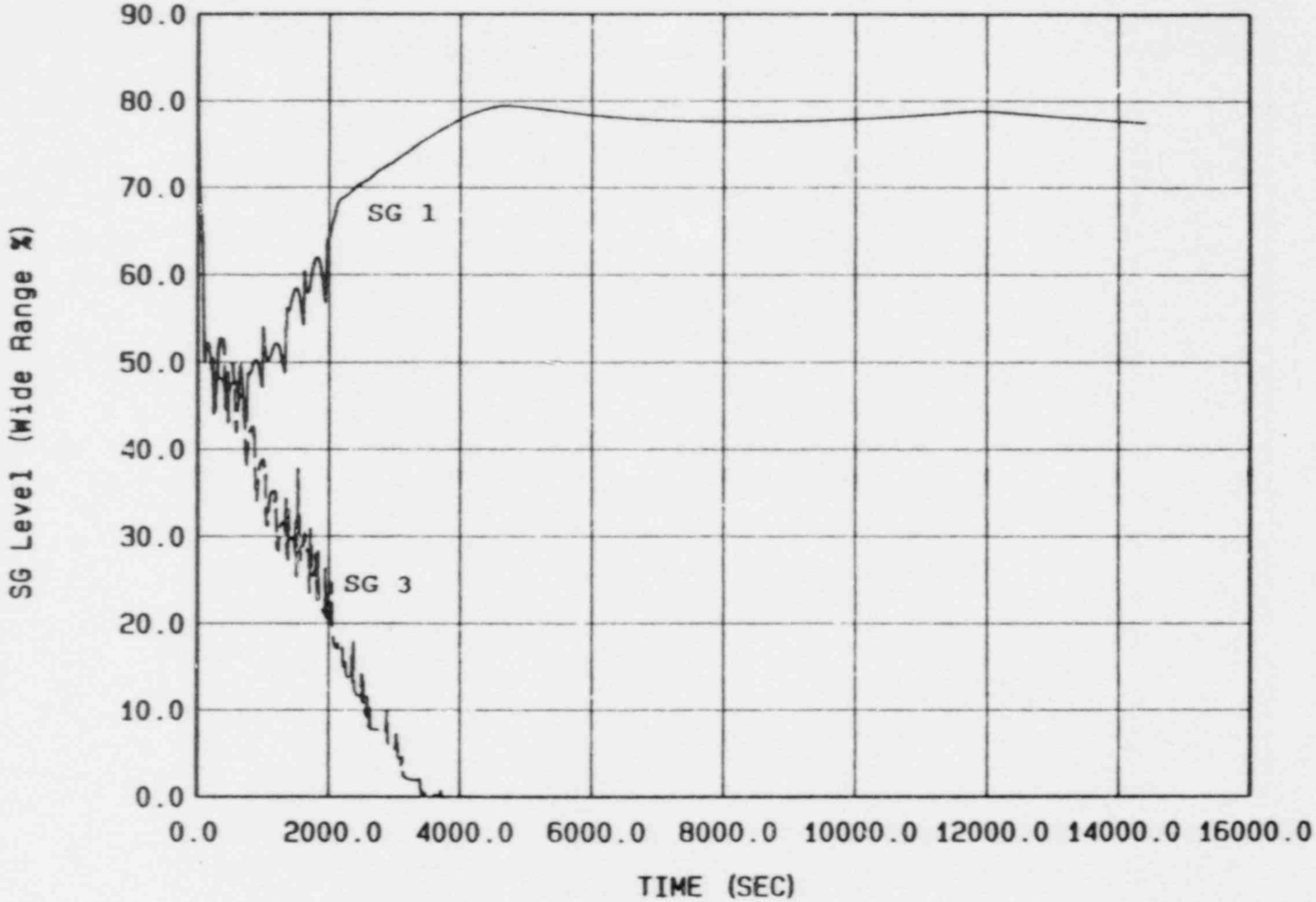

Figure 4.3-5 Steam Generator Levels for Hot Standby Period

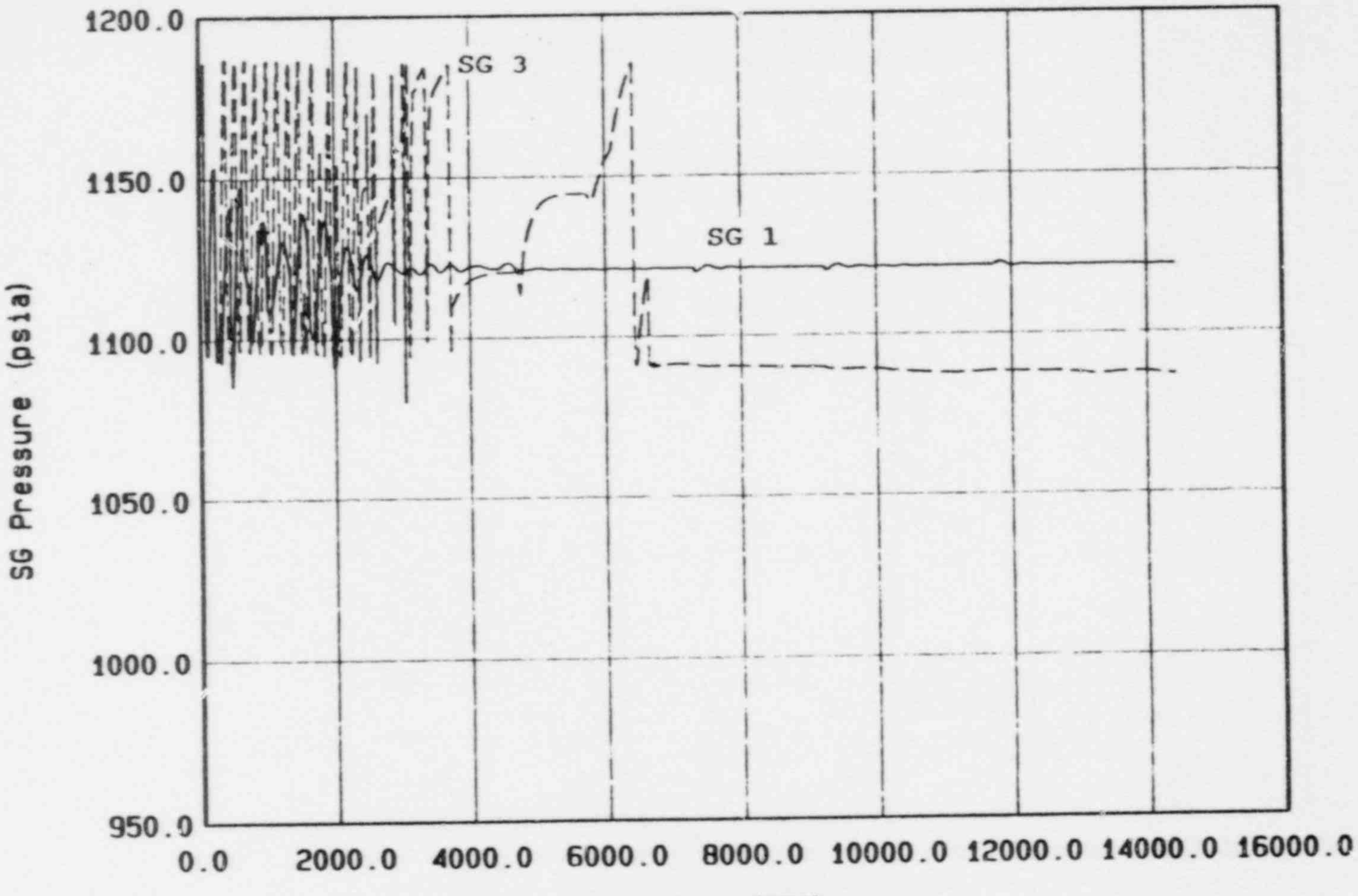

Figure 4.3-6 SG Pressures for Hot Standby Period

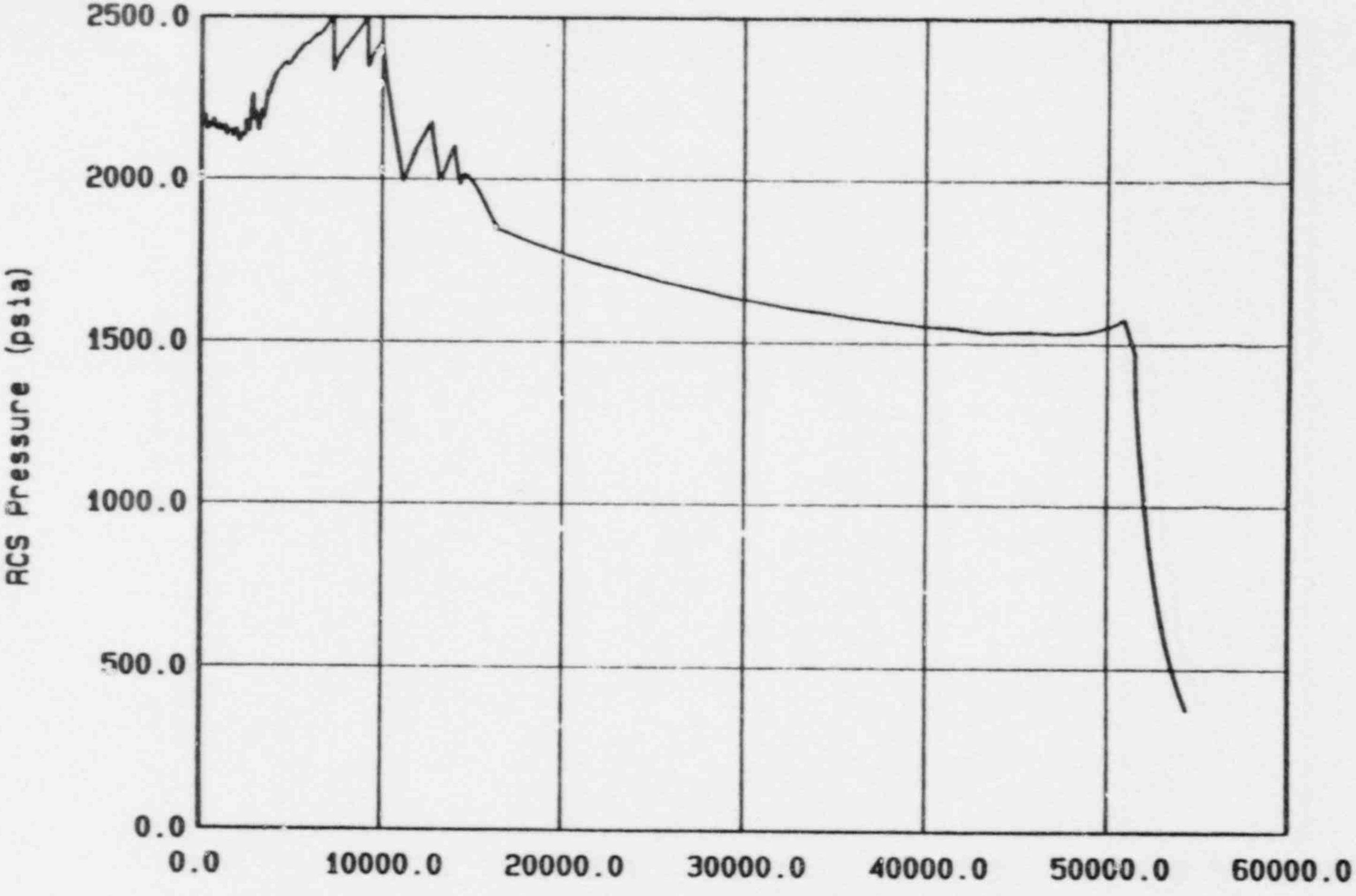

Figure 4.3-7 RCS Pressure

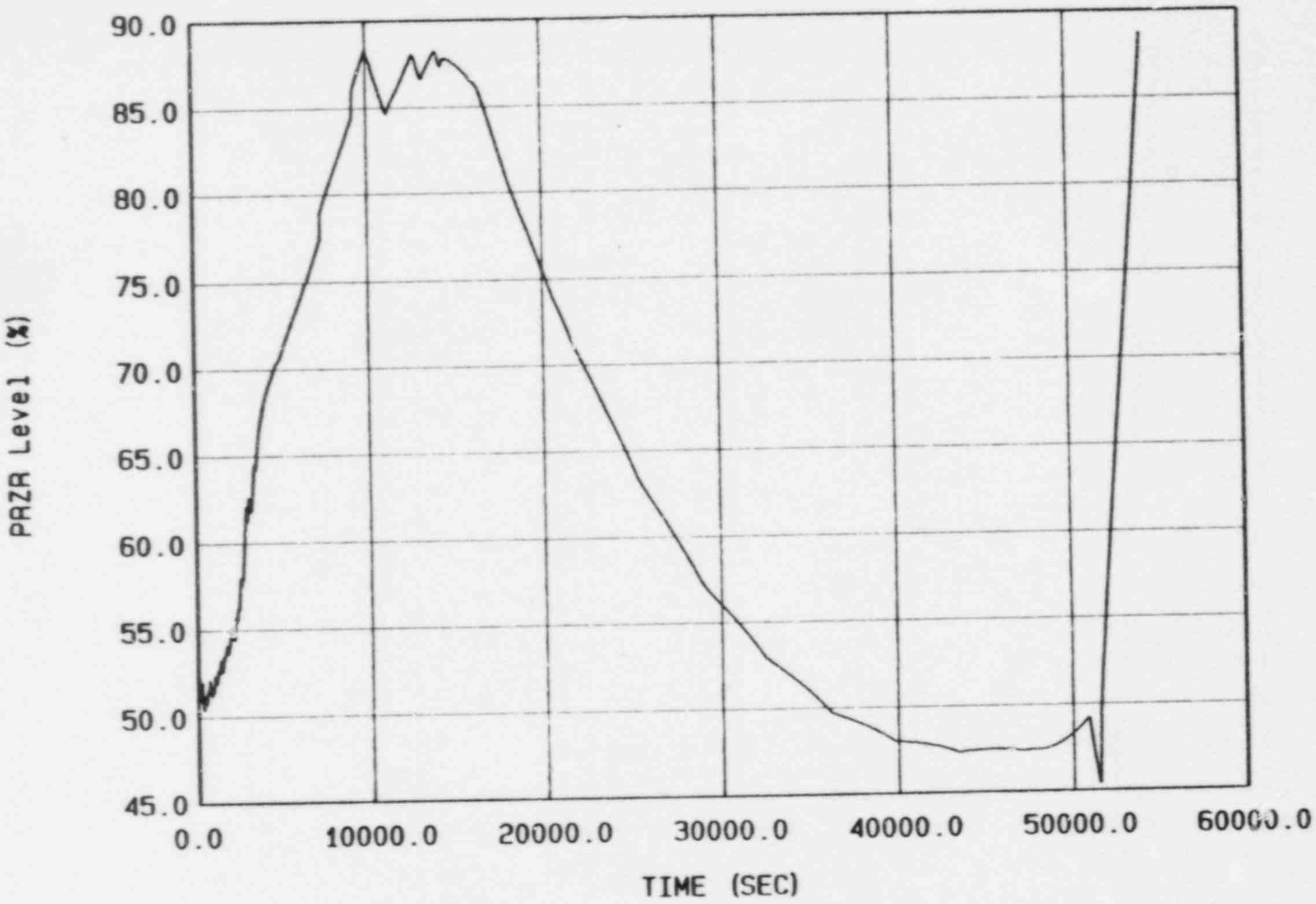

Figure 4.3-8 Pressurizer Level

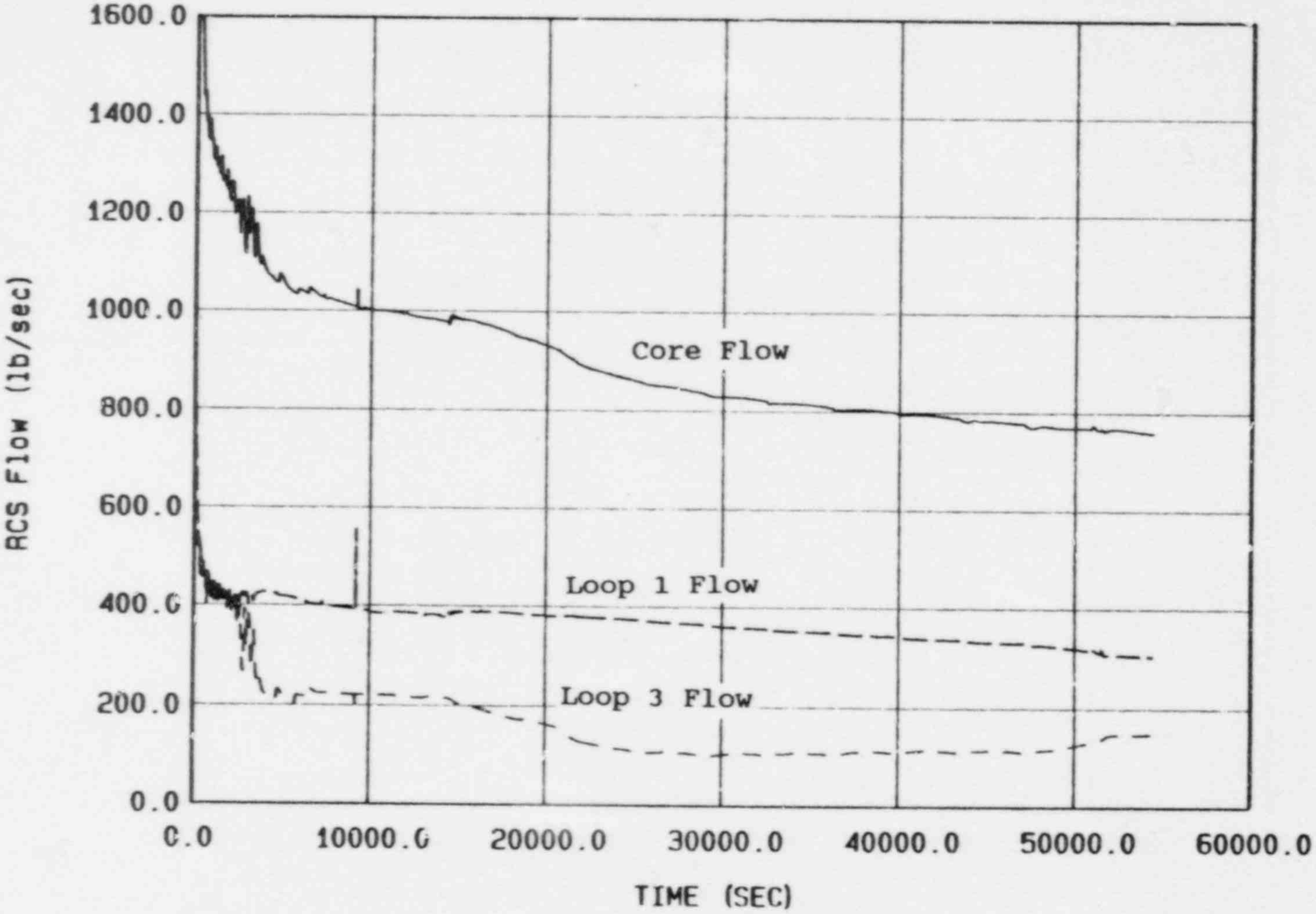

Figure 4.3-9 RCS Flows

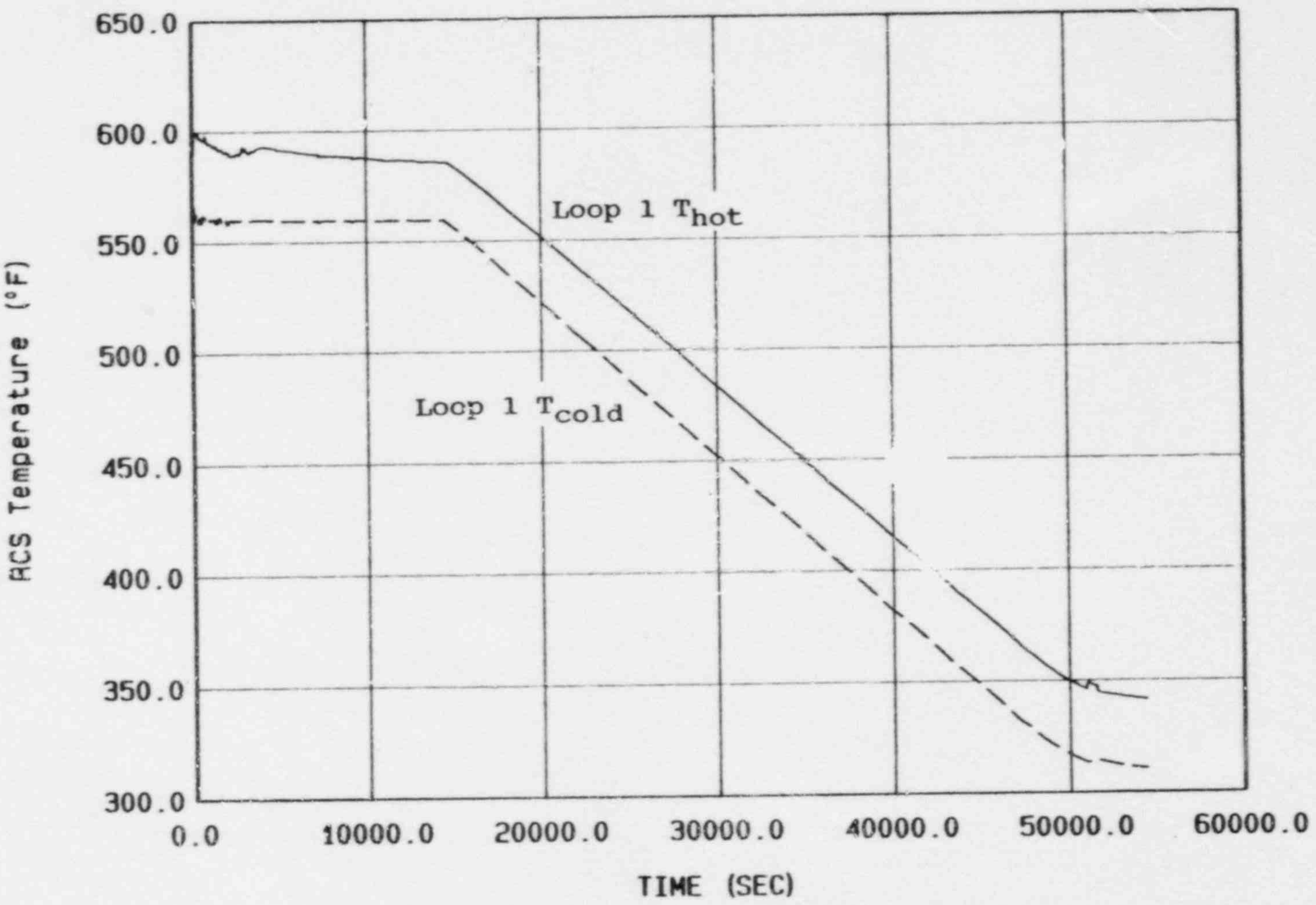

Figure 4.3-10 Loop 1 RCS Temperatures

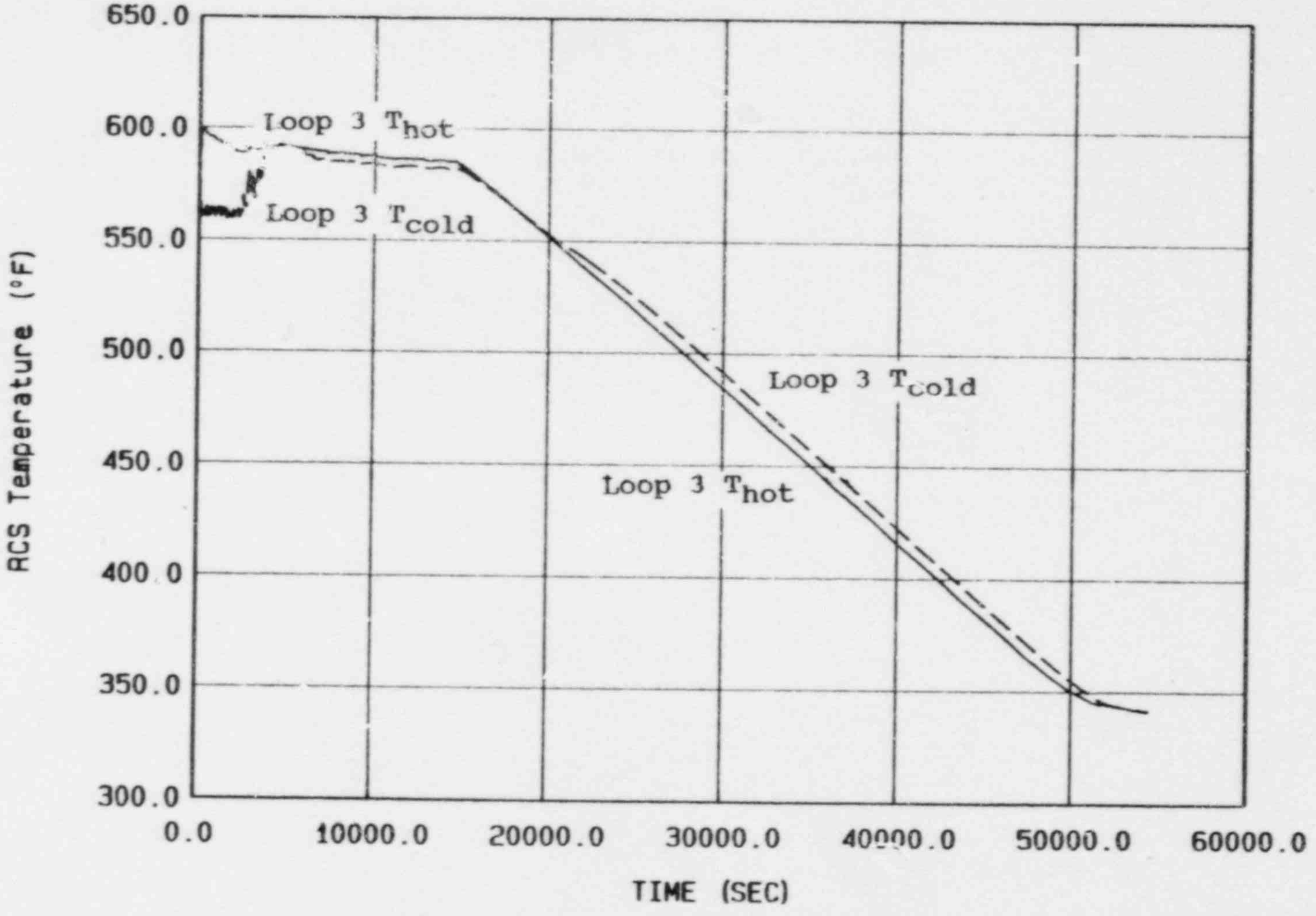

Figure 4.3-11 Loop 3 RCS Temperatures

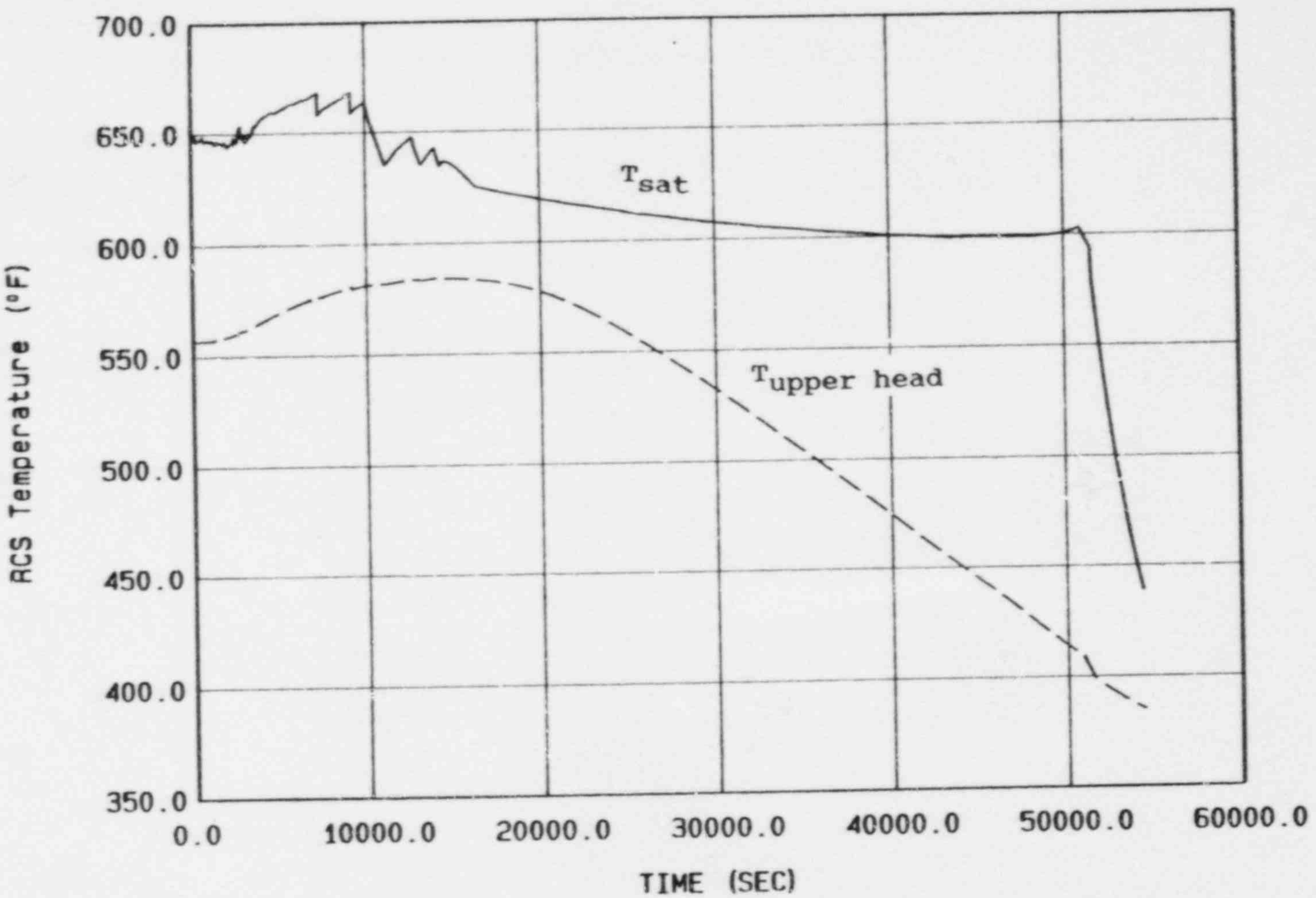

Figure 4.3-12 RCS Saturation Temp. vs. Upper Head Temp.

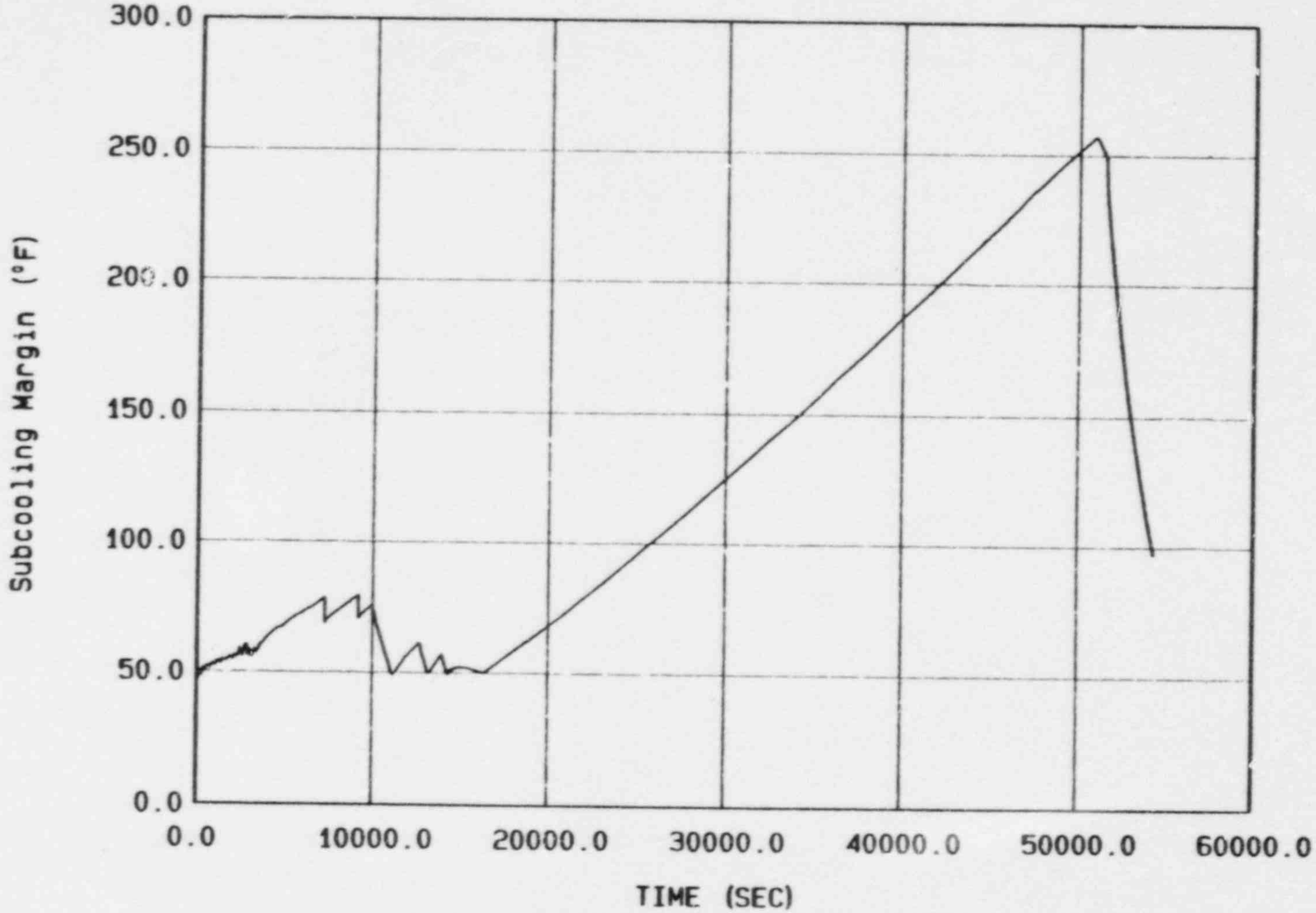

Figure 4.3-13 RCS Subcooling Margin

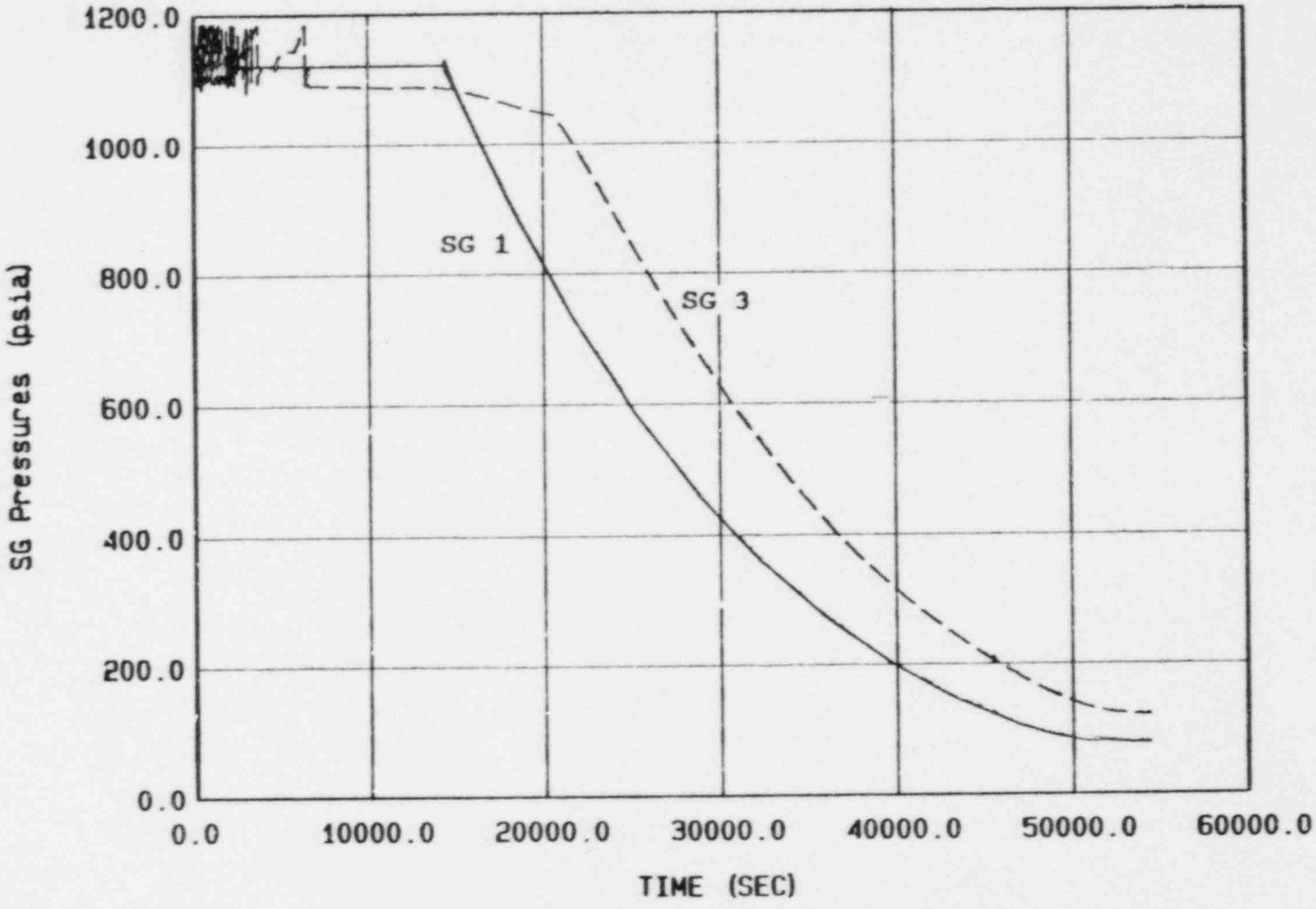

Figure 4.3-14 Steam Generator Pressures

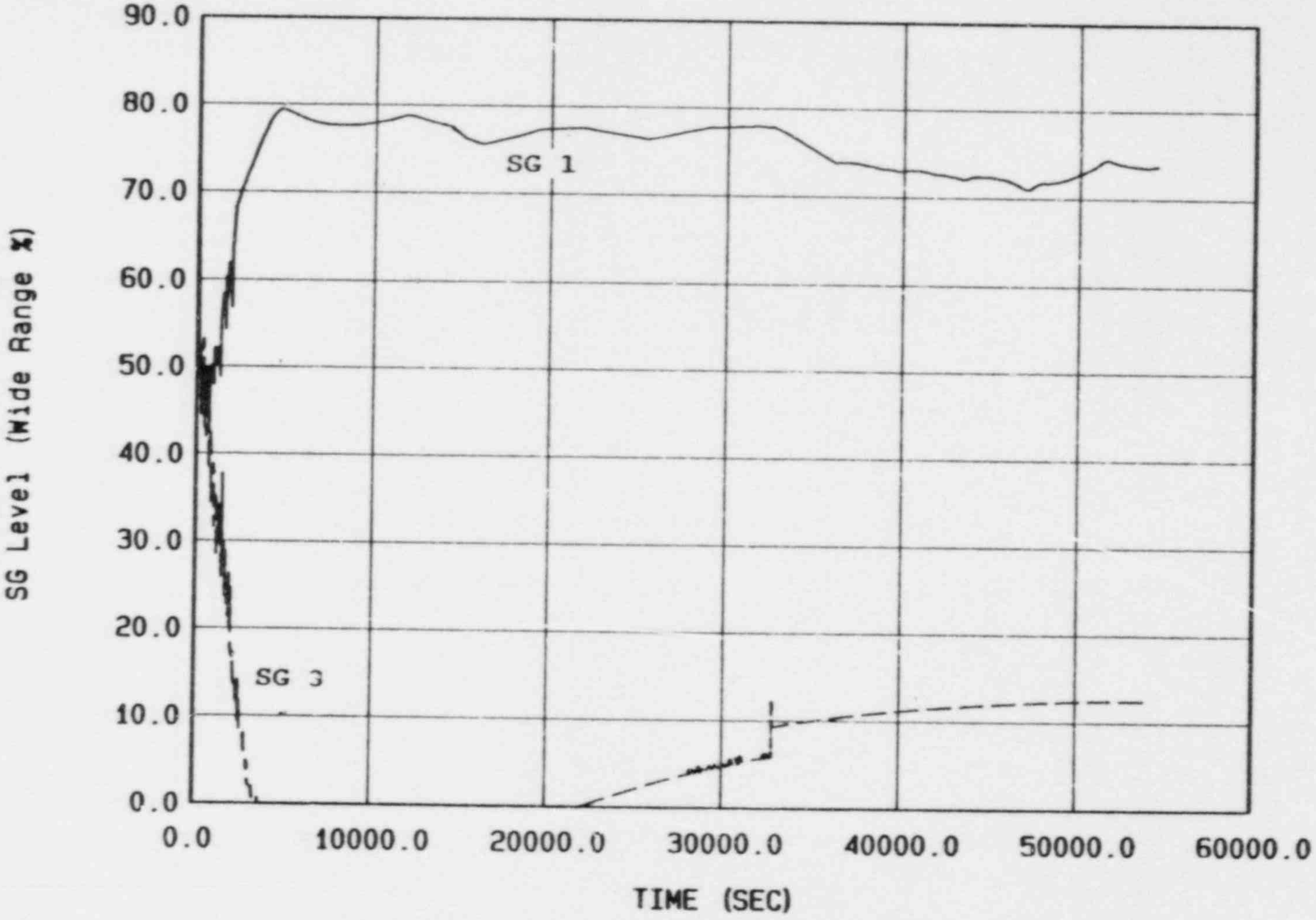

Figure 4.3-15 Steam Generator Levels

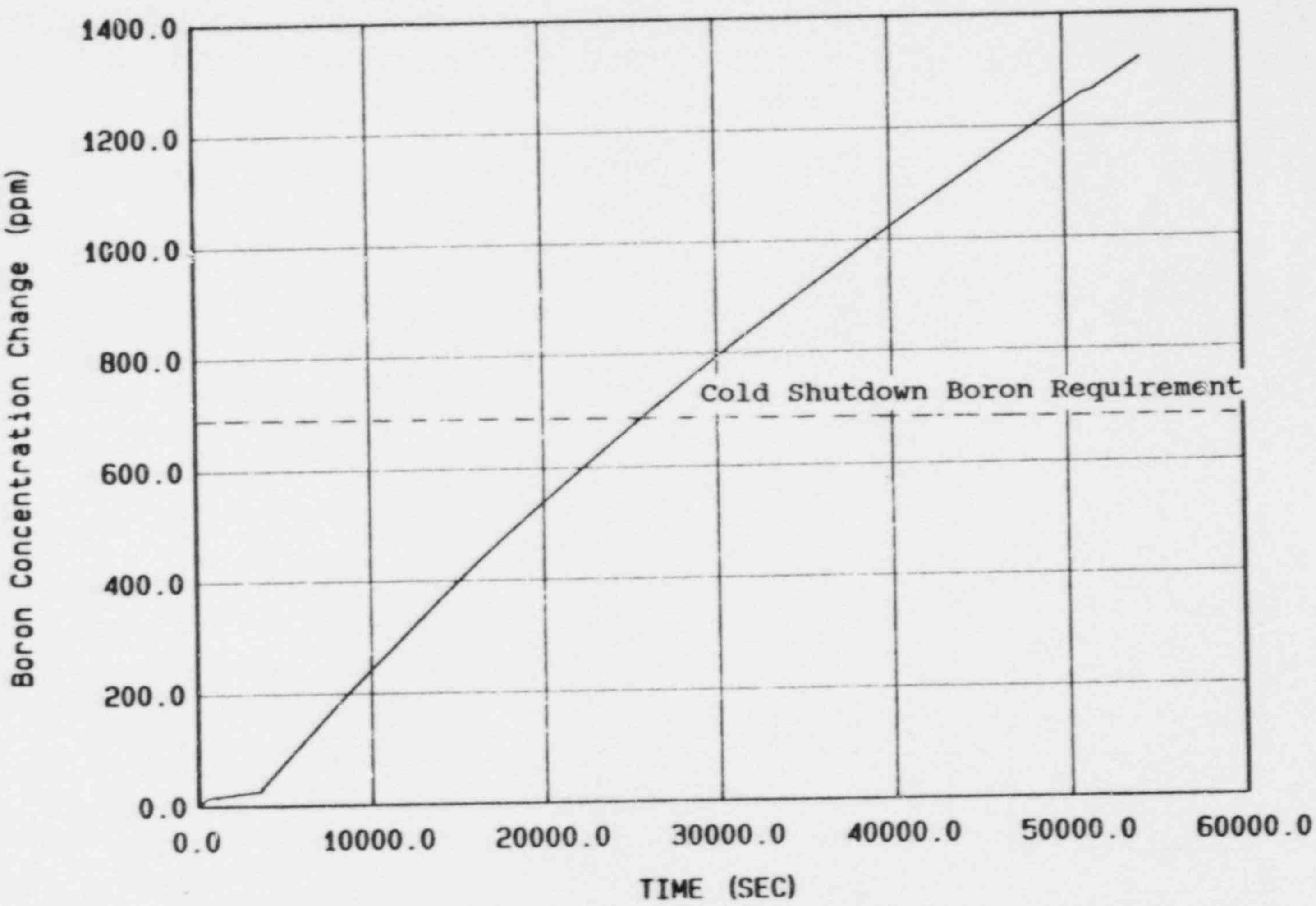

Figure 4.3-16 Core Boron Concentration Change

4.4 Comparison with Diablo Canyon Cooldown Transient Simulation

In their review of the Diablo Canyon natural circulation cooldown/depressurization/boron mixing test, the NRC consultant performed a simulation of a cold shutdown scenario for the Diablo Canyon plant using the RELAP5/MOD1 code (Reference 8). This simulation and subsequent report addressed some of the issues not directly addressed in the actual Diablo Canyon plant test. Table 4.4-1 provides a comparison of some of the relevant parameters between the Diablo Canyon RELAP5/MOD1 and the Shearon Harris TREAT simulations. The data for the Diablo Canyon calculations are abstracted form Table 5.1 of Reference 8. It should be noted that due to differences in plant design and equipment availability status, the two assumed cold shutdown scenarios are not identical. This contributes significantly to the observed differences which are outlined in Table 4.4-1. However, the following observations can be made via a comparison of the two simulations:

1) The predicted natural circulation flow rates per loop are similar.

2) Shearon Harris has significantly higher downcomer to upper head bypass flow as compared to Diablo Canyon. This should improve the cooling and mixing of fluid in the upper head. The TREAT simulation shows significant cooling of the upper head which is similar to the RELAP calculation. The NRC simulation assumed a long soak time to address potential upper head fluid stratification. For the Shearon Harris cold shutdown scenario, the head vent was operated to induce mixing and cooling of the upper head. As a consequence, no upper head soak time is required.

3) In both cases, it was demonstrated that the required cold shutdown boron concentration can be achieved prior to reaching RHR cut-in conditions. The time required to borate to cold shutdown boron concentration is longer for the Shearon Harris scenario. This is due to the difference in

RCS makeup (boration) capability, the source boron concentration and the required boron concentration change for the two plants. Diablo Canyon was able to utilize normal charging from a Boron Injection Tank 20000 ppm source while Shearon Harris was limited to 15 gpm seal injection makeup with the 7000 ppm (minimum) Boric Acid Tank as the source. Also, the Diablo Canyon simulation goal was a boron increase of 300 ppm while the Shearon Harris simulation conservatively used a boron increase of 688 ppm. Accordingly, the required RCS boron concentration increase took longer to attain for Shearon Harris.

4) The cooldown capability between the two plants (i.e., SG PORV capacity) is similar. The time to attain the RHR cut-in temperature for Shearon Harris was longer since the cooldown rate was slower (25°F/hr) as compared to the assumed Diablo Canyon cooldown rate (50°F/hr). However, for both cases sufficient auxiliary feedwater was available for the plant cool down.

5) Both simulations demonstrate the capability of the RCS to be depressurized to the RHR cut-in pressure in a relatively short time by using the pressurizer auxiliary spray system.

TABLE 4.4-1

KEY PARAMETERS FOR NATURAL CIRCULATION COOLDOWN COMPARISONS

Natural Circulation Condition/ Other Plant Parameters	Diablo Canyon RELAP Simulat.	Shearon Harris TREAT Simulat.
Natural Circulation Flow	1600-1200 lb/sec for 4 loops	1000-780 lb/sec for 3 loops
Decay Heat	ANS	ANS
Steady State Coolant Flow	36,918 lb/sec	30,278 lb/sec
Elevation Change Between Core and Steam Generators	58.3 ft	53.7 ft
Upper Head Bypass Flow	13 lb/sec	30 lb/sec
Steady State Bypass Flow	77 lb/sec	520 lb/sec
Pressure Differential Across Downcomer/Core/SG	8.9/24.6/31.4	6.7/21.1/29.7
Boron Injection Time	1 Hour	7 Hours
Injection Mode	Normal Charging	Seal Injection
Injection Flow Rate	150 gpm	15 gpm
Source Boron Concentration	21,000 ppm	7000 ppm
Desired Concentration Change	300 ppm	963 ppm
RCS Volume	12,080 ft^3	8040 ft^3
Boron Source Capacity	3,000 gallon	36,000 gallon
Cooldown Rate	50°F/hr	25°F/hr
SG PORV (ASDV) Capacity	1.53E06 lb/hr at 775 psig (106.3 lb/sec per valve)	120.4 lb/sec per valve at set pressure of 1106 psig
Auxiliary Spray Flow Rate	40 gpm	50 gpm
Depressurization Rate	8 psia/min	24 psia/min
Pressurizer Water Volume	900 ft^3	840 ft^3
Upper Head Cooling Time	43 Hours w/no CRDM	See Sect. 4.3.3
Cooling Water	360,000 gal	220,000 + gal
CST Capacity	400,000 gal	415,000 gal (min) 270,000 gal

5.0 CONCLUSIONS

It has been demonstrated through a qualitative systems and equipment comparison that the results of the Diablo Canyon Natural Circulation/Boron Mixing/Cooldown Test are applicable to Shearon Harris. It has also been shown through a TREAT simulation of the worst-case cold shutdown scenario that Shearon Harris can achieve cold shutdown conditions under the requirements established in BTP RSB 5-1. Shearon Harris meets the functional requirements of of BTP RSB 5-1 by demonstrating via comparison and simulation that:

- Sufficient similarities exist with the W PWR Diablo Canyon plant such that the favorable results of the Diablo Canyon Natural Circulation Boron Mixing/Cooldown Test apply to Shearon Harris.

- Adequate natural circulation was established following reactor trip and RCP coastdown and the plant was capable of removing decay heat by natural circulation using only qualified equipment.

- Boron mixing during natural circulation conditions was sufficient to attain the cold shutdown boron requirement prior to reaching RHR initiating conditions.

- The RCS can be cooled to the RHR system initiating conditions while maintaining adequate subcooling during natural circulation using only qualified equipment within a reasonable period of time.

- The Shearon Harris Tcold upper head design in conjunction with adequate precautions ensure that the reactor vessel upper head will not void during RCS cooldown and depressurization to RHR initiating conditions.

- A sufficient supply of qualified secondary cooling water was available to support the 4 hour hot standby period, RCS cooldown and depressurization to RHR initiating conditions.

- One motor-driven auxiliary feedwater pump was sufficient to supply the cooling water for adequate decay heat removal throughout the transient.

- Sufficient steam generator PORV capacity was available to cool down the RCS to the RHR cut-in temperature.

It is concluded that the Shearon Harris plant satisfies the test requirement of BTP RSB 5-1 based upon the favorable qualitative comparison with the Diablo Canyon test results and the supporting quantitative thermal/hydraulic analysis of the Shearon Harris cold shutdown scenario. Therefore, natural circulation cooldown testing is not required at the Shearon Harris plant.

6.0 REFERENCES

1. Branch Technical Position RSB 5-1, Design Requirements for Decay Heat Removal Systems, Revision 2, July 1981.

2. WCAP-11086 (Proprietary), Diablo Canyon Units 1 and 2 Natural Circulation/Boron Mixing/Cooldown Test Final Post Test Report, March, 1986.

3. Shearon Harris FSAR Section 5.4.7, Residual Heat Removal System.

4. Westinghouse Owners Group, Emergency Response Guidelines, Revision 1A, ES-0.2, "Natural Circulation Cooldown".

5. WCAP-11232 (Proprietary) and WCAP-11297 (Non-Proprietary), Comparison of the TREAT and NOTRUMP Small Break LOCA Transient Results, September, 1986.

6. Westinghouse Report "South Texas Project Fire Hazards Analyses and Cold Shutdown Report", June, 1986.

7. Tajbakhsh, A. E., et. al., A Benchmark Simulation of the Diablo Canyon Unit-1 Natural Circulation Test With a Plant Analyzer, Paper Presented at ASME Annual Winter Meeting, December, 1987.

8. "Technical Evaluation Report for Diablo Canyon Natural Circulation, Boron Mixing, and Cooldown Test", J. H. Jo, K. R. Perkins and N. Caralina, Brookhaven National Laboratory Technical Report A-3843, December 23, 1986.