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NATURAL CIRCULATION, BORON MIXING, AND COOLDOWN TEST

FINAL POST-TEST REPORT

MARCH 1986

PACIFIC GAS AND ELECTRIC COMPANY
Diablo Canyon Power Plant
Units 1 and 2

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP 11095

DIABLO CANYON
UNITS 1 AND 2
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FINAL POST TEST REPORT

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PREFACE

This report presents the results of the natural circulation, boron mixing and cooldown test performed by PGandE at the Diablo Canyon Unit 1 Plant in March 1985. The preparer of the report, the Westinghouse Corporation, has deemed the following portions of this report commercially sensitive.

Section: 5.2 DEFINITION OF COLD SHUTDOWN
OPERATIONS STRATEGY

Figures: 5-1, 5-2, 5-3

As such, these items are not included. A report containing these deleted items has been published and is identified by the Westinghouse proprietary document number WCAP 11086.

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EXECUTIVE SUMMARY

Following the Hosgri Seismic Evaluation, PG and E performed an evaluation of the systems and equipment required to achieve and maintain hot standby of the DCPP units following a safe shutdown earthquake. As part of the evaluation, PGandE committed to perform a natural circulation, boron mixing, and cooldown test prior to commercial operation of Unit 1.

A preliminary procedure was developed and submitted to the NRC in 1979 for their review. Following their review, a final procedure was developed to include a Pre-Test and Post-Test Report. The basic objectives of the test were to (1) establish natural circulation using core decay heat, (2) confirm that borated water added to the RCS prior to the cooldown could be adequately mixed with the RCS during the low flow conditions characteristic of natural circulation, (3) maintain hot standby conditions under natural circulation for at least four hours, (4) cooldown and depressurize the RCS from hot standby to cold shutdown, and (5) obtain cooldown rates for both the reactor vessel upper head metal and RCS bulk water.

On March 28 and 29, 1985, this test was performed at DCPP Unit 1. The test consisted of tripping the reactor from 100 percent power, stabilizing at hot shutdown for four hours, tripping the RCPs to initiate natural circulation and boron mixing, cooling down and depressurizing from hot standby to the point of initiation of the RHR system, and cooldown to cold shutdown conditions. The test was successfully performed and all objectives and acceptance criteria were met. Comparison of test results with pre-test predictions showed good agreement.

Based upon the results from the natural circulation, boron mixing and cooldown test, operator strategies were developed to show that the reactor could be brought to cold shutdown using only seismically qualified equipment. These strategies are discussed for a sample scenario. The effect of a single active failure of seismically qualified equipment on the ability to take the reactor to cold shutdown was also analyzed. It was concluded that there is no credible single active failure that would preclude the plant from achieving a condition of cold shutdown following a postulated seismic event.

The results of the natural circulation, boron mixing and cooldown test performed on DCPP Unit 1 conclusively demonstrated that the plant can be taken to a cold shutdown condition following a safe shutdown earthquake. This conclusion is fully applicable to DCPP Unit 2 as well.

TABLE OF CONTENTS

Page

1.0 INTRODUCTION

2.0 TEST PURPOSE AND OBJECTIVES

3.0 TEST DESCRIPTION

4.0 INTERPRETATION AND ANALYSIS OF TEST RESULTS

4.5 REACTOR VESSEL UPPER HEAD METAL AND FLUID COOLDOWN

4.5.1 DESCRIPTION

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 BACKGROUND

Circulation of reactor coolant is a key function in placing and maintaining the Diablo Canyon Power Plant in the hot standby (safe shutdown) operational mode and in the operations to take the plant to cold shutdown. During these plant operations, at least one reactor coolant pump (RCP) is normally in operation to ensure forced circulation of reactor coolant for boron mixing and 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 trip the reactor and the plant will automatically be placed in the hot standby operational mode. The plant is designed to be maintained in this operational mode until forced circulation is restored and normal plant operations can be resumed. Under this plant condition, circulation of reactor coolant is provided by natural circulation 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 steam generator atmospheric power operated relief valves, or the safety valves if needed.

Although hot standby remains the design and licensing safe shutdown basis for the Diablo Canyon Power Plant, following the Hosgri Seismic Evaluation, Pacific Gas and Electric Company (PG and E) performed an evaluation of the systems and equipment required to achieve and maintain hot standby and cold shutdown of Diablo Canyon Power Plant Units 1 and 2 following a safe shutdown earthquake. As part of this evaluation, PG and E elected to perform a natural circulation, boron mixing, and cooldown test to demonstrate the plant's capability to achieve cold shutdown conditions following a safe shutdown earthquake.

A Diablo Canyon Unit 1 Test Procedure was developed by PG and E for the subject test. A preliminary draft of this procedure was reviewed by the NRC Reactor Systems Branch in 1979 relative to the requirements of Branch Technical Position RSB 5-1 "Design Requirements for the Residual Heat Removal System." NRC comments resulting from this review were transmitted to PG and E in October, 1979. Following receipt of the NRC letter, the test procedure was modified to address NRC comments and to include a Pre-Test and Post-Test Report. A Pre-Test Report was subsequently developed to outline the bases, objectives and evaluation/acceptance criteria for the test. The Pre-Test Report and the test procedure were the subject of several subsequent NRC meetings and both documents were revised to resolve comments on the subject test. The final versions of these documents that are applicable to the subject test are Revision 3 to Test Procedure No. 42.7, Natural Circulation Boron Mixing Test and Revision 2 to the Diablo Canyon Natural Circulation Pre-Test Report.

The Diablo Canyon natural circulation, boron mixing and cooldown test was performed at Unit 1 on March 28 and 29, 1985, beginning with the trip of Unit 1 from hot full power conditions at 2130 hours on March 28 and continuing until 2245 hours on March 29 when cold shutdown conditions were achieved.

On August 12, 1985, PG and E submitted the preliminary post test report which provided an initial assessment of the test results and in general terms demonstrated that the test objectives were satisfied and that the acceptance criteria had been met.

This final post-test report presents a more detailed description and analysis of the test results and satisfies Pacific Gas and Electric Company's commitments with respect to Branch Technical Position RSB 5-1.

1.2 REPORT STRUCTURE

This test report is structured to describe the test, summarize the test results, and describe the applicability of the test results to performing a natural circulation cooldown of the Diablo Canyon Power Plant using only seismically qualified systems and equipment.

The test purpose and objectives are provided in Section 2.0 of the report.

Section 3.0 provides a general description of the test and Section 4.0 provides interpretation and analysis of the test results. For each of the phenomena, the test results are described and compared with pretest predictions. Evaluation of any differences in the actual and predicted results is presented, and the applicability of the test results to cold shutdown operations is described.

Section 5.0 addresses the definition of an appropriate cold shutdown strategy, considering the test results and existing procedures and technical specification requirements.

Section 6.0 presents a single active failure evaluation of the cold shutdown scenario presented in Section 5.0

Section 7.0 presents the conclusions of the report.

2.0 TEST PURPOSE AND OBJECTIVES

2.1 PURPOSE

The purpose of the test was to investigate the phenomena associated with plant cooldown following a postulated seismic event. These phenomena and associated objectives are summarized below:

- <u>Natural Circulation</u>

  Establish natural circulation conditions using core decay heat.

- <u>Boron Mixing</u>

  Confirm that adequate mixing of borated water added to the reactor coolant system prior to cooldown can be achieved under natural circulation conditions.

  Verify that the RCS can be borated to the cold shutdown concentration.

- <u>Reactor Coolant System Cooldown</u>

  Maintain Hot Standby conditions under natural circulation conditions for at least 4 hours.

  Determine if cooldown of the RCS from normal hot standby to cold shutdown conditions can be accomplished using only seismically qualified equipment.

Verify that adequate water volume is available in the condensate storage tank to cool down the plant.

- Reactor Coolant System Depressurization

  Determine if depressurization of the RCS from normal hot standby to cold shutdown conditions can be accomplished using only seismically qualified equipment.

  Evaluate the effect of a charging valve failure during the use of auxiliary spray for depressurization.

- Reactor Vessel Upper Head Cooldown

  Obtain reactor vessel head cooldown rates (both metal and water).

2.2 ACCEPTANCE CRITERIA

The acceptance criteria for each phase of the test are described below:

- Natural Circulation

  The natural circulation evaluation was to verify that RCS natural circulation flow could be established, thereby permitting boron mixing and RCS cooldown/depressurization to RHR system initiation conditions.

This phase had no specific acceptance criteria since it was to be evaluated based on the results of the boron mixing and cooldown/depressurization phases of the natural circulation cooldown test.

- Boron Mixing

The boron mixing evaluation was to demonstrate adequate boron mixing under natural circulation conditions when highly borated water at low temperatures and low flow rates (relative to RCS temperature and flow rate) is injected into the RCS, and to evaluate the time delay associated with boron mixing under these conditions.

The acceptance criterion for this phase of the 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.

- Reactor Coolant System Cooldown

The cooldown portion of the test was to demonstrate the capability to cool down the RCS to RHR system initiation conditions using all four steam generators for natural circulation, to evaluate reactor vessel head and steam generator cooling under these conditions and to demonstrate the capability to cool down the RCS to cold shutdown conditions once the RHR system had been placed in service.

The acceptance criteria for the cooldown portion of the test were that:

- Control plant cooldown under natural circulation conditions to be within Technical Specification limits
- Maintain temperature of all active portions of the RCS uniformly within ±100°F of the core average exit thermocouple temperature
- Maintain the temperature of the steam generators and reactor vessel upper head to <450°F when the core average exit thermocouple temperature is 350°F
- Assure that the RHR system is capable of cooling down the RCS to cold shutdown conditions.

o Reactor Coolant System Depressurization

The depressurization portion of the test was intended to demonstrate the capability to significantly reduce pressure in the RCS under natural circulation conditions. The acceptance criterion was that pressure in the RCS should be reduced lower than RHR system initiation pressure (390 psig).

- <u>Reactor Vessel Upper Head Cooldown</u>

This part of the test was intended to monitor the upper head bulk water temperature and the upper head vessel metal temperature.

The acceptance criterion for the upper head bulk water temperature was that a 50°F subcooling margin be maintained during cooldown and depressurization. A 100°F difference between the core average exit temperature and the upper head bulk water temperature was imposed as an administrative limit. Since there was no measured data to accurately predict the behavior of the upper head metal during cooldown under natural circulation conditions, an administrative limit was established to maintain a temperature increase in the upper head metal over the core average exit temperature to less than 100°F.

3.0 TEST DESCRIPTION

3.1 GENERAL DESCRIPTION

On March 28 and 29, 1985, Diablo Canyon Unit 1 conducted a natural circulation, boron mixing, and cooldown test. The unit was tripped from full power conditions by manually initiating a turbine trip at 2130 hours on March 28. The test continued until 2245 hours on March 29 when RCS temperatures were reduced below 200°F and the plant was placed in the cold shutdown operational mode. 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 shutdown 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 were performed.

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

The test began by initiating a plant trip at 2130 hours on March 28. The plant was subsequently maintained at hot standby conditions for the natural circulation and boron mixing test phases. At 0028 on March 29, the operators initiated the natural circulation portion of the test by tripping the reactor coolant pumps. Natural circulation conditions were verified twenty minutes later. The boron mixing portion of the test was initiated at 0052 by injecting the contents of the Boron Injection Tank (BIT). The flow rate into the reactor coolant system was approximately 150 gpm. Boron Injection Tank flow was terminated at 0113 hours. Natural circulation under hot standby conditions was maintained for more than four hours and was terminated at 0450 hours, when the next test phase began.

At 0450 hours, the cooldown/depressurization portion of the test was initiated. The tests were conducted by isolating letdown and cooling down with the 10% atmospheric steam dump (ASD) valves. The cooldown rate was controlled at approximately 20°F/hour. Letdown was occasionally used to control pressurizer level, which increased due to the continuous RCP seal injection flow. The cooldown/depressurization testing was continued until RHR initiation conditions were achieved at 1805 hours.

The final portion of the test was initiated at 1805 hours when RHR system operation was initiated. Cooldown to cold shutdown conditions using the RHR system continued until 2245 hours when cold shutdown conditions were achieved.

Figures 3-1 and 3-2 illustrate the location of the reactor vessel head magnetic thermocouples and the location of the incore thermocouples used for test temperature indications.

3.2 CHRONOLOGY OF EVENTS AND OPERATOR ACTIONS

The significant events and major operator actions performed during the Diablo Canyon Test are summarized in Table 3-1.

TABLE 3-1

CHRONOLOGY OF EVENTS AND OPERATOR ACTIONS

TIME	EVENT/ACTION
HOT STANDBY (FORCED CIRCULATION)	
2130:	Plant operating at 100% power. Operators initiated the plant trip from 100% power by manually initiating a turbine trip.
2140:	Reactor was shut down and plant was in hot standby conditions. Operators were securing the plant secondary side. Relief valves on the #2 heaters had lifted. Operators were attempting to reseat the reliefs and waiting for the steam generator levels to return to 44% narrow range level.
2150:	Operators have begun their Class 1 equipment alignment per Test Procedure 42.7.
2230:	Operators have attempted to relatch the main turbine to minimize steam leakage on the secondary side.
2300:	Steam generator levels were at 44% narrow range level.
2330:	Main turbine was relatched. Vital power breaker for pressurizer heater 1-3 did not reenergize.
2400:	Vital power breaker for pressurizer heater 1-3 had a blown fuse. Pressurizer heater 1-3 was aligned to vital power.
0015:	All Class 1 equipment was aligned. Total RCP seal injection flow was approximately 50 gpm.
HOT STANDBY (NATURAL CIRCULATION AND BORON MIXING)	
0028:	Operators begin tripping the reactor coolant pumps.
0048:	Natural circulation conditions have been verified.
0052:	Contents of the Boron Injection Tank (BIT) injected into RCS. Flow rate was approximately 150 gpm.

TABLE 3-1 (Continued)

TIME	EVENT/ACTION
0058:	Power operated relief valve (PORV), PCV-456, opened to relieve excessive pressurizer pressure. PCV-456 actuated nine times from 0058 to 0110 hours.
0111:	Operators established letdown to lower the pressurizer level and minimize PORV actuation.
0113:	Operators terminated BIT injection. RCS boron concentration increased from 890 ppm to 1195 ppm. Continued with the four hour at hot standby stabilization period. RCS temperature was steadily drifting downwards, due to operators trying to maintain the secondary side under hot conditions.
0200:	Operators minimized steam loss on the secondary side by securing 50% of the condenser steam jet ejectors.
0415:	Operators lowered pressurizer level by initiating letdown.
0440:	Operators demonstrated that RCP seal injection flows can be controlled by manually throttling the isolation valve downstream of FCV-128 when using a centrifugal charging pump. After the demonstration, the reciprocating charging pump was placed in service. This would give operators better control of RCP seal injection flow during the remainder of the test, thereby minimizing RCP seal damage due to high seal injection flow.
0450:	Plant has been at hot standby natural circulation conditions for greater than four hours. Operations set VCT makeup control system to provide 2000 ppm makeup to the Volume Control Tank (VCT). This simulated the charging pumps which were aligned to the Refueling Water Storage Tank (RWST).
RCS COOLDOWN/DEPRESSURIZATION TO RHR INITIATION CONDITIONS	
0450:	Operators isolated letdown and commenced cooldown using the 10% atmospheric steam dumps. Cooldown rate was approximately 20°F/hour.
0533:	Initiated letdown to lower pressurizer level and lower primary/secondary system differential pressure.
0833:	Isolated letdown.
0845:	Secured Control Rod Drive Mechanism (CRDM) fan 1-1.

TABLE 3-1 (Continued)

TIME EVENT/ACTION

0957: Initiated letdown to lower pressurizer level.

1319: All four loops T_{HOT} less than 350°F. Plant in Mode 4 condition.

1356: Charging valve 8146 and auxiliary spray bypass valve 8148 open. No appreciable depressurization in the RCS observed.

1402: Closed charging valve 8146. Depressurization rate was 8.0 psi/min.

1515: Operators opened PORV PCV-456 to depressurize the RCS and also isolated letdown.

RCS COOLDOWN TO COLD SHUTDOWN CONDITIONS

1805: Operators initiated the RHR system. RHR pump was 1-2 placed in service.

1831: The remaining CRDM fans were secured.

2015: Operators re-energized the CRDM fans (3 only).

2245: RCS temperature below 200°F. Plant in Mode 5 condition.

4.0 INTERPRETATION AND ANALYSIS OF TEST RESULTS

4.1 NATURAL CIRCULATION

The natural circulation test was performed to verify that the RCS natural circulation flow could be established, thereby permitting boron mixing and RCS cooldown/depressurization to RHR system initiation conditions. This portion of the test had no specific acceptance criteria. The evaluation was based on the results of the boron mixing and cooldown/depressurization portions of the natural circulation cooldown test.

The test results indicate that adequate natural circulation flowrates were maintained throughout the test to ensure core decay heat removal, boron mixing, and plant cooldown/depressurization. The response of RCS temperatures indicated stable natural circulation flow conditions throughout the test. The RCS hot leg/cold leg differential temperature was approximately 15-20°F throughout the natural circulation cooldown part of the test.

4.2 BORON MIXING

The boron mixing test was used to demonstrate the concept of boration without letdown. The test was performed under natural circulation conditions when highly borated water at low temperatures and low flowrates (relative to the RCS temperature and pressure) was injected into the RCS. The test also provided information on the time delay associated with boron mixing under natural circulation conditions.

The boron mixing test was conducted by aligning the charging pump to deliver the contents of the boron injection tank (BIT) to each of the four RCS cold legs. A total of 900 gallons of 21000 ppm borated water was added to the RCS. To ensure that the BIT's contents were flushed to the RCS cold legs, the charging pump was aligned to the BIT for approximately 20 minutes. The total flow rate was about 150 gpm.

Boron injection was initiated at 0052 hours and was terminated at 0113 hours. Initially, the RCS boron concentration increased to 1224 ppm. This represented a 340 ppm increase in the boron concentration. Approximately 12 minutes after delivery of the BIT's contents, the RCS boron concentration was within 20 ppm of the concentration at the conclusion of the boron injection phase. The boron concentration was monitored throughout the test and reached a peak concentration of approximately 1325 ppm at 2200 hours. Although a PORV lifted during the test, the change in boron concentration was rapid and good mixing occurred prior to initiating letdown to prevent cycling of the PORV.

Figure 4-1 provides a comparison of the increase in boron concentration experienced during the test relative to the LOFTRAN analysis prediction in the Pre-Test Report. This comparison shows conservatism in the prediction methodology and good agreement for the change in boron concentration. LOFTRAN predicted a quick rise in boron concentration which leveled off at a change in boron concentration of 275 ppm. Although initial boron concentration was lower for the actual test than the LOFTRAN analysis, the change in boron concentration is similar (300 ppm). Also, the actual test and the LOFTRAN analysis both show a quick rise in boron concentration with the final concentration. Although the rate of increase for the test was slower than the LOFTRAN analysis, it was sufficiently quick to ensure the rapid and adequate mixing of boron added to the RCS under natural circulation.

Following injection, makeup to the VCT was set to provide 2000 ppm boron. This simulated suction of the charging pumps aligned to the RWST. This alignment was continued through the remainder of the test causing the boron concentration of the RCS to continue to increase as anticipated, as illustrated by Figure 4-2.

4.3 REACTOR COOLANT SYSTEM COOLDOWN

The cooldown test demonstrated the capability to cool down the RCS to RHR system initiating conditions using all four steam generators for natural circulation. This portion of the test demonstrated the capability to cool the RCS to RHR system initiation conditions. 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 at 350°F.

At 0450 hours, cooldown of the RCS commenced at a rate of 20°F/hr using the 10% atmospheric steam dumps. The RCS cooldown progressed smoothly and at 1313 hours hot leg temperature (T_{HOT}) in all 4 loops was <350°F. For plant cooldown to RHR initiation conditions, the Pre-Test Report LOFTRAN analysis predicted a constant cooldown rate of 25°F/hr. Figure 4-3 shows the actual decrease in RCS hot leg temperature vs. time for the test. The actual cooldown was very similar to the predicted. For the LOFTRAN analysis, hot leg temperature was predicted to rise initially following the trip and then to decrease. The actual RCS temperature did not exhibit this initial rise. This is due to the small amount of steam that was escaping from the condenser steam jet ejectors. Once the steam loss was secured, the cooldown progressed as predicted.

An additional objective of the cooldown test was to verify that adequate water volume was available in the condensate storage tank (CST) to cooldown the plant. During the cooldown, the CST level dropped from 91% at the beginning of the test to 61% at the end of the test. This corresponds to a 126,000 gallon usage from the 400,000 gallon tank. Because decay heat decreases exponentially with time and the water usage during the cooldown occurred over a period of approximately 18 hours (including 4 hours at hot standby), the data indicates that the CST has sufficient capacity to cool down the plant for extended periods.

Alternate sources of water are also available for cooldown. These include 1,000,000 gallons of water per unit from the raw water reservoir. This quantity of water is sufficient to permit both units to remain at hot standby for 100 hours or to permit one unit to remain at hot standby for 200 hours, following shutdown from full power. Finally, in emergency situations, sea water from the auxiliary salt water system may be provided as auxiliary feedwater makeup.

4.4 REACTOR COOLANT SYSTEM DEPRESSURIZATION

The depressurization test was used to demonstrate the capability to significantly reduce RCS pressure under natural circulation conditions.

The test results as shown in Figure 4-4 indicate that the objective and acceptance criterion were satisfied. During the RCS cooldown, pressurizer pressure exhibited a downward trend (due to ambient heat losses from the pressurizer) from normal operating pressure to approximately 1300 psig at 1400 hours. Depressurization was then initiated using auxiliary spray. It was previously determined, during the special low power test program, that for auxiliary spray to be effective, the charging lines to the RCS loops must be isolated. This prediction was verified during the test.

Auxiliary spray then reduced RCS pressure at a rate of approximately 8 psi/minute. At 1515 hours, pressure was 700 psig. Auxiliary spray was then terminated and the pressurizer PORV PCV-456 was used to complete the depressurization. At 1550 hours, pressure had dropped to 375 psig. Both auxiliary spray and pressurizer PORVs were determined to be effective in reducing RCS pressure.

4.5 REACTOR VESSEL UPPER HEAD METAL AND FLUID COOLDOWN

4.5.1 DESCRIPTION

4.5.1.1 Reactor Vessel Upper Head Cooldown. The reactor vessel head cooldown evaluation had two objectives: 1) to monitor the upper head bulk water temperature and 2) to monitor the upper head metal temperature.

During normal cooldown under forced circulation conditions, the reactor vessel upper head is cooled by forced flow into the upper head region. Under natural circulation conditions, flow is still directed into the head, but at a significantly lower flow and a different flow pattern. Accurate data to predict head temperatures during a natural circulation cooldown were not available. As part of the cooldown test, head temperature was monitored to provide data that can be used to quantify the temperature gradient across the head during a natural circulation cooldown transient.

The change in upper head metal temperature is illustrated in Figure 4-5. The change in the reactor vessel upper head water temperature is illustrated in Figure 4-6.

During the initial portion of the test, the upper head temperature remained cooler than the RCS. The trend continued until, at 0845 hours, when CRDM fan 1-1 was secured with fans 1-2, 1-3, and 1-4 remaining in operation. At this point, the upper head water temperatures started increasing relative to the RCS temperatures. At 1230 hours, the upper head was approximately 15°F higher than the RCS. Between 1230 and 1330 hours, the RCS cooldown rate was increased to approximately 25°F/hour. The increase in the cooldown rate combined with securing the CRDM fan caused the ΔT between the RCS and the upper head to increase to about 40°F.

The cooldown of the RCS was temporarily halted between 1400 and 1517 hours while the RCS was depressurized, which caused the upper head/RCS ΔT to decrease to less than 0°F. When the cooldown was reestablished at 1517 hours, the increase in the upper head/RCS ΔT was again observed. The increase in the upper head/RCS ΔT continued until about 1835 hours, when all CRDM fans were secured. Securing all CRDM fans caused the upper head/RCS ΔT to increase to about 20°F. At 2015 hours, the CRDM fans were reenergized and the temperature differential remained below 20°F.

4.5.1.2 Reactor Vessel Head Fluid Cooldown. The Diablo Canyon Pre-Test Report did not evaluate cooldown rates for the fluid in the reactor vessel head. However, subsequent work performed by the Westinghouse Owners Group did evaluate head fluid cooldown rates and their implications on head void formation during natural circulation cooldown.

The purpose of this section of the report is to analyze the cooldown of the upper head fluid during the natural circulation cooldown portion of the Diablo Canyon test and compare the results to the cooldown rates determined from the analyses performed to support the Westinghouse Owners Group (WOG) Emergency Response Guidelines (ERGs).

In the WOG ERG natural circulation cooldown analysis, it was found that natural circulation flow produced an average upper head fluid temperature reduction of approximately 10°F/hour during a 25°F/hour cooldown of the RCS. This cooldown was due to colder RCS fluid entering the hotter upper head region fluid through the guide tubes and exiting the upper head region via the upper head spray nozzles. (In the ERG analysis, about 2 to 4 minutes after RCP trip, the normal flow path up through the spray nozzles and down through the guide tubes reversed due to density variations in the system. Flow was then up through the guide tubes and down through the spray nozzles). In the WOG ERG analysis Diablo Canyon Unit 1 is considered to be a T_{HOT} plant (i.e., due to the limited flow through the spray nozzles, during full power operation, the upper head fluid temperature is closer to the hot leg temperature than the cold leg temperature). In the analysis for the ERGs the initial upper head fluid temperature for T_{HOT} plants was conservatively assumed to be equivalent to the hot leg temperature.

For a T_{HOT} upper head plant with the number of control rod drives (53) Diablo Canyon Unit 1 has, the CRDM fan heat removal rate from the upper head fluid was determined in the WOG ERG analysis to vary from approximately 17°F/hour at an upper head fluid temperature of 600°F to approximately 9°F/hour at an upper head fluid temperature of 350°F with all CRDM fans running.

4.5.2 INTERPRETATION OF THE TEST RESULTS

The natural circulation cooldown portion of the test has been broken down into several time periods based on the number of CRDM fan coolers running, whether or not the plant was in a cooldown phase and which type of cooldown was in progress (the results included the initial stages of RHR system operation after the natural circulation cooldown had been completed). For the various stages of the cooldown, the average RCS and upper head fluid cooldown rates have been determined (see Table 4-1). The four hot leg monitors TO419A, TE413A, TO439A, TE423A, TO459A/TE433A, and TO479A/TE443A were used to determine the average RCS temperature, while the four upper head fluid monitors TO016A/TT16, TO021A/TT21, TO025A/TT25, and TO049A/TT49 were used to determine the average upper head fluid temperature. Also, for each time period the ΔT range of the RCS and upper head fluid average temperatures has been determined (see Table 4-2).

During the initial time period from 0100 to 0445 hours, the plant was at hot standby with natural circulation established and all four fan coolers running. The boron mixing portion of the test was being completed during this time period. The plant had previously been tripped (at 2130 hours on March 28) and the RCPs stopped (at 0028 hours on March 29). By running the RCPs for an extended period (3 hours) after reactor trip and by having all fan coolers in operation for an extended period (over 7 hours) between reactor trip and the initiation of natural circulation cooldown, the upper head fluid was cooled significantly by the time the natural circulation cooldown phase was reached. In fact, for the initial time period of the natural circulation cooldown from 0445 to 0845, hours the average upper head fluid temperature was <u>less than</u> the average RCS temperature for essentially the entire time period (see Table 4-2). In the WOG ERG analysis, the reactor trip and RCP trip had occurred at full power <u>at the same time</u> (to conservatively prevent upper head cooloff via forced flow into the upper head by the RCPs) and the natural circulation cooldown had been initiated approximately 12 minutes after the reactor and RCPs were tripped. This, combined with the assumption that the initial upper head fluid temperature was equivalent to the full power hot leg temperature, resulted in the upper head fluid temperature being significantly higher (615°F) at the time the natural circulation cooldown was initiated in the ERG analysis.

The RCS temperature being higher than the upper head fluid temperature for the majority of the time period from 0445 to 0845 hours resulted in the natural circulation flow slightly heating up the upper head fluid instead of cooling it off. Thus, the upper head fluid cooloff rate of 17°F/hour was due to the four CRDM fans with each fan removing heat from the upper head fluid at a rate of approximately 4.3°F/hour.

For the 0445 to 0845 hour time period and the 0845 to 1400 hour time period, the RCS cooled at approximately the same rate (i.e., 19°F/hour versus 21.3°F/hour). During the 0445 to 0845 hour time period four CRDM fan coolers were running, while during the 0845 to 1400 hour time period three CRDM fan coolers were running. The effect of turning off one of the CRDM fans was seen in both the reduction of the upper head fluid cooloff rate (13.8°F/hour versus 17°F/hour), as well as the significant heatup of the upper head fluid (from essentially the same temperature as the RCS to 38°F hotter than the RCS at the end of the time period). The three running CRDM fans lowered the temperature at a rate of approximately 13°F/hour, and provided nearly all of the heat removal from the upper head fluid during this time period. Some slight cooling of the upper head fluid due to the natural circulation flow was occurring since the upper head fluid was hotter than the RCS during this time period.

From 1400 to 1515 hours the cooldown was stopped and the RCS was depressurized. During this time period, the RCS temperature increased approximately 20°F (from 329°F to 350°F), while the upper head fluid temperature decreased approximately 20°F (from 367°F to 348°F). Thus, while the upper head fluid was approximately 40°F higher than the RCS at the start of this time period, the temperature at the end of the time period was approximately the same. With four CRDM fans running, an upper head fluid cooloff rate of 15.6°F/hour resulted, which was comparable to that of the previous time period. As in the previous time period, the three CRDM fans were removing heat at a rate of approximately 13°F/hour, with the natural circulation flow accounting for the remainder.

The natural circulation cooldown was reinitiated at the start of the next time period (1515 to 1800 hours) during which three CRDM fans were running. The upper head fluid cooloff due to the natural circulation flow should be minimal during this time period, since the upper head fluid temperature was slightly less (-2°F) than the RCS temperature at the start of the time period and only moderately higher (5°F) at the end of the time period. The majority of the temperature decrease (10.6°F/hour) cooloff rate of the upper head fluid for this time period was due to the three CRDM fans. The natural circulation cooldown phase of the test was completed at the end of this time period.

For the final three time periods considered (1800 to 1830 hours, 1830 to 2015 hours and 2015 to 2300 hours) the RHR system was used to cool down the plant. The upper head fluid temperature had cooled to the point that the CRDM fans were less effective in removing heat. The flow into the upper head region became cooler than the upper head fluid temperature during the time periods (from 5°F cooler at the start to 50°F cooler at the close) and upper head cooling from this flow increased with time. In fact, for the 1830 to 2015 hour time period, no CRDM fans were running and this flow cooled the upper head fluid approximately 5°F/hour from the upper head fluid. Even though three CRDM fan coolers were turned on for the final time period, the guide tube flow removed as much or more heat from the upper head fluid as the CRDM fans.

As discussed above, the WOG ERG analysis determined that with all CRDM fans running the cooloff rate of the upper head varied from approximately 17°F/hour at an upper head fluid temperature of 600°F to approximately 9°F/hour at an upper head fluid temperature of 350°F. The test results indicated higher cooloff rates due to the CRDM fans than the analysis. With upper head fluid temperatures ranging from 507°F to 440°F during the 0445 to 0845 hour period, the test results indicated an upper head fluid cooloff rate of approximately 4.3°F/hour per CRDM fan. Thus, if four CRDM fans had been running, the upper head fluid would have cooled off at approximately 20°F/hour to 24°F/hour even at upper head fluid temperatures considerably less than 600°F. During the last time period with natural circulation cooldown in progress (1515 to 1800 hours) the test results indicated significant upper head fluid cooling by the CRDM fans. The RCS temperature varied slightly from the upper head fluid temperature during this time period. There should be minimal cooling of the upper head fluid, due to natural circulation flow. Each of the three CRDM fans running during this time period removed at least 3°F/hour from the upper head fluid. The upper head fluid temperatures ranged from 348°F to 318°F. Thus, if all four CRDM fans had been running, the upper head fluid would have cooled off at greater than 12°F/hour. This rate is greater than the 9°F/hour at an upper head fluid temperature of 350°F determined in the WOG ERG Analysis.

As previously noted, the WOG ERG analysis assumed that the reactor and RCPs were tripped at the same time with the reactor at full power. During the test, the RCPs were run for approximately three hours after reactor trip, but before natural circulation cooldown was initiated. Four CRDM fans were run for approximately seven hours after reactor trip. Thus, at the time natural circulation was established, the upper head fluid temperature was well below what it had been at full power operation and in fact was less than the RCS temperature. In the WOG ERG analysis there was a significant ΔT between the upper head fluid and the rest of the RCS during the natural circulation cooldown. In the ERG analysis, the upper head fluid was 585°F when the RCS temperature was 500°F, and the upper head fluid was 510°F when the RCS temperature was 350°F. No ΔTs of this magnitude were observed during the test. Consequently, due to the nature of the test, the heat removal from the upper head fluid due to the natural circulation flow was small during the test and never approached the 10°F/hour cooloff rate determined in the ERG analysis for a T_{HOT} plant.

TABLE 4-1

AVERAGE COOLDOWN RATES OF RCS AND UPPER HEAD FLUID

TIME PERIOD (HOURS)	NATURAL CIRC. COOLDOWN IN PROGRESS	NUMBER OF CRDM FANS RUNNING	AVERAGE(1) RCS COOLDOWN RATE (°F/HOUR)	AVERAGE(2) UPPER HEAD COOLDOWN RATE (°F/HOUR)
3.75 (0100 TO 0445)	NO(3)	4	6.7	8.3
4 (0445 TO 0845)	YES	4	19	17
5.25 (0845 TO 1400)	YES	3	21.3	13.8
1.25 (1400 TO 1515)	NO(4)	3	(6)	15.6
2.75 (1515 TO 1800)	YES	3	13.5	10.6
0.5 (1800 TO 1830)	NO(5)	3	24.6	10
1.75 (1830 TO 2015)	NO(5)	0	5.0	6
2.75 (2015 TO 2300)	NO(5)	3	23.9	9.8

(1) Averaged using readings of 4 hot leg monitors (T0419A/TE413A, T0439A/TE423A, TE459A/TE433A, and T0479A/TE443A).

(2) Averaged using readings of 4 upper head fluid monitors (T0016A/TT16, T0021A/TT21, T0025A/TT25, and T0049A/TT49).

(3) In hot standby with natural circulation flow.

(4) RCS being depressurized with no RCS cooldown in progress.

(5) RHR System in service.

(6) Three RCS hot legs monitors heat up from 329°F to 339°F. The Loop 2 RCS hot leg monitor heats up from 328°F to 381°F. This response difference is assumed to be caused by the outsurge to the pressurizer (loop 2) during the depressurization. After the depressurization the four hot leg monitors returned to equal values.

TABLE 4-2

RCS AND UPPER HEAD FLUID AVERAGE TEMPERATURE ΔT

TIME PERIOD (HOURS)	RCS T_{HOT} TEMPERATURE RANGE (°F)	UPPER HEAD TEMPERATURE RANGE (°F)	UPPER HEAD TO RCS ΔT (RANGE) (°F)
3.75 (0100 TO 0445)	542 TO 515	538 TO 507	-4 TO -8
4 (0445 TO 0845)	515 TO 440	507 TO 440	-8 TO 0
5.25 (0845 TO 1400)	440 TO 329	440 TO 367	0 TO 38
1.25 (1400 TO 1515)	329 TO 350	367 TO 348	38 TO -2
2.75 (1515 TO 1800)	350 TO 313	348 TO 318	-2 TO 5
0.5 (1800 TO 1830)	313 TO 300	318 TO 313	5 TO 13
1.75 (1830 TO 2015)	300 TO 292	313 TO 303	13 TO 11
2.75 (2015 TO 2300)	292 TO 226	303 TO 276	11 TO 50

4.5.3 COMPARISON OF TEST RESULTS WITH PRE-TEST REPORT ANALYSIS

The purpose of this section is to compare the natural circulation test results to the Pre-Test Report analysis of the head metal temperatures.

4.5.3.1 Pre-test Analysis. The Diablo Canyon Pre-Test Report analysis considered two cases:

Case 1: Case 1 evaluated the envelope condition where the metal temperature of the head is maintained at 550°F (no-load temperature) while the water below the head is cooled from 550°F to 350°F in four hours (50°F/hour).

Case 2: Case 2 evaluated the desired condition where the temperature of the water in the closure head cools from 550°F to 450°F while the water below the closure head is cooled from 550°F to 350°F.

In both cases, it was determined that the critically stressed components were the reactor vessel closure studs.

The natural circulation test measured the reactor vessel head metal temperatures (head, flange, and bolts), the upper head fluid temperature, and the average RCS temperature. These measured temperatures will be compared to the analysis temperature envelopes to determine acceptance.

4.5.3.2 Test Results. During the initial natural circulation flow period of 4.25 hours (0028 to 0445 hours) the head metal cooled from 397°F to 382°F (15°F delta) while the water below the closure head (i.e., RCS hot leg) cooled from 544°F to 514°F (30°F delta). These results fall within the Case 1 envelope of a constant head metal temperature at 550°F while the RCS hot leg fluid cooled from 550°F to 350°F in four hours (200°F delta). During the next four hours (0445 to 0845 hours) with natural circulation cooldown, the head metal cooled from 382°F to 343°F (39°F delta) while the RCS hot leg fluid cooled from 514°F to 440°F (74°F delta). These results also fall within the Case 1 envelope.

The Case 2 analysis covers the four hour period where upper head fluid cools from 550°F to 450°F (100°F delta) while RCS average temperature cools from 550°F to 350°F (200°F delta), during the time period of 0445 to 0845 hours. During this four hour test period the upper head fluid cooled from 508°F to 440°F (68°F delta) while the RCS average temperature decreased from 518°F to 440°F (78°F delta). These test results (68°F delta/78°F delta) fall within the Case 2 envelope.

The two previous test results were achieved with the CRDM fans running, therefore, additional head cooling is provided. To analyze the reactor vessel head metal temperatures without CRDM fan cooling, the time period of 1830 to 2015 was examined. The reactor vessel head metal temperature increased from 245°F to 298°F within 45 minutes and then stablized near that value for the remaining 60 minutes. The reactor vessel flange and bolt temperatures remained stable at their 1830 time values and did not increase. However, the core exit temperatures decreased at a rate of 5°F/hour. The differential temperature between the metal and the RCS average temperature stabilized at approximately 20°F and then metal temperature began to decrease with the RCS average temperature. This 20°F difference is much less than the 100°F administrative limit set for the test.

It is concluded that the test acceptance criteria were satisfied during the natural circulation cooldown test. The test results fall within the Pre-Test Report analysis envelope which considers the vessel component stresses. In addition, the 100°F administrative temperature difference limit was also satisfied.

5.0 USE OF TEST RESULTS IN EVALUATION OF COLD SHUTDOWN OPERATIONS

5.1 EVALUATION OF EXISTING OPERATING PROCEDURES AND TECHNICAL SPECIFICATIONS

The present Diablo Canyon Emergency Operating Procedures (EO.2-R1, EO.3-R1, EO.4-RO) for reactor trip response and natural circulation cooldown, are based on the Westinghouse Owners Group (WOG) Emergency Response Guidelines (Rev. 1). The WOG generic guidelines for reactor trip response and natural circulation cooldown use normal operational systems. The WOG guidelines were not developed to generically address the requirements in Branch Technical Position RSB 5-1 and do not provide guidance for the situation where only seismically qualified systems are available. Consequently, this guidance is not contained in the present Diablo Canyon EOPs.

An evaluation of cold shutdown operations has been performed to define the operational strategies needed if only seismically qualified systems are available to achieve cold shutdown. This evaluation addresses the design of the Diablo Canyon systems, and defines how the systems will be operated to achieve cold shutdown in the optimal manner.

To illustrate why alternative operational strategies will be developed for cold shutdown if only seismically qualified systems are available, refer to Table 5-1 for a summary of operator functions that are needed to control the reactor coolant system (RCS) and secondary system during plant cooldown. Under each function, the normal system capabilities that the operator would use (based on the Diablo Canyon procedures) are specified. Also identified on Table 5-1 are alternative systems capabilities not presently utilized in the procedures but potentially available for use in a cold shutdown. The systems capabilities that are seismically qualified on Diablo Canyon are asterisked in Table 5-1. These normal and alternative capabilities must be evaluated in order to define the optimal use of plant systems to achieve a seismically qualified cold shutdown following a safe shutdown earthquake.

A review of Table 5-1 shows that the systems normally used to achieve cold shutdown are not all seismically qualified. To address Branch Technical Position RSB 5-1, the non-seismically qualified systems that are used must be justified or alternative systems must be used. Each operator function is discussed below:

o RCS Boron Concentration

The operator does not have normal systems capability for control of RCS boron concentration since the RCS makeup system is not seismically qualified. Alternative seismically qualified capability such as emergency boration from the Boron Injection Tank (BIT), Boric Acid Tank (BAT) or the Refueling Water Storage Tank (RWST) must be used.

o RCS Inventory

The operator does not have normal systems capability for control of RCS inventory. Although seismically qualified charging and RCP seal injection capability is available, letdown and excess letdown capability is not available due to the fact that air operated valves on these letdown lines do not have a seismically qualified air supply. A seismically qualified reactor vessel head vent is available for letdown but its use should be restricted to minimize potential discharge of reactor coolant to the containment. An additional potential letdown path is the RCP seal leakoff system. If RCS seal injection is terminated, the seal system will leak coolant from the RCS, with leakage flow rate dependent on RCS pressure and temperature.

- RCS Pressure

The operator does not have normal systems capability for RCS pressure control. Although seismically qualified pressurizer power operated relief valves (PORVs) and auxiliary spray are available to reduce pressure, seismically qualified pressurizer heaters are not available to increase and maintain pressure. However, two of the four heater groups can be manually switched and powered from vital buses.

- RCS Temperature

The operator does not have normal systems capability for RCS temperature control. Seismically qualified steam generator PORVs and the Residual Heat Removal (RHR) system are available to control RCS temperature in the active portions of the RCS. However, the control rod drive mechanism

(CRDM) fans are not seismically qualified and are not available for heat removal from the reactor vessel upper head. Also, as stated above, the pressurizer heaters are not available for heat addition to the pressurizer. Consequently, seismically qualified temperature control for the inactive portions of the RCS is not available. This inability to control temperature in the pressurizer and reactor vessel head may result in potential void formation in the reactor vessel head or, alternatively, may necessitate the reactor vessel head vent path be used to prevent void formation.

- Secondary Inventory

  The operator does have normal systems capability for control of secondary inventory since the condensate storage tank (CST) and auxiliary feedwater (AFW) system are seismically qualified.

- Secondary Pressure

  The operator does have normal systems capability for control of secondary pressure since the 10% atmospheric steam dumps (ASD) are seismically qualified.

To further illustrate where operational strategies may differ, Table 5-2 and Table 5-3 identify the high level steps associated with response to a reactor trip and natural circulation cooldown, respectively, based on the Diablo

Canyon procedures. Several of these steps that use non-seismically qualified systems are identified by asterisks and the non-seismically qualified systems are identified under the high level steps. For Diablo Canyon, alternative operational strategies will be developed to provide the operational guidance and technical basis to demonstrate that the Diablo Canyon plant can be taken from normal operating conditions to cold shutdown using only seismically qualified systems. The alternative operational strategies and procedure revisions will be considered and, if applicable, integrated into the present procedures so that the operator may first use the normal systems to the extent that they are or can be made available. Alternative seismically qualified system capabilities will be considered for incorporation into the procedures as contingencies that are employed only if necessary to achieve cold shutdown conditions.

TABLE 5-1

OPERATOR FUNCTIONS AND SYSTEMS CAPABILITIES

RCS BORON CONCENTRATION

Normal

RCS Makeup System

Alternative

*BIT/Boration
*RWST/Boration
*BAT/Emergency Boration
(RCS Temperature)(1)

RCS INVENTORY

Normal

*Charging
Letdown
Excess Letdown

Alternative

*Safety Injection
*RCP Seal Injection
RCP Seal Leakoff
*RV Head Vent
(RCS Temperature)(1)

RCS PRESSURE

Normal

*Pressurizer Auxiliary Spray
*Pressurizer PORVs
Pressurizer Heaters

Alternative

(RCS Temperature)(1)
(RCS Inventory)(1)

RCS TEMPERATURE

Normal

*10% Atmospheric Steam Dumps
*RHR System
CRDM Fans (Upper Head)
Pressurizer Heaters

Alternative

*RV Head Vent

*Seismically qualified

(1) These operator functions also provide alternative capability for control.

TABLE 5-1 (Continued)

OPERATOR FUNCTIONS AND SYSTEMS CAPABILITIES

SECONDARY INVENTORY	SECONDARY PRESSURE
Normal	Normal
Condenser/Main Feedwater	Condenser Steam Dump Valves
*CST/Auxiliary Feedwater	*10% Atmospheric Steam Dumps
Alternative	Alternative
None Needed	None Needed

* Seismically qualified.

TABLE 5-2

EMERGENCY OPERATING PROCEDURE
E-0.1 REACTOR TRIP RESPONSE

1. Check RCS Average Temperature - Stable or Trending to 547°F
2. Check FW Status
3. Verify All Control Rods Fully Inserted

* 4. Check PRZR Level Controls
   - use letdown, excess letdown and charging

* 5. Check PRZR Pressure Control
   - use PRZR heaters

6. Check SG Levels
7. Verify Main Generator Trip After 30 Second Delay
8. Verify All AC Buses - Energized by Offsite Power
9. Check RCP Status - At Least One Running
10. Check Turbine Status During Coastdown
11. Align MSRs
12. Check If Source Range Detectors Should Be Energized
13. Shutdown MFW Pumps If Not Needed For Feedwater Control
14. Check If Condenser Steam Dump Should Be In Pressure Control Mode
15. Shutdown Unnecessary Plant Equipment As Desired
16. Align Auxiliary Steam As Desired
17. Notify The Following Of The Reactor Trip

*18. Maintain Stable Plant Conditions
   - use letdown, excess letdown and charging
   - use PRZR heaters

19. Complete Required Reports And Notifications
20. Go To Applicable Plant Procedure

*Steps that use non-seismically qualified systems

TABLE 5-3

EMERGENCY OPERATING PROCEDURE
E-0.2 NATURAL CIRCULATION COOLDOWN

1. Try to Restart an RCP
2. Verify Instrument Air Available
3. Monitor Cooldown
4. Initiate Degassing of RCS If RCS Will Be Opened

* 5. Borate RCS to Cold Shutdown Boron Concentration
   - use letdown, excess letdown, charging and RCS makeup system

6. Verify Cold Shutdown Boron Concentration By Sampling

* 7. Check VCT Makeup Control System
   - use letdown, excess letdown, charging and RCS makeup system
* 8. Verify All CRDM Fans - Running
   - use CRDM fans

9. Initiate RCS Cooldown to Cold Shutdown
10. Check WR RCS T-Hot Temperature - Less than 550°F
11. Depressurize RCS to Allow Block Of PZR Press SI
12. Continue The Cooldown While Maintaining The Following Conditions (Pressure 1865, Pressurizer level 22-60%)
13. Monitor RCS Cooldown
14. Initiate RCS Depressurization While Continuing With The Cooldown
15. Check PRZR Level - No Unexpected Large Variations
16. Check If Accumulators Can Be Isolated

*17. Maintain Letdown Flow (If Available)
   - use letdown, excess letdown

18. Maintain RCP Seal Injection Flow
19. Verify RHR Boron Concentration Greater Than Or Equal To RCS Concentration
20. Establish The Following Conditions (Temperature <350°F, T_{cold} >323, Pressure 390 psig)
21. Align For Overpressure Protection
22. Place RHR System In Service
23. Continue RCS Cooldown to Cold Shutdown
24. Continue Cooldown of Inactive Portions of RCS
25. Continue RCS Cooldown

*Steps that use non-seismically qualified systems

5.2 DEFINITION OF COLD SHUTDOWN OPERATIONS STRATEGY

To define alternative strategies necessary to achieve cold shutdown following a seismic event, the operator functions have been evaluated to determine how they are affected by the unavailability of non-seismically designed systems and equipment. A review of Table 5-1 indicates that the functions of Secondary Inventory and Secondary Pressure control can be performed by the operator using seismically qualified equipment. However, the operator functions of controlling RCS boron concentration, RCS inventory, RCS pressure and RCS temperature are affected to various extents by the unavailability of non-seismically qualified systems.

5.2.1 Description of Unavailable Systems

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5.2.1.1 Letdown. [

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5.2.1.2 Reactor Makeup Control System. [

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5.2.1.3 Pressurizer Heaters. [

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5.2.1.4 <u>CRDM Fan Availability</u>. [

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5.2.2 DESCRIPTION OF OPERATOR FUNCTIONS

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5.2.2.1 Secondary Pressure Control. [

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5.2.2.2 Secondary Inventory Control. [

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Operation	Operation Time (Hours)	
	Best Estimate	Limiting
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[		]^{a,c}
[		]^{a,c}

[ ]^{a,c}

Case	CST Volume$^{(1)}$
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[	]^{a,c}
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5.2.2.3 RCS Boron Concentration. [

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5.2.2.4 RCS Inventory. [

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5.2.2.5 RCS Pressure. [

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5.2.2.6 RCS Temperature. [

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5.3 DESCRIPTION OF COLD SHUTDOWN SCENARIO

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Time 0 to 1 Hour

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Time 1 to 3 Hours

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Time 3 Hours

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Time 3 Hours to 6 Hours

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Time 6 Hours

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Time 6 Hours to 10 Hours

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Time 10 Hours to 13.5 Hours

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Time 13.5 Hours to 18 Hours

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Time 18 Hours

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6.0 SINGLE ACTIVE FAILURE EVALUATION

The scenario described in Section 5 has been evaluated to determine the impact of single active failures on the capability to take the Diablo Canyon Power Plant from hot standby to the cold shutdown condition. As can be seen from Table 6-1 there is no credible single active failure that would preclude achieving cold shutdown.

The probability of mechanical failure of either valve 8701 or 8702 in the RHR suction line has been evaluated. The mechanical failure of the disc separating from the stem has been determined to be in the range of 10^{-4} to 10^{-3} per year. The probability of a Hosgri earthquake is less than 2×10^{-5}. The combined probability of valve stem failure coincident with the earthquake is 10^{-7}. Thus, it is not appropriate to postulate this failure for the purposes of this report.

TABLE 6-1

SINGLE FAILURE EVALUATION
NATURAL CIRCULATION

Component	Malfunction	Comments
Motor Driven Auxiliary Feed Pump(s)	Fails to start	2 pumps provided, only one is required, in addition, the turbine driven pump provides the same function.
S/G PORV (10% Atm. Steam Dump Valve)		
PCV-19 (20,21,22 analogous)	Fails to open	Redundant valves provided, only one is required.
TDAFWD S/G Level Control Valve FCV-106 (107,108,109 analogous)	Fails closed	Flow can be provided to 3 steam generators from turbine pump.
NDAFWD S/G Level Control Valve LCV-110 (111,113,115 analogous)	Fails to open	Manual cross connect can be opened to reestablish flow to all 4 steam generators via motor driven pump.

[illegible]ABLE 6-1 (Continued)

BORATION

Component	Malfunction	Comments
Centrifugal Charging Pump (APCH 1, APCH 2 analogous)	Fails to start	2 provided; one required.
8803A/B BIT inlet isolation	Fails to open	Two parallel lines; one valve in either line required to open.
8801A/B BIT outlet	Fails to open	Two parallel lines; one valve in either line required to open.
8870A/B Recirculation path to BAT	Fails to close	Two valves in series, one valve required to close.
8805A/B Suction line RWST to CCP	Fails to open	Two parallel lines; one valve in either line required to open.
8107, 8108 Discharge line to normal charging path	Fails to close	Two valves in series; only one valve required to close.
8105, 8106 Miniflow line	Fails to close	Two valves in series; only one valve required to close.
LCU 112 B,C Suction from VCT	Fails to close	Two valves in series; only one valve required to close.
Boric Acid Transfer Pumps, (APBA)	Fails to start	2 pumps provided. Only 1 required.
HCV-104 HCV-105	Fails to close	2 flow paths; only 1 required to close.

TABLE 6-1 (Continued)

DEPRESSURIZATION

Component	Malfunction	Comments
HV-1 (HV-2, HV-3, HV-4 Analogous), Head Vent Valve	Fails to open	Function can be accomplished by stopping the charging pumps.
PCV-455 (PCV-456, PCV-474 analogous)	Fails to open	3 redundant valves provided, 1 required.

TABLE 6-1 (Continued)

RHR COOLDOWN

Component	Malfunction	Comments
RHR Pumps	Fails to start	2 provided, 1 pump provides sufficient flow.
Suction isolation valves 8701, 8702	Fails to open	Manual action required to open failed valve.
Isolation valves 8700 A/B	Fails to open	2 parallel flow paths; only one is required to open.
8809A/B RHR/SI isolation	Fails closed	2 parallel flow paths; only one is required.

7.0 CONCLUSIONS

Although the safe shutdown basis for the Diablo Canyon Power Plant is that the plant can be brought to and maintained at hot standby conditions, the results of the Unit 1 natural circulation, boron mixing and cooldown test and the evaluation of cold shutdown operations presented in this report have conclusively demonstrated that the plant can safely be taken to cold shutdown conditions following a safe shutdown earthquake. The effect of a single active failure of seismically qualified equipment on the ability to take the reactor to cold shutdown was also analyzed. It was concluded that there is no credible single active failure that would preclude the plant from achieving a condition of cold shutdown following a postulated seismic event.

These conclusions reached from the DCPP Unit 1 tests are applicable to DCPP Unit 2 as well, since Unit 2 is nearly identical to Unit 1. Although there are some differences between the Unit 1 and Unit 2 reactor vessel internals, an evaluation of these differences has shown that both the flow area through the spray nozzles and the loss coefficient through the spray nozzles are the same. In addition, the flow area through the upper support plate is the same. Overall the Unit 1 internals have a higher flow resistance than Unit 2. Therefore, the test results from Unit 1 are not only applicable to Unit 2 but are conservative with respect to the Unit 2 internals design. The systems required for achieving cold shutdown have the same design bases as those in Unit 1. That is, the sizing, the functional requirements, and the equipment design parameters, as well as their operation, are the same for both units.

In addition, the test has demonstrated that natural circulation, boron mixing, and cooldown can be accomplished while remaining within the Technical Specification limits.

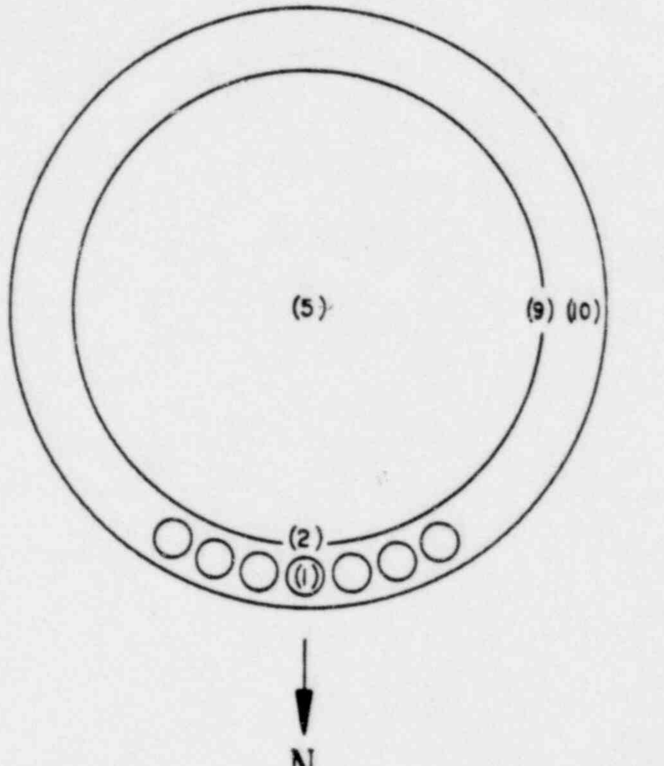
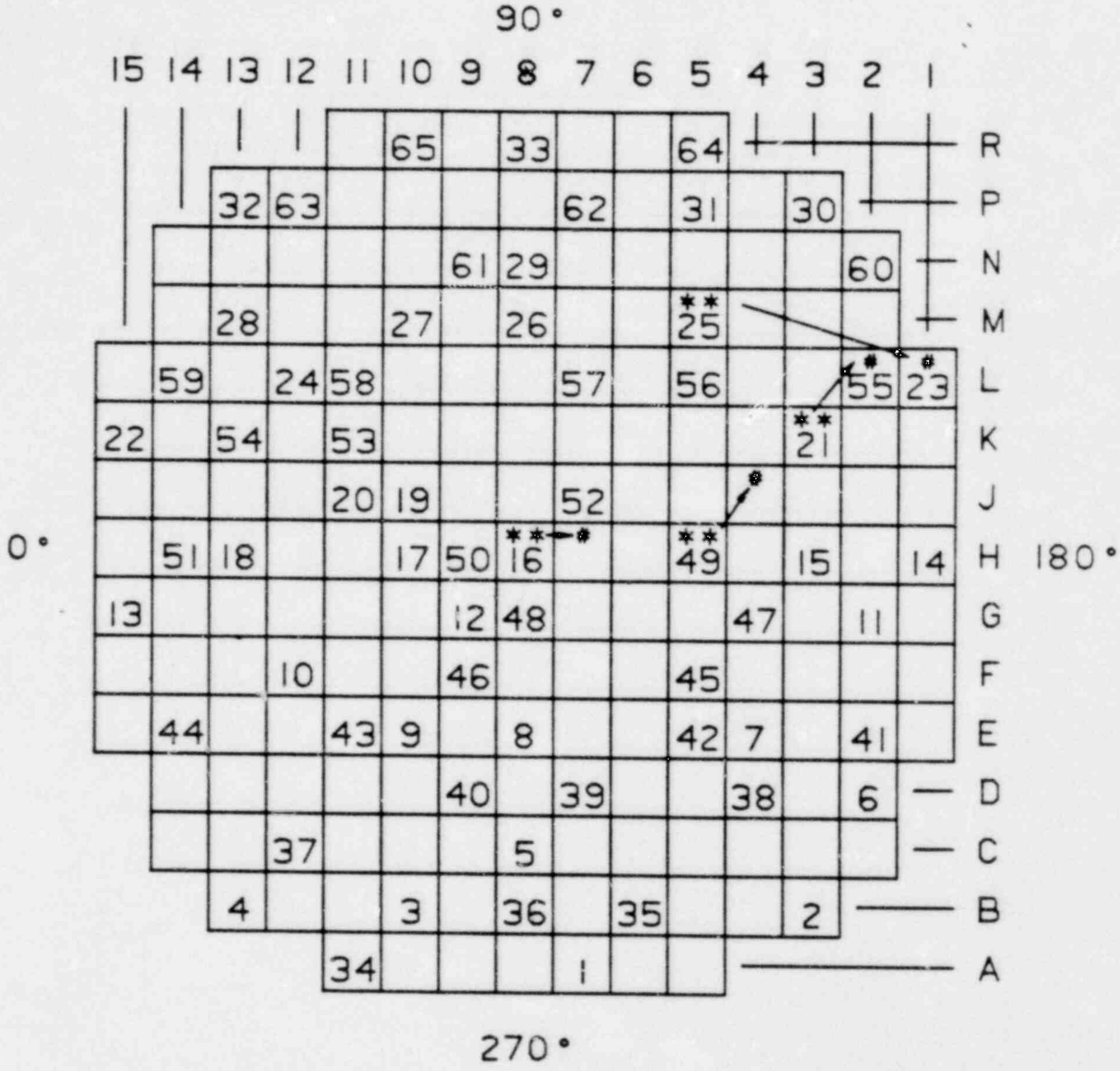


FIGURE 3-1 REACTOR VESSEL HEAD MAGNETIC T/C LOCATIONS

[illegible]



DCPP UNIT 1

INCORE THERMOCOUPLE (T/C) LOCATIONS

** - OLD LOCATION OF THERMOCOUPLES

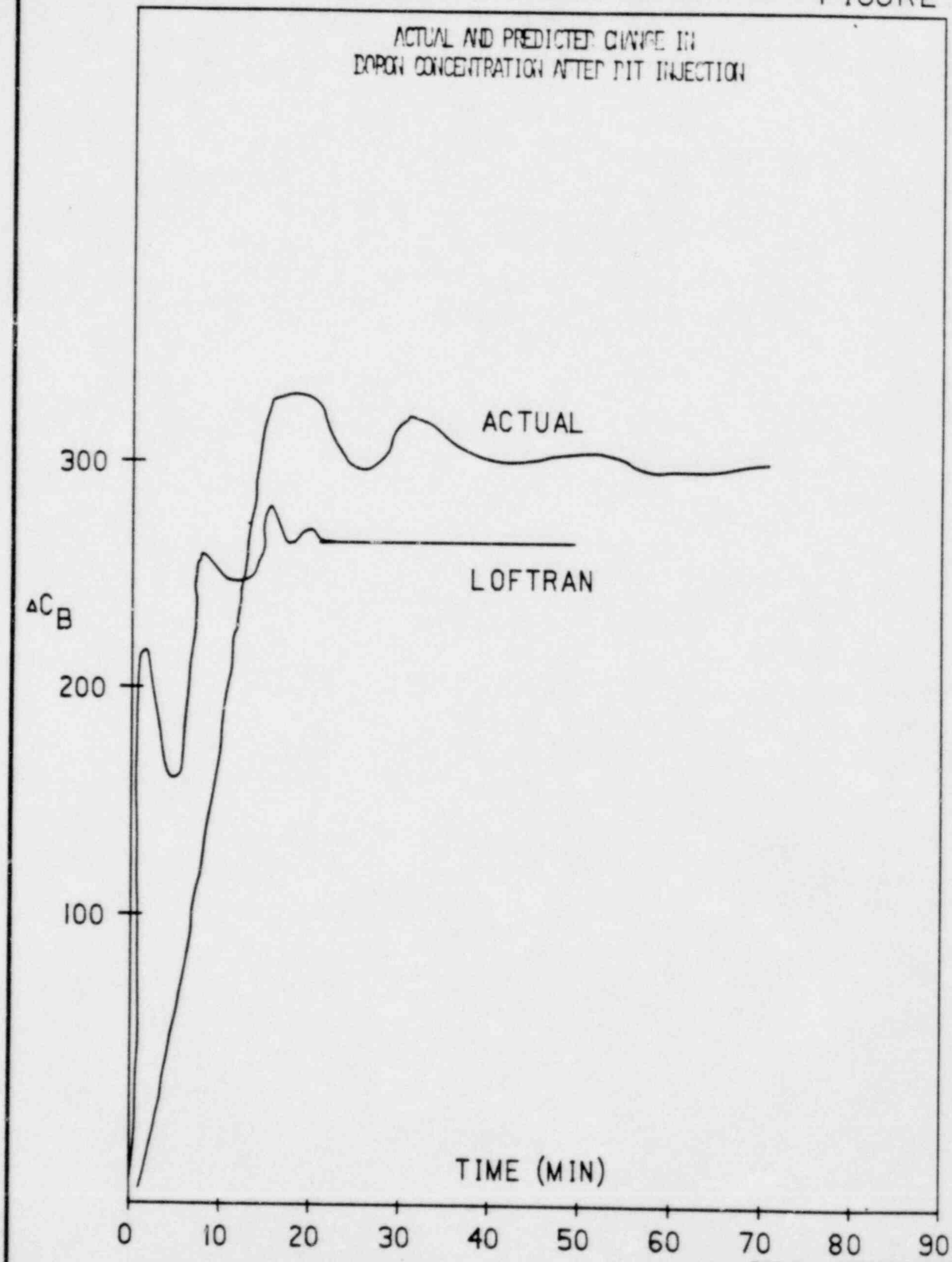
● - NEW LOCATION OF UPPER HEAD THERMOCOUPLES

FIGURE 3-2

DCHA.CAL 1.1403CXX.XXX.03.001.030896

ΔC_B vs TIME FROM BIT INJECTION

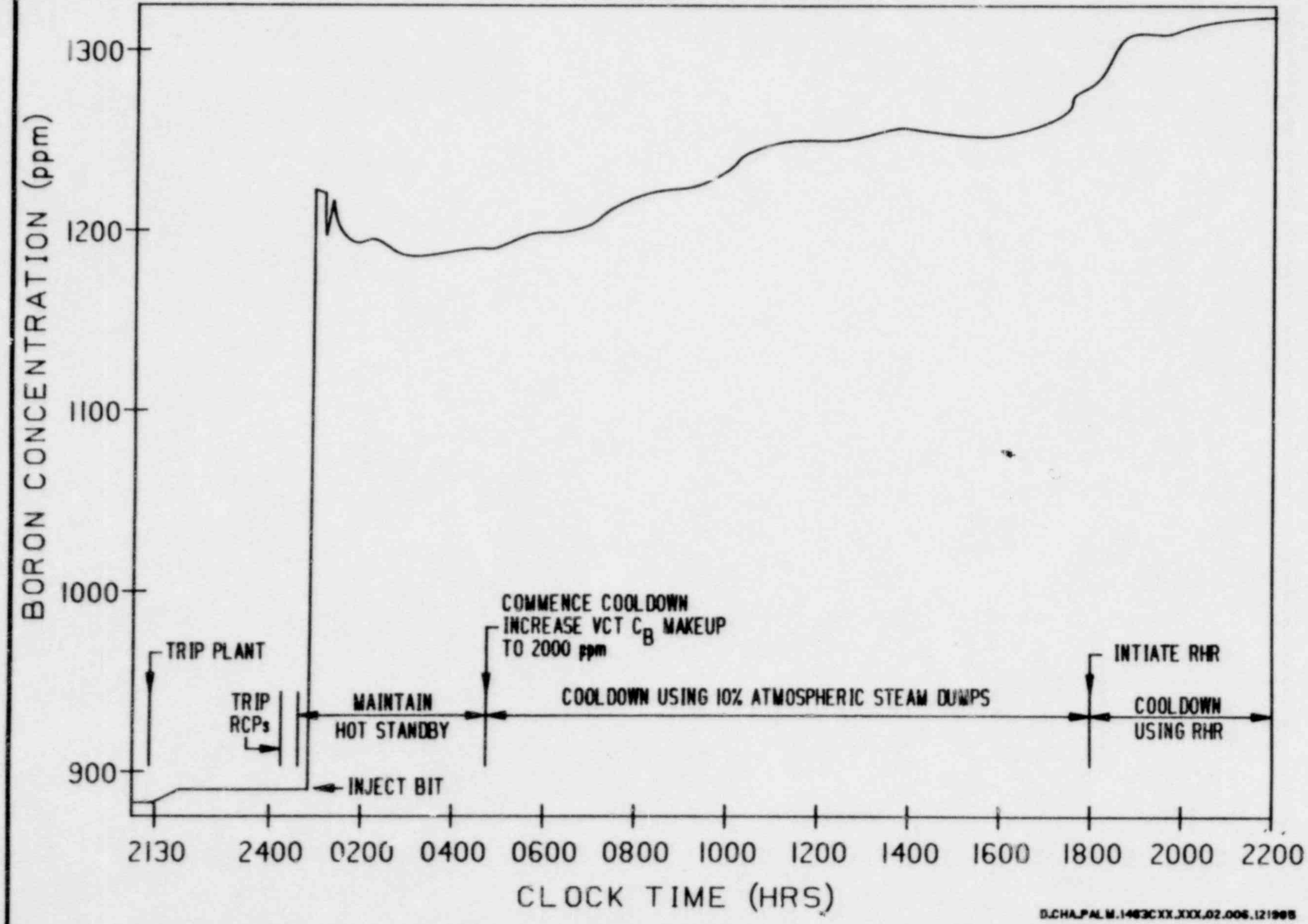
FIGURE 4-1



D.CHA.PAL.M.1463CXX.XXX.02.008.121985

FIGURE 4-2

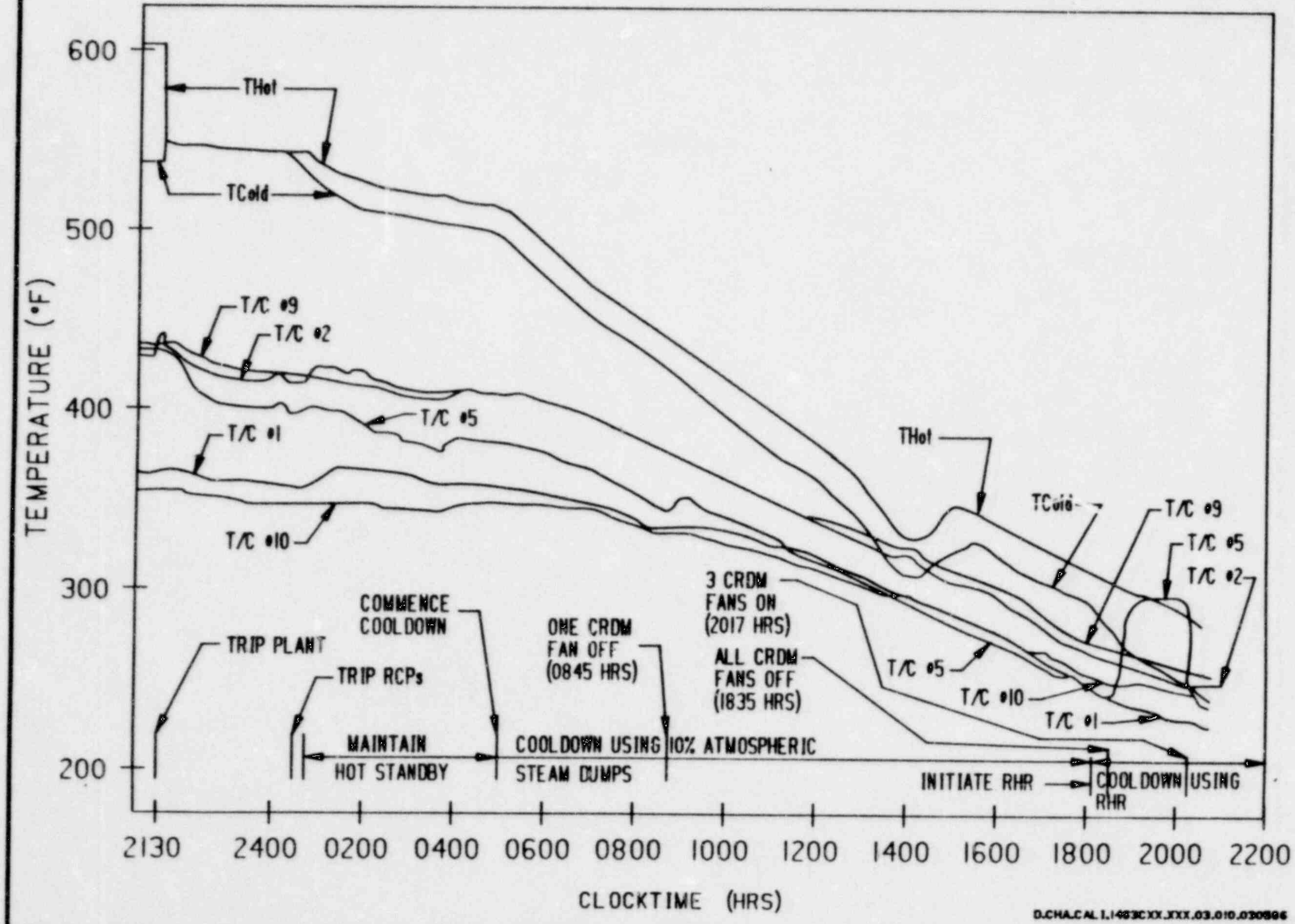
RCS BORON CONCENTRATION vs TIME



D.CHA.PAL M.1463CXX.XXX.02.006.121985

FIGURE 4-3

THOT, TCOLD & RV HEAD METAL TEMPERATURE vs TIME



D.CHA.CAL 1.1463CXX.XXX.03.010.030686

FIGURE 4-4

PRESSURIZER LEVEL & PRESSURIZER PRESSURE vs TIME

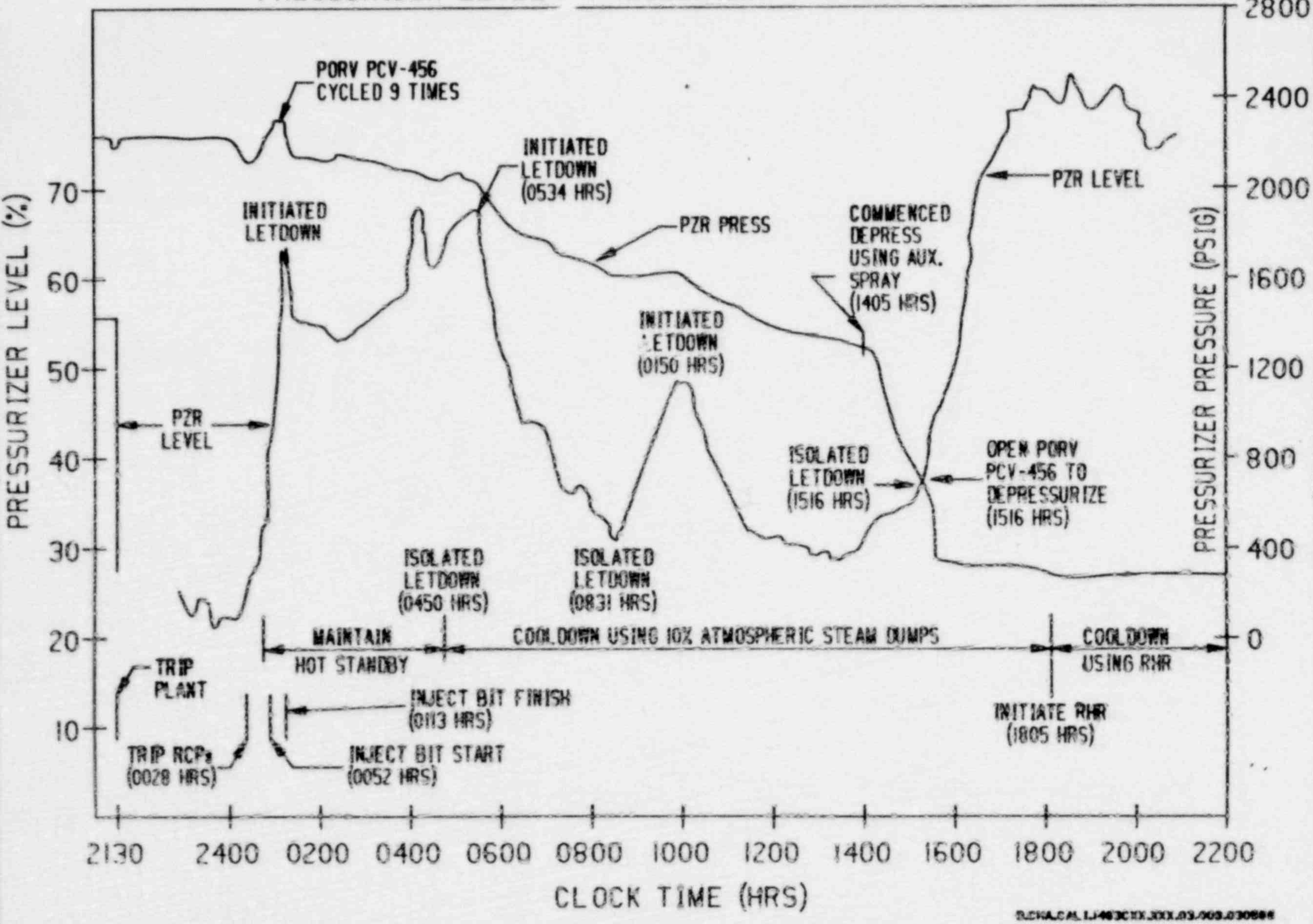


FIGURE 4-5

CHANGE IN UPPER HEAD METAL TEMPERATURE

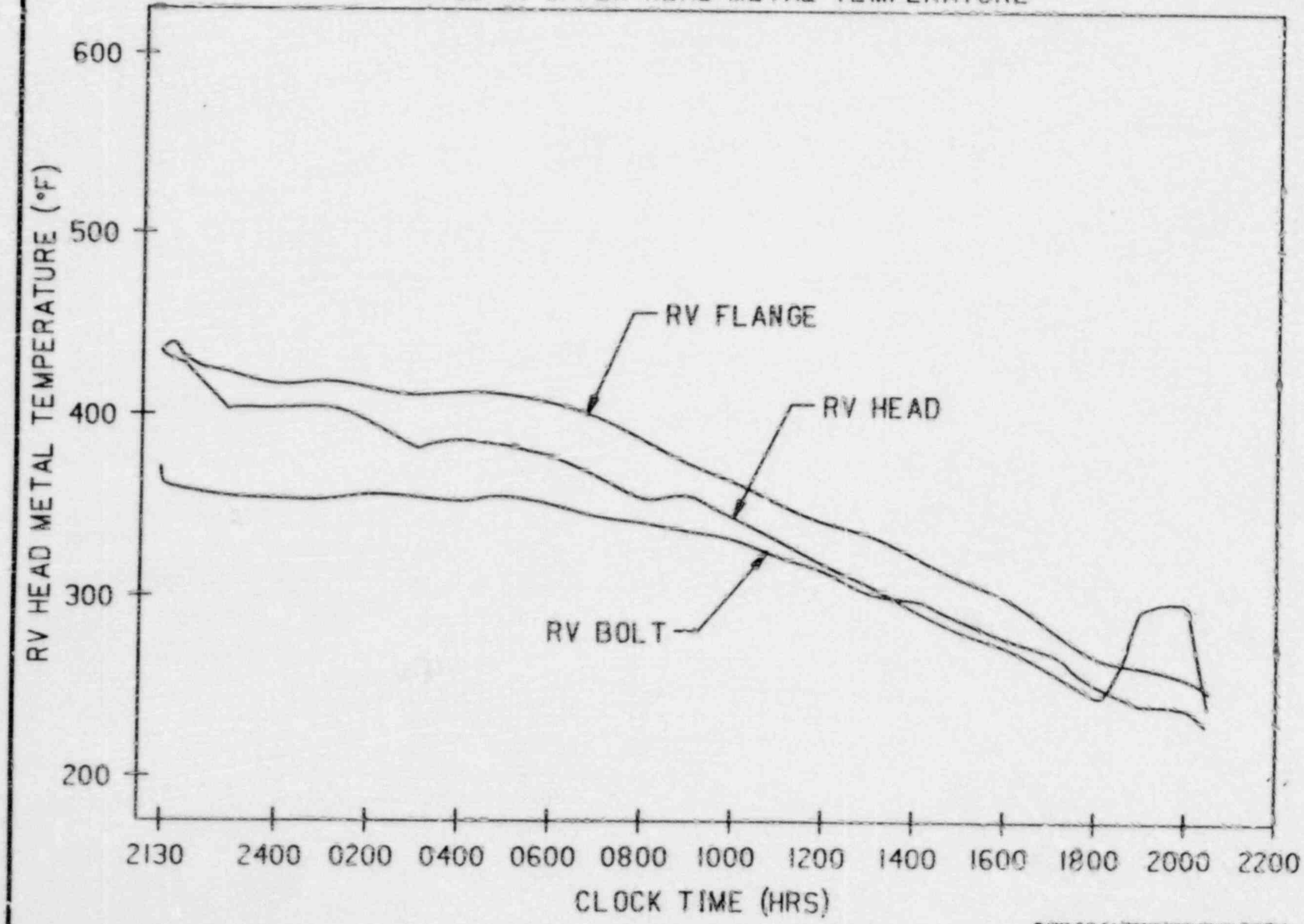
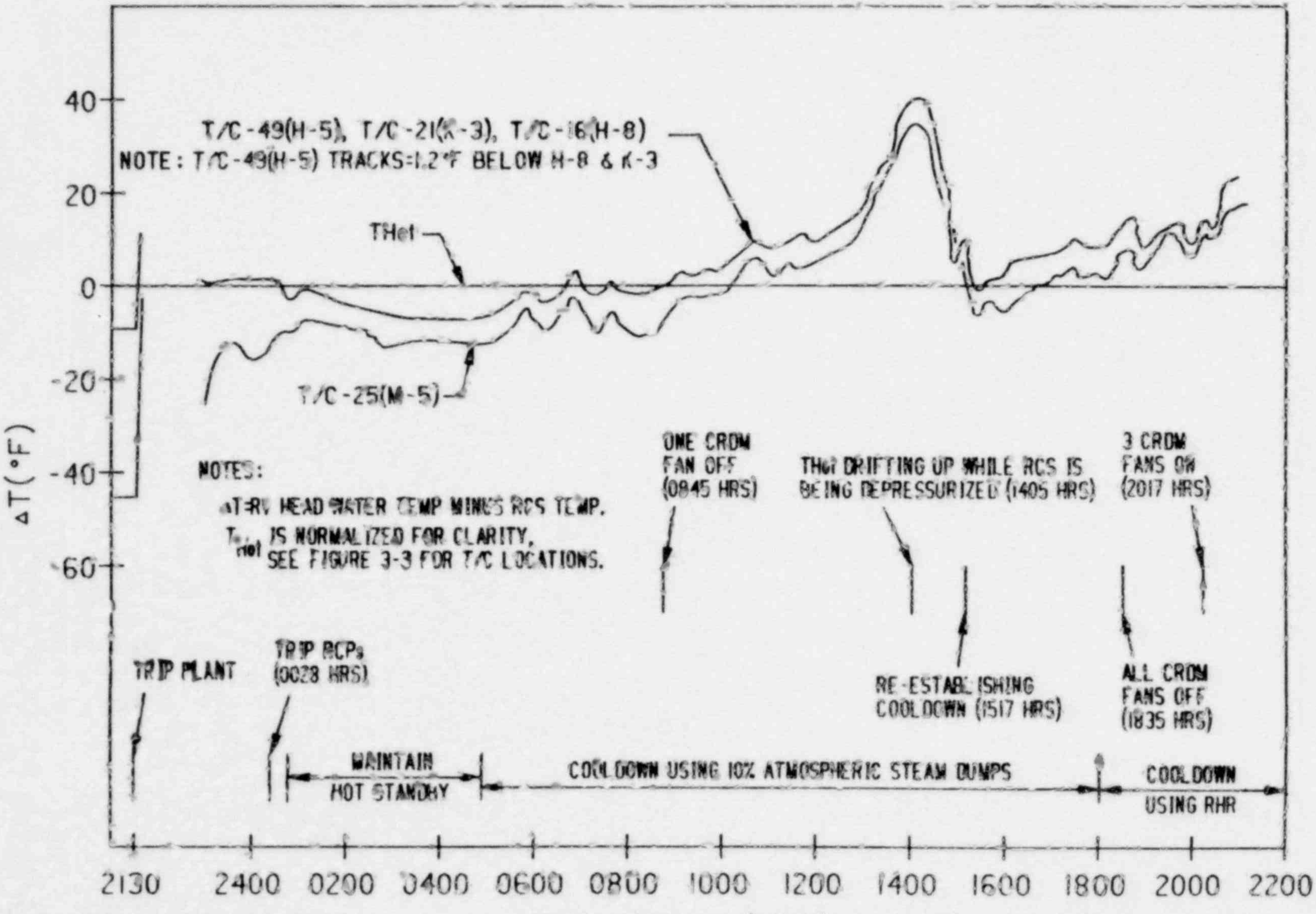


FIGURE 4-6

RV UPPER HEAD AND RCS WATER TEMPERATURE ΔT vs TIME



[illegible]

a,

FIGURE 5-1 RELATIONSHIP OF AVAILABLE SYSTEMS TO COLD SHUTDOWN SCENARIOS a,c

FIGURE 5-2 COLD SHUTDOWN SCENARIO

a,c

FIGURE 5-3 COLD SHUTDOWN SCENARIO