ATTACHMENT
ST-HL-AE-1827
PAGE 1 OF 38

NATURAL CIRCULATION COOLDOWN

AND BORON MIXING

Applicability of Tests Performed at Diablo Canyon Unit

for Conformance to BTP RSB 5-1

South Texas Project

Houston Lighting and Power Company

December 1986

Table of Contents

1.0 INTRODUCTION

The NRC staff indicated in paragraph 5.4.7.6 of the SER that

"In response to a staff inquiry regarding natural circulation boron mixing and cooldown testing, the applicant indicated that the Diablo Canyon test results would be representative for South Texas natural circulation because of the similarity between the plants with regard to piping, components, and elevation head. The applicant estimates that the natural circulation loop flow rate for the two plants would differ by not more than 5%. The appli cant will review the results of the Diablo Canyon tests for applicability. Until the applicant reviews the Diablo Canyon test results and satisfac torily demonstrates that these results are applicable to South Texas or makes a commitment to perform these tests this remains a confirmatory item."

The natural circulation boron mixing and cooldown test was performed at Diablo Canyon Unit 1 on March 28 and 29, 1985 beginning with the trip of the unit from hot full power conditions at 2130 hours on March 28 and con tinuing until 2245 hours on March 29 when cold shutdown conditions were achieved. The results of this test were published in WCAP 11095. The test was successfully performed and all objectives and acceptance criteria were met. This report provides the required comparison and establishes the applicability of the Diablo Canyon test to the STP design such that this confirmatory item may be closed.

[illegible]

[illegible]

2.0 NRC BRANCH POSITION

A. Functional Requirements

The System(s) which can be used to take the reactor from normal operating conditions to cold shutdown shall satisfy the functional requirements listed below.

1. The design shall be such that the reactor can be taken from normal operating conditions to cold shutdown using only safety grade systems. These systems shall satisfy General Design Criteria 1 through 5.

2. The system(s) shall have suitable redundancy in components and features, and suitable interconnections, leak detection, and isolation capabilities to assure that for onsite electrical power system operation (assuming offsite power is not available) and for offsite electrical power system operation (assuming onsite power is not available) the system function can be accomplished assuming a single failure.

3. The system(s) shall be capable of being operated from the control room with either only onsite or only offsite power available. In demonstrating that the system can perform its function assuming a single failure, limited operator action outside of the control room would be considered acceptable if suitably justified.

4. The system(s) shall be capable of bringing the reactor to a cold shutdown condition, with only offsite or onsite power available, within a reasonable period of time following shutdown, assuming the most limiting single failure.

5. The seismic Category I water supply for the auxiliary feedwater system shall have sufficient inventory to permit operation at hot shutdown* for at least 4 hours, followed by cooldown to the conditions permitting operation of the RHR system. The inventory needed for cooldown shall be based on the longest cooldown time needed with either only onsite or only offsite power available with an assumed single failure.

3.0 SAFETY GRADE SHUTDOWN AT STP

In accordance with BTP RSB 5-1, the plant is capable of being taken to cold shutdown within a reasonable period of time provided that limited manual actions are performed. Analysis shows that RHR operating conditions can be reached in approximately eighteen hours which includes the time required to perform any necessary action during a four-hour period at hot standby and a 14 hour cooldown period at 25° F/HR including the most limiting single failure (Ref. 12).

The four key processes involved in cooldown are: heat removal, RCS de pressurization, RCS flow circulation, and reactivity control.

*At STP, this mode of operation is referred to as "hot standby".

Heat removal will be accomplished by using the Auxiliary Feedwater System to provide water to the steam generators. During hot standby, steam will be released from the generators by either the steam generator code safety valves or safety-grade, power-operated relief valves. During cooldown steam will be released by the power-operated relief valves. Water for the cooldown will be supplied from the safety-class Auxiliary Feedwater Storage Tank.

RCS depressurization is accomplished with the pressurizer power-operated relief valves. It may be necessary to use the pressurizer heaters to remain at hot standby for four hours and they may also be used periodically during cooldown. The heaters themselves are not classified as Class 1E components; however, two banks of heaters can be powered from Class 1E power supplies. (Ref. 4)

RCS flow circulation is provided by natural circulation from the core to the steam generators. During startup testing, the establishment of stable natural circulation conditions will be verified. (Ref. 9)

Reactivity control is accomplished by providing boric acid to the charging pumps from the boric acid tanks. This is done by the boric acid transfer pumps or by direct gravity feed. Makeup required in addition to that needed for boration can be provided from the RWST.

All of the systems required for cooldown to RHR operating conditions, with the exception of the pressurizer heaters, are safety-grade systems and satisfy GDC 1 through 5.

The systems contain suitable redundancy in components, features and isolation capabilities to assure that the system safety function can be accomplished assuming the availability of either only on-site power or only off-site power, and, assuming a single failure.

All systems are capable of being operated from the Control Room with either only onsite or only offsite power available. Should a single failure result in a loss of redundancy in the aforementioned systems, limited operator or action outside the Control Room may be necessary.

The Operating Procedures developed specifically for STP are based on guidelines for plant safe shutdown. (Ref. 10 and 11)

4.0 SUMMARY OF DIABLO CANYON TEST AND RESULTS

4.1 Diablo Canyon Test Purpose and Objectives

4.1.1 Purpose

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

Natural Circulation

Establish natural circulation conditions using core decay heat.

Boron Mixing

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.

Reactor Coolant System Cooldown

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

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).

4.1.2 Acceptance Criteria

The acceptance criteria for each phase of the tests 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 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 $\pm 100^{O}F$ of the core average exit thermocouple temperature

- Maintain the temperature of the steam generators and reactor vessel upper head to $<450^{O}F$ when the core average exit thermocouple temperature is $350^{O}F$

- Assure that the RHR system is capable of cooling down the RCS to cold shutdown conditions.

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.

[illegible]

Reactor Vessel Upper Head Cooldown

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 $50^{O}F$ subcooling margin be maintained during cooldown and depressurization. A $100^{O}F$ 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 $100^{O}F$.

4.2 General Test 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 $200^{O}F$ 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 hours 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.

4.3 Chronology of Events and Operator Actions

The significant events and major operator actions performed during the Diablo Canyon Test are summarized in the following Table 4-1.

TABLE 4-1

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.

TABLE 4-1 (Continued)

CHRONOLOGY OF EVENTS AND OPERATOR ACTIONS

TIME	EVENT/ACTION
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.
0058:	Power operated relief valve (PORV), PCV456, 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.

TABLE 4-1 (Continued)

CHRONOLOGY OF EVENTS AND OPERATOR ACTIONS

TIME	EVENT/ACTION
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 down wards, 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 FCV128 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

TABLE 4-1 (Continued)

CHRONOLOGY OF EVENTS AND OPERATOR ACTIONS

TIME	EVENT/ACTION
	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^{o}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.
0957:	Initiated letdown to lower pressurizer level.
1319:	All four loops T_{HOT} less than 350^{o}F. Plant in Mode 4 condition.

TABLE 4-1 (Continued)

CHRONOLOGY OF EVENTS AND OPERATOR ACTIONS

TIME	EVENT/ACTION
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 1-2 was placed in service.
1831:	The remaining CRDM fans were secured.
2015:	Operators re-energized the CRDM fans (3 only).
2245:	RCS temperature below 200^{o}F. Plant in Mode 5 condition.

4.4 INTERPRETATION AND ANALYSIS OF TEST RESULTS

4.4.1 Natural Circulation

The natural circulation test was performed to verify that 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^{O}F throughout the natural circulation cooldown part of the test.

4.4.2 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 temper atures 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. 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.

A comparison of the increase in boron concentration experienced during the test relative to the LOFTRAN analysis prediction in the Pre-Test Report was made. 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 concentra tion 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 concen tration 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.

4.4.3 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. 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 pro gressed 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. The actual cooldown was very similar to the predicted rate. 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 cool down 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 exponen tially 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 shut down from full power. Finally, in emergency situations, sea water from the auxiliary salt water system may be provided as auxiliary feedwater makeup.

4.4.4 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 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.

4.4.5 Reactor Vessel Upper Head Metal And Fluid Cooldown

4.4.5.1 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 circula-

tion 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.

During the initial portion of the test, the upper head temperature remained cooler than the RCS. The trend continued until 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^{o}F higher than the RCS. Between 1230 and 1330 hours, the RCS cooldown rate was increased to approximately 25^{o}F/hour. The increase in the cooldown rate combined with securing the CRDM fan caused the Δ T between the RCS and the upper head to increase to about 40^{o}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 Δ T to decrease to less than 0^{o}F. When the cooldown was reestablished at 1517 hours, the increase in the upper head/RCS Δ T was again observed. The increase in the upper head/RCS Δ T continued until

about 1835 hours, when all CRDM fans were secured. Securing all CRDM fans caused the upper head/RCS Δ T to increase to about 20°F. At 2015 hours, the CRDM fans were reenergized and the temperature differential remained below 20°F.

4.4.5.2 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^{o}F/hour at an upper head fluid temperature of 600^{o}F to approximately 9^{o}F/hour at an upper head fluid temperature of 350^{o}F with all CRDM fans running.

5.0 COMPARISON OF STP AND DIABLO CANYON DESIGN FEATURES

	Diablo Canyon (Note 1) - STP
Reactor	
Power	3,800 MWt
Fuel Assemblies	193
Vessel Height (Exterior)	43'-10"
Diameter (Inside)	173'
Volume	4562 ft^3
Operating Temperature (Nominal)	
Hot Leg/Cold Leg	626.1/560.4^{0}F
RCPs	
Model	M100A
Capacity	102,500 gpm
Elevation of Discharge Above Top of Fuel Assembly	5'-3-2/3"
Seal Water Injection	8 gpm
Seal Water Return	3 gpm
Steam Generators	
Model	E
Height Length	71'-6"
Diameter (Tube Section)	135"
Tube Number	4864
Elevation of "U" Tubes Above Top of Fuel Assembly	48'-7"

RCS Piping and Valves

Loop Isolation Valves	No
Hot Leg Inside Diameter	29"
Cold Leg Inside Diameter	27-1/2"
RCP Suction Leg Inside Diameter	31"
Are there any significant differences in the RCS piping layout?	No

Pressurizer

Volume	2100 ft^3
Design Temperature	680^{O}F
Elevation Above Top of Fuel Assembly	19'-11"

CVCS

Borated Water Sources	
BAT ppm/Volume	7000/33,500 Per Tank
RWST ppm	2500
Injection Point to RCS	RCP Discharge Loops 1 or 3

AFWS

Volume	525,000 gal.

RHRS

Initiation Pressure/Temperature	350 psig/350^{O}F

<u>System Pressure Drops (psi) at Best Estimate Flow</u>

RV	58.8 psi
S/G	44.4 psi
Hot Leg	1.3 psi
Pump Suction	34 psi
Cold Leg	34 psi
Pump Head	341 ft.
Cold Leg	1.3 psi

<u>TOTAL RCS VOLUME</u>	14043 ft^3

Note 1 - The information provided by Pacific Gas & Electric is considered confidential information and shall not be given to any third parties without PG&E's written consent.

6.0 EVALUATION

NATURAL CIRCULATION

The Diablo Canyon test results indicated that natural circulation flowrates were adequate to ensure 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 throughout the test.

The South Texas Project and Diablo Canyon Unit 1 have been compared in detail to ascertain any differences between the two plants that could potentially affect natural circulation flow. Because of the similarity between the plants, it was concluded that the natural circulation capabilities would be similar; therefore, the results of prototypical natural circulation cooldown tests conducted at Diablo Canyon are representative of the of the capability at South Texas. The natural circulation flow ratio for South Texas/Diablo Canyon is 1.02.

The general configuration of the piping and components in each reactor coolant loop is the same in both South Texas and Diablo Canyon. The head represented by these components and the system piping is similar in both plants.

Steam generator units 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. It was concluded that there are no differences in the original design of the steam

generators in the two plants that would adversely affect the natural circulation characteristics. (Ref. 13).

6.2 Boron Mixing

At Diablo Canyon, 900 gallons of 21,000 ppm borated water from the Boron Injection Tank (BIT) was used to achieve the required shutdown margin. 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 2100 ppm borated water was added to the RCS. To ensure the BIT's contents were flushed to the RCS colds legs, the charging pump was aligned to the BIT for approximately 20 minutes. The total flow rate was about 150 gpm.

The STP design does not include a BIT. Boration will be achieved using the boric acid tanks (BAT) as the source of water for the Charging System. STP has two 33,500 gallon tanks available. The tanks contain 7,000 ppm borated water. This supply is more than adequate to provide the required shutdown margin. (Ref. 13).

6.3 Reactor Coolant System Cooldown

The cooldown portion of the test demonstrated the capability to cool down the RCS to RHR system initiating conditions at approximately 25^{O}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^{O}F of the average core exit temperature. Also, both the steam generators and

reactor vessel head were cooled to below 450^{o}F when the core exit temperature was 350^{o}F.

For the South Texas plant, 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 system. After initiation, the RHR system will be used to cool the plant down to cold shutdown temperatures (Ref. 13).

6.4 Reactor Coolant System Depressurization to RHR

At Diablo Canyon RCS depressurization was accomplished primarily through the use of the Auxiliary Spray System. A pressurizer PORV was used for the last part of the task. At STP, the intent is to use the PORV to depressurize. The Diablo Canyon test showed that spray and PORV were equally effective in depressurizing.

Auxiliary sprays cause the reactor inventory to increase while PORVs cause it to decrease. During the Diablo Canyon test, reactor inventory increased to the point that the Letdown System was used. At STP letdown, if required, is available via the safety grade reactor head vent system.

During PORV use, reactor inventory losses will be made up by the Charging System. At Diablo Canyon, as the PORV decreased RCS pressure from 700 to 350 psig, the Charging System increased pressurizer level from 40% to 70%. Charging from the Boric Acid Tank (7000 ppm Boron) shall further increase shutdown margin.

The maximum RHR initiation pressure is 390 psig at Diablo Canyon and 350 psig at STP. During the test at Diablo Canyon, RCS pressure was reduced to less than 375 psig before initiating RHR. Therefore, the testing is applicable to both situations. (Ref. 13.)

6.5 Reactor Vessel Upper Head Cooldown

This part of the test monitored the upper head bulk water temperature and the upper head vessel metal temperature, providing information on cooldown rates relative to operation of the CRDM fans. For the South Texas plant, operation of the CRDM fans during a natural circulation cooldown will reduce upper head temperatures in a manner similar to that experienced at Diablo Canyon.

Without CRDM fans in operation, the quantity which most affects upper head cooling capability is the head cooling time constant which is proportional to the product of the head volume and the square root of the head bypass flow resistance. The smaller the time constant, the more easily the head is cooled. The time constant ratio of South Texas/Diablo Canyon is 0.862.

Since the Head Cooling Time Constant Ratio is less than one, the South Texas plant responds more rapidly and is more easily cooled.

Thus, it is concluded that cooling of the upper head without CRDM fans at Diablo Canyon will be representative of cooling of the upper head without CRDM fans at South Texas (Ref. 13).

6.6 Auxiliary Feedwater Requirements

STP estimates the auxiliary feedwater requirements to be a maximum of 377,000 gallons to address the scenario of a four hour hot standby, followed by a fourteen hour (approximately) natural circulation cooldown, including the most limiting single failure (Ref. 12).

The auxiliary feed tank's usable capacity is 525,000 gallons.

7.0 CONCLUSION

Design features which are important to natural circulation cooldown and boron mixing are substantially the same at STP and Diablo Canyon. As discussed in Sections 5.0 and 6.0 those features which are different either are not significant or favor STP.

The testing at Diablo Canyon has proven for both designs that:

- Boron mixing is essentially complete one hour after injection; and.

- Natural circulation cooldown can be achieved within the limits specified in Emergency Operating Procedures based on the Westinghouse Owner's Group Emergency Response Procedures.

REFERENCES

1. Nureg0800-Rev. 3-April 1984. - Residual Heat Removal (RHR) System

2. Regulatory Guide 1.139-May 1978-Guidance for Residual Heat Removal

3. ST-WN-YB2175 - Westinghouse letter - Auxiliary Feedwater Storage Tank Volume Requirements

4. SR-14-9-Z-42151 (R4) - Reactor Coolant Pressurizer Heater back up group 1A and 1B Logic Diagram.

5. WCAP11095 - Diablo Canyon Units 1 and 2 Natural Circulation/Boron Mixing/Cooldown Test

6. ST-WN-HL3161 - Westinghouse Fire Hazards Analysis and Cold Shutdown

7. ST-HL-AE1683 - Final Safety Analysis Report Amendment 54 - June 20, 1986

8. South Texas Project Safety Evaluation Report (SER), NUREG-0781, April 1986

9. 1EP4ZX10 - Natural Circulation Verification Test

10. 1-POP05-EO-ES02 - Natural Circulation Cooldown

11. 1-POP05-EO-ES03 - Natural Circulation Cooldown With Steam Void in Vessel

12. ST-HL-AE-1767 - Long term cooling.

13. ST-WN-HL-3158 Natural Circulation Comparison Evaluation (Westinghouse Propriety Class II).