ENCLOSURE

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

SAFETY EVALUATION REPORT
DIABLO CANYON UNIT 1
NATURAL CIRCULATION, BORON MIXING, AND COOLDOWN TEST
DOCKET NO. 50-275

INTRODUCTION

As part of the seismic evaluation of the postulated Hosgri earthquake in 1978, the licensee committed in the Hosgri Report to perform a natural circulation, boron mixing, and cooldown test (Reference 1). Appendix J to the Hosgri Report provides the scenario and identification of systems and components that would be utilized for natural circulation cooldown to cold shutdown conditions following the postulated SSE. The staff addressed the test in Section 3.2.1 of its Safety Evaluation Report Supplement No. 7 in 1978 (Reference 2). The licensee conducted the test in March 1985 and provided the evaluation and results in a report (proprietary and non-proprietary version) by letter dated March 25, 1986 (Reference 3). The NRC staff has reviewed the report and was assisted in this effort by its consultant, Brookhaven National Laboratory (BNL). NRC staff and BNL met with the licensee and Westinghouse, its consultant, on November 21, 1986 to discuss the preliminary BNL evaluation (Reference 4).

This is the staff's evaluation of the test. The BNL evaluation and results of their studies are included in this evaluation as Enclosure 1.

Branch Technical Position RSB 5-1, "Design Requirements of the Residual Heat Removal (RHR) System", states that test programs for PWRs:

> "shall include tests with supporting analysis to (a) confirm that adequate mixing of borated water added prior to or during cooldown can be achieved under natural circulation conditions and permit estimation of the times required to achieve such mixing, and (b) confirm that the cooldown under natural circulation conditions can be achieved within the limits specified in the emergency operating procedures. Comparison with performance of previously tested plants of similar design may be substituted for these tests."

Therefore, as stated above, the licensee committed to perform a natural circulation, boron mixing, and cooldown test at Diablo Canyon Unit 1.

OBJECTIVES

The objectives of the test were to establish natural circulation conditions using core decay heat, confirm that adequate mixing of borated water added to the reactor coolant system (RCS) prior to cooldown can be achieved under natural circulation conditions, verify that the RCS can be borated to the cold shutdown concentration, maintain hot standby conditions under natural circulation

conditions for at least 4 hours, determine if cooldown and depressurization of the RCS from normal hot standby to cold shutdown conditions can be accomplished using only safety-grade equipment, obtain reactor vessel head cooldown rates, and verify that adequate water volume is available in the condensate storage tank to cool down the unit.

The acceptance criteria as stated in the test report (Reference 3) was as follows:

(1) 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.

(2) 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 the RCS hot legs (Loops 1 and 4) indicate that the active portions of the RCS were borated such that the boron concentration had increased by 250 ppm or more.

(3) The acceptance criteria for the cooldown portion of the test were to 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, and assure that the RHR system is capable of cooling down the RCS to cold shutdown conditions.

(4) 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.

(5) The acceptance criterion for the depressurization portion of the test was that RCS pressure be reduced below RHR system initiation pressure (390 psig).

TEST

The test was performed at Diablo Canyon Nuclear Power Plant, Unit 1 on March 28 and 29, 1985. The reactor was tripped from 100% power and the plant maintained at hot standby. The reactor coolant pumps (RCPs) were operated for the first 3 hours and then tripped. Natural circulation flow was verified and the boron mixing part of the test was then initiated by injecting the contents of the boron injection tank (BIT). The system was maintained at hot standby under natural circulation conditions for approximately 4 hours. Cooldown at a rate of 20°F per hour was initiated using the atmospheric steam dumps (ASDs). The

RCS was then depressurized to RHR initiation conditions. The time for the combined cooldown/depressurization steps was about 13 hours. The RCS was then brought to a cold shutdown condition in about 4 1/2 hours utilizing the RHR system. A test chronology is included in Enclosure 1. The acceptance criteria for the test were met. The test was witnessed by NRC personnel.

It is noted that some non-safety grade systems and components were utilized during the test. These included the letdown system, 3 control rod drive mechanism (CRDM) fans, pressurizer heaters and volume control tank (VCT). The use of the CRDM fans was required to maintain the CRDM temperatures within acceptable limits. However, in the event of loss of offsite power (LOOP) because of the SSE or for other reasons, the fans would not be available during the cooldown. This has a major impact on upper head cooling. The letdown system was used to prevent overfilling the pressurizer since RCP seal injection was maintained during the test. The safety-grade reactor vessel head vent could have been used as an alternate means of letdown but its use could have entailed potential discharge of reactor coolant to the containment. Contraction of the coolant volume during plant cooldown would also tend to mitigate the effects of seal injection. The safety grade refueling water storage tank (RWST) could have been used as an alternate to the VCT but the RWST contains high levels of dissolved oxygen and its use could have resulted in exceeding technical specification oxygen concentration limits which in turn could have resulted in excessive localized corrosion and consequent increased radiation exposures to plant workers.

EVALUATION

In the event of an SSE, the operator would not have normal system capability for RCS pressure control. Pressure reduction could be achieved by the seismically qualified PORVs or, within thermal stress limits, by the auxiliary pressurizer spray. The pressurizer heaters are not seismically qualified, but two of the four heater groups can be manually powered from vital buses. The charging pumps could probably be used to maintain or increase pressure, but this could result in pressurizer overfill. With regard to the delay in tripping the RCPs the licensee stated that this would ensure a more stable condition so that the test could be properly conducted. The delay in the RCP trip allowed RCS temperature to become more uniform, including some reduction in the upper head temperature. The delay also reduced the level of decay heat somewhat. As noted in Enclosure 1, this slightly reduced the natural circulation flow and increased the boron mixing time. It also allowed the upper head temperature to become more uniform.

The Diablo Canyon Plant emergency operating procedures (EOPs) are based on the Westinghouse Owners Group Emergency Response Guidelines (ERGs), which assume the use of normal operation systems. Reference 3 identifies the systems that would be normally used for natural circulation cooldown. It also identifies alternate seismically qualified systems that could be utilized in the event the normal systems are incapacitated, and demonstrates how the necessary functions would be achieved. The effect of CRDM fan unavailability is discussed below. In Reference 3, the licensee also committed to develop alternative operational strategies 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.

In support of the staff evaluation of the Diablo Canyon Unit 1 test, the staff consultant Brookhaven National Laboratory (BNL) performed test simulation analyses as reported in a Technical Evaluation Report (TER), included as Enclosure 1. The RELAP5/MOD1 code was utilized. The sequence of events assumed by BNL in the analysis differed somewhat from the test. As noted in Enclosure 1, the purpose of the BNL analysis was not to duplicate the test but to provide the information necessary to assess the impact of the use of non-safety grade equipment during the test. Reasonably good agreement between the test data and analytical results were obtained for RCS natural circulation flow and temperature. Since the BNL analysis did not assume utilization of the pressurizer heaters and the letdown system, it is difficult to compare RCS pressure test data and analytical results.

The largest difference between the test and analytical results were obtained for reactor upper vessel head cooling time. The CRDM fans were operated during the entire test, except for a 2 hour period. The use of the CRDM fans provided adequate cooldown of the upper head. The maximum temperature differential between the RCS and upper head temperature was 40°F. However, the CRDM fans are not safety grade. Since the Diablo Canyon Plant is a T-HOT plant, the upper head temperature is near the RCS hog leg temperature during normal operation because the bypass flow rate between the upper downcomer and the upper head is relatively low. As noted in Reference 5, for T-HOT plants without CRDM fan operation, a waiting period (soak time) is required before the RCS is depressurized to RHR entry conditions. This period is 8 hours for top hat upper support plate plants, which include the Diablo Canyon Plant. The BNL calculations, on the other hand, indicate a required waiting period of about 35 hours. These calculations were done conservatively by dividing the upper head into 4 heat conduction nodes, with the upper head fluid assumed completely stagnant. Conduction was the only mechanism assumed for cooldown, the heat loss from the dome to the containment environment was ignored, and the bypass fluid mixed only with the fluid in the bottom of the upper head. During the test all CRDM fans were turned off for about 100 minutes. The average upper head cooldown rate was estimated to be approximately 6°F per hour, which translates into about a 25 hour hold period. However, the time period for the test without CRDM fans was too short to be conclusive.

Reference 3 states that 126,000 gallons of water from the condensate storage tank (CST) was used as auxiliary feedwater (AFW) makeup for plant cooldown. However, with the CRDM fans unavailable, the BNL calculations conservatively result in a 360,000 gallon secondary water makeup requirement. The Diablo Canyon CST has a volume of 400,000 gallons, of which 178,000 gallons are dedicated for AFWS supply. Additionally, 270,000 gallons of water are maintained in the fire water storage tank for AFWS supply. As stated in the FSAR (Reference 6) the fire water storage tank and the piping between it and the CST are Seismic Category I. The staff concludes that for the Diablo Canyon Plant a sufficient assured water supply is available for plant cooldown via the steam generators even when the CRDM fans are not available.

CONCLUSIONS

Based on the Diablo Canyon Unit 1 test results (Reference 3) and their analyses reported in Enclosure 1, BNL concluded that:

1) The Diablo Canyon Unit 1 test demonstrated that adequate natural circulation was established and the plant was capable of removing the decay heat by natural circulation using only safety-grade equipment.

2) Adequate boron mixing was achieved during natural circulation in the main flow path of the RCS using only safety-grade equipment.

3) The effect of relatively unborated water entering the RCS from the upper head and pressurizer appears to be minimal as long as depressurization is conducted carefully to limit the size of possible void formation.

4) The pressure would rise and reach the PORV actuation pressure without letdown during the boron mixing period.

5) The test adequately demonstrated that the RCS can be cooled to the RHR system initiation temperature while maintaining adequate subcooling during natural circulation using only safety-grade equipment.

6) The test demonstrated that the upper head could be cooled without void formation when the CRDM fans were in operation.

7) The tests results indicate that the upper head cooldown rate without the CRDM fans is about 6°F per hour. This is higher than the conservative BNL calculation based only on conduction heat loss, which estimated a minimum rate of 3°F per hour.

8) The RCS pressure should be maintained about 1200 psia by means of either the pressurizer heaters (if available) or charging during the cooldown period to prevent upper head voiding when the CRDM fans are not in operation.

9) A sufficient supply of safety grade cooling water was available to support the proposed plant cooldown method even if the CRDM fans were not available for the Diablo Canyon Plant.

10) Only one motor-driven AFW pump was sufficient to supply the necessary cooling water throughout the transient.

11) Sufficient ASD valve capacity was available to support the cooldown even when the cooldown rate was assumed to be 50°F per hour.

12) The availability of the pressurizer heaters and letdown system, while not essential, would affect the operational procedures in a major way. The strategy to reduce the upper head cooling time by intentionally forming a void may be difficult to perform without pressurizer heaters.

13) The RCS pressure would increase and stay high, and the PORV may be actuated periodically if the letdown system were not available, due to boron injection and the continuous injection of RCP seal flow. The operation of the auxiliary pressurizer spray normally requires letdown to be in operation to prevent possible thermal stress on the spray nozzle.

References 1 and 3 contain single failure analyses demonstrating redundancy of safety grade systems that would be utilized following a seismic event. BNL has independently verified that adequate cooldown could be accomplished with failure of one AFW pump or ASD. The Diablo Canyon Plant design provides a single RHR drop line with two inlet isolation valves in series. In response to a staff request to provide justification that the probability of mechanical failure of either of the two valves is sufficiently low as to not merit consideration as a single failure, the licensee stated that the combined probability of valve stem failure coincident with the SSE is on the order of 10^{-7} per year (Reference 4). The licensee has also indicated that failure of a power train or valve operator could be mitigated by local operator action (Reference 1).

The staff concludes, therefore, that based upon the licensee's submittals and the BNL analysis, the Diablo Canyon Unit 1 natural circulation, boron mixing and cooldown test adequately demonstrates that the Diablo Canyon Plant systems meet the intent of BTP RSB 5-1 for a class 2 plant.

APPLICABILITY TO OTHER PLANTS

The Diablo Canyon Unit 1 test has been referenced by a number of near-term-operating-license (NTOL) plants and recently licensed Westinghouse plants. Several of these plants have a limited safety grade supply for the AFW system. Also, some plants have different design upper vessel heads which contain much larger volumes of relatively stagnant water. It is, therefore, appropriate to perform more realistic calculations for upper head cooldown with only safety grade systems, in order to provide assurance that each plant in this category has a sufficient volume of safety grade water supply. The staff has, therefore, requested additional information from Westinghouse with regard to the upper head mixing phenomena, convection heat losses, and other pertinent items (Reference 7). If adequate information on these subjects is obtained, BNL could reanalyze upper head cooling in order to obtain more realistic cooldown times. The results of such reanalysis would be documented appropriately. While the staff considers natural circulation cooldown without voids as more desirable, cooldown with voids may be acceptable provided it can be accomplished using only safety grade equipment (including adequate instrumentation), approved procedures, and the operators have adequate training in the use of these procedures. If the use of safety grade head vents is contemplated in order to vent the steam in the upper head and/or enhance upper head mixing, due consideration should be given to the effect of this operation on the integrity of the pressurizer relief tank and the effect of loss of its integrity.

It is the intent of a number of recent licensees and NTOLs to reference the Diablo Canyon Unit 1 test to demonstrate conformance with the testing requirements of BTP RSB 5-1. The staff requires that licensees/applicants referencing the Diablo Canyon Unit 1 test be able to demonstrate thermal and hydraulic similarity of their plants with the Diablo Canyon design. Each plant must also demonstrate that an adequate safety grade water supply is available for secondary makeup during natural circulation cooldown without offsite power. In addition Westinghouse should provide the details of its estimation for the upper head cooling time without the CRDM fans. The BNL analysis and the test data indicate that the cooling period should be substantially longer than the 8 hour hold period estimated by Westinghouse.

In order to facilitate the staff's evaluation of this matter, the BNL report, included as Enclosure 1, includes a sensitivity analysis which identifies plant parameters that may affect application of the test results to other Westinghouse plants, and provides estimates of the sensitivity of the results to these parameters. Table 5.1 of Enclosure 1 shows the sensitivity of the natural circulation flow to these parameters in terms of percent change in natural circulation flow to a 10% change from the Diablo Canyon Unit 1 parameter. However, it should be noted that the "Remark" column of this table is subjective and may vary from plant to plant.

PRINCIPAL CONTRIBUTOR:

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REFERENCES

(1) PG&E Report "Seismic Evaluation For Postulated 7.5M Hosgri Earthquake, Units 1 & 2, Diablo Canyon Site", Appendix J "Systems/Equipment For Achieving & Maintaining Hot Standby & Cold Shutdown of Diablo Canyon Units 1 & 2 Following SSE", March 1978.

(2) U.S Nuclear Regulatory Commission, NUREG-0675, "Supplement No. 7 to the Safety Evaluation Report of the Diablo Canyon Nucler Power Station Units 1 and 2", May 1978.

(3) WCAP-11095 (Non-Proprietary), "Natural Circulation, Boron Mixing, and Cooldown Test - Final Post Test Report for Diablo Canyon Power Plant Units 1 and 2, March 1986", Letter DCL 86-078 from J. D. Shiffer (PG&E) to S. A. Varga (NRC) dated March 25, 1986.

WCAP-11096 (Proprietary) - same as above but proprietary

(4) "Meeting Summary - Natural Circulation, Boron Mixing, and Cooldown Test (November 21, 1986)", H. Schierling (NRC), dated December 9, 1986.

(5) Westinghouse Owners Group Emergency Response Guidelines, "Background Information for the Westinghouse Emergency Response Guidelines, ES-0.2, Natural Circulation Cooldown."

(6) Diablo Canyon FSAR Update, Revision 1, September 1985.

(7) "Request for Additional Information Needed to Evaluate Reactor Vessel Upper Head Cooling During Natural Circulation Cooldown", Letter from C. H. Berlinger (NRC) to D. Butterfield (WOG), January 15, 1987.

ENCLOSURES

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