REVIEW OF THE DCPRA: LETTER REPORT-06/REV.1

A REVIEW OF SYSTEM ANALYSIS IN THE DCPRA: COMPONENT COOLING WATER SYSTEM, REACTOR COOLANT PUMP SEAL COOLING EQUIPMENT

G. Bozoki
R. Fitzpatrick
M. Sabek

May 1989

Risk Evaluation Group
Department of Nuclear Energy
Brookhaven National Laboratory
Upton, NY 11973

Prepared for
U.S. Nuclear Regulatory Commission
Washington, DC 20555
Contract No. DE-AC02-76CH00016
FIN A-3958

96

1. INTRODUCTION

1.1 Objectives

The main objective of this letter report is to summarize the results, to date, of reviewing the unavailability modelling of the Component Cooling Water System (CCWS) and the Reactor Coolant Pump (RCP) Seal Cooling equipment described in the DCPRA.[1] An additional objective is to determine a BNL value for the initiator "Total Loss of Component Cooling Water (LOCCW)" based on generic plant experience appropriately updated for Diablo Canyon using Bayesian techniques. This was done to compare with the currently used (PG&E) value obtained by calculating the total yearly failure frequency of the CCW system via fault tree analysis. All findings and insights listed in this report reflect BNL's current understanding of the DCPRA and as such must be considered interim results. Final results for this analysis will be provided in the NUREG/CR document to be issued at the end of the project and will reflect, at that time, any additional supporting input submitted by PG&E as well as any direct feedback on these preliminary findings.

1.2 Organization of the Report

Section 2 provides a brief description of functions and the configurations, the dependency on support equipment, the surveillance and maintenance conditions, the unavailability modelling of the CCWS as given in the DCPRA, and the original PRA results. Similarly, Section 4 describes the approach used by PG&E to analyze the unavailability of the equipment necessary to maintain RCP seal cooling and the corresponding PRA results. The purpose of this approach is to present to the reader stand alone documentation to which this review's findings can be directly related or compared. Section 3 contains the results of the BNL review of the CCWS and presents a new value for the LOCCW initiator. Section 5 presents some unresolved questions raised by BNL in reviewing the unavailability analysis of the RCP seal cooling.

For completeness, the documentation of the information used by BNL for determination of the initiator frequency (LOCCW) is presented in Appendix A.

2. UNAVAILABILITY MODELLING OF THE COMPONENT COOLING WATER SYSTEM IN THE DCPRA

2.1 System's Functions, Description and Operation

The functions of Component Cooling Water System (CCWS) at Diablo Canyon are:

a. to supply cooling water to vital and non-vital loads after an accident,

b. to provide cooling water to various plant components during normal operation, and

c. to provide cooling water to the RHR system during plant cooldown.

The CCWS also represents a monitored intermediate barrier between radioactive fluids and the Auxiliary Saltwater System to which it rejects its heat.

The CCWS consists of three CCW pumps, two CCW heat exchangers, an internally baffled surge tank, and two chemical addition tanks. Its piping consists of three parallel loops. Two are separable redundant vital service loops, "A" and "B", serving only the unit's emergency safety feature equipment and post-LOCA sample cooler. A miscellaneous service loop, "C", serves non-vital equipment. The loads on the three loops are listed in Table 2.1. The system's drawing is shown in Figure 2.1. The Reactor Coolant Pump (RCP) seal water heat exchanger, as well as the RCP thermal barrier and motor oil coolers do not represent "vital" loads as they are located on Loop C.

The CCWS is normally operating with all loops in service. Usually, two CCW pumps and one CCW heat exchanger are in operation. The third pump and the second heat exchanger are in standby. The standby pump starts on low pressure in loops A or B. (The pump breaker will not close until lube oil pressure is 6 psig; the lube oil pressure is provided by a lube oil pump.) With ocean water temperature in excess of 64°F, two CCW heat exchangers are in service.

The flow through the heat exchangers is controlled from the control room by switching the CCW heat exchanger control valves.

During cooldown, all loops are operated with two or three pumps and two heat exchangers. If one of the pumps or one of the heat exchangers is inoperative, orderly shutdown is not affected, but the time for cooldown is extended.

Following an initiating event an "S" signal starts all non-operating CCW pumps. (The S signal bypasses the lube oil pressure interlock.) A transfer to emergency power trips all three CCW pumps on under voltage, then restarts the three pumps when bus voltage is restored. Loop C is automatically isolated on high-high containment pressure (Phase B isolation, "P" signal) or it can be isolated manually. The operator can also reduce flow to the containment fan coolers.

2.2 Top Event Definition, Success Criteria

Associated with the unavailability of the CCW function, the DCPRA defines only one top event to be used in the support system event tree ("mechanical" part). The designator of this top event is: CC. It is evaluated for nine boundary conditions depending on the initiator and/or the unavailability of certain trains of support systems.

One of the boundary conditions (designator: CCI) was taken as an initiator among one of the initiator groups of the DCPRA called "common cause initiating events." The initiator name "total loss of LPCC" indicates the initiating event frequency when all the CCW pumps fail. Its value is computed as: LPCC=CCI.

The success criteria of the top event CC is described in Table 2.2 for post accident injection and recirculation phases as well as for normal plant operation and cooldown. The table also indicates the Technical Specifications. A comparison of the top event success criteria with the

success requirements for this system described in the DCFSAR[2] showed that the top event success criteria cover those given in the DCFSAR.

2.3 Logic Model, Dependency on Other Support Systems

The logic model of the top event CC describing the CCW system configuration is shown in Figure 2.2. The CCWS is modelled with one heat exchanger, because the second heat exchanger is isolated during normal operation and there is no operating procedure for placing the standby heat exchanger in service following failures of the operating one. The isolation valve for Loop C (FCD-355) is not modelled because flow to Loop C is not required for system success. (Loop C is located within the reactor primary shield wall. It is the most vulnerable of the CCW loops to a failure concurrent with a major LOCA.) The DCPRA assumes that excessive leakage from the CCWS would be discovered and corrected prior to any initiating event; therefore, failure of makeup to the surge tank will not fail the system function during the 24 hour mission time. It assumes also that pumps 1-1 and 1-2 are the running pumps and pump 1-3 is in standby, and a check valve failure at the discharge side of the standby pump produces sufficient bypass flow to fail the system function.

2.4 Boundary Conditions of Top Event CC

Boundary conditions include loss of offsite power and degraded states of support systems such as: vital 4.16kV ac buses, vital 480V ac and 125V dc buses, the SSPS trains A and B. The nine split fraction boundary conditions cover all combinations of support system effects on the CCWS.

The failure of the operator action to throttle CCW flow to the containment fan coolers is included in the unavailability model. The detailed list of the boundary condition definitions and the designators of the associated top event split fractions are given in Table 2.3.

2.5 Quantification of Top Event Split Fractions, CC

Table 2.4 lists the values of CC split fractions associated with the various boundary conditions quantified by PG&E. The table presents the total unavailabilities (TTL) along with the main contributors to the total unavailabilities, such as hardware (HW), maintenance (MN), test (TS), and human error (HE). At a given boundary condition the hardware contribution relates to the normal alignment of the CCWS, when no test or maintenance activities are being performed. The table also indicates the two constituent parts of the hardware contribution to the unavailability, the independent (HWI) and the dependent (HWD, i.e., common cause) failures of supercomponents of the CCWS. The definition and the failure rates of the supercomponents of the CCWS are given in Chapter D.2.7 of the DCPRA and are therefore not repeated here.

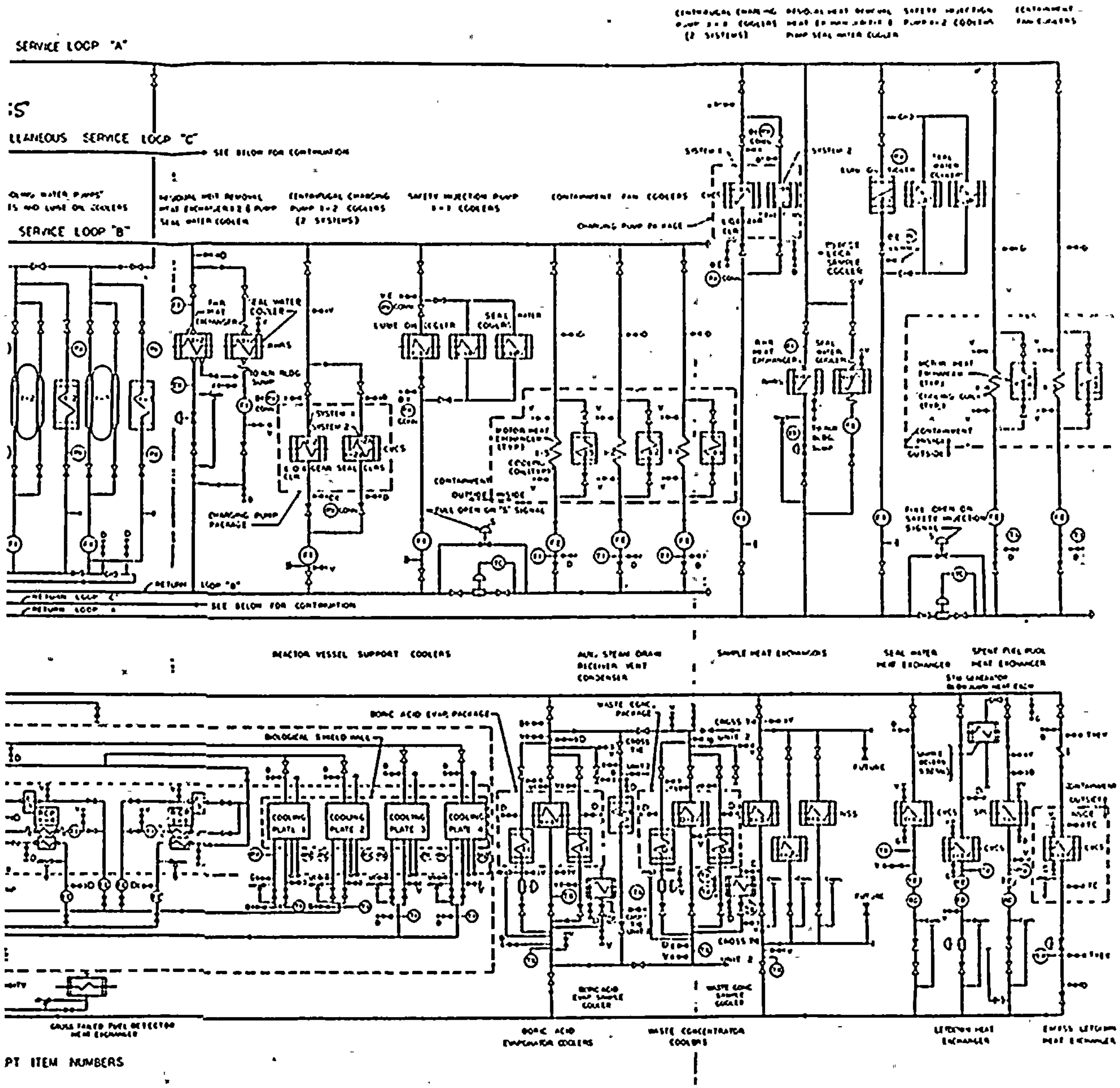
The CCW pumps are tested for auto start on low header pressure at a nominal three year frequency. The CCW pumps and their respective discharge check valves are tested for operability on a quarterly basis. When the CCW heat exchanger outlet valves are tested and the RCPs are running both heat exchangers must be in service (the valve would be closed for less than one minute). Since these tests were not considered as making the system unavailable, there was no contribution due to test included in the system unavailability model. Similarly, following a test, misalignment errors were assumed to be insignificant on the basis that several independent errors would have to be made to make the system unavailable.

Maintenance on the heat exchangers was not included because only one heat exchanger is modelled (no unavailability is incurred if the standby heat exchanger happens to be in maintenance).

The impact of seismic failure is modelled by assuming structural failures in the vital loads (see Loops A and B in Table 2.1).

2.6 Quantification of the Initiator: LPCC

The DCPRA models and quantifies the initiator LPCC as loss of all CCW pumps or loss of two CCW pumps in the event if the third pump would be in maintenance. In the calculation it was assumed that there is a weekly changeover between the operating and standby pumps. The numerical result of the quantification is indicated at boundary condition CCI and denoted by "LPCC" in Table 2.4. BNL review comments on LPCC are found in Section 3.5.



ooling Water System.

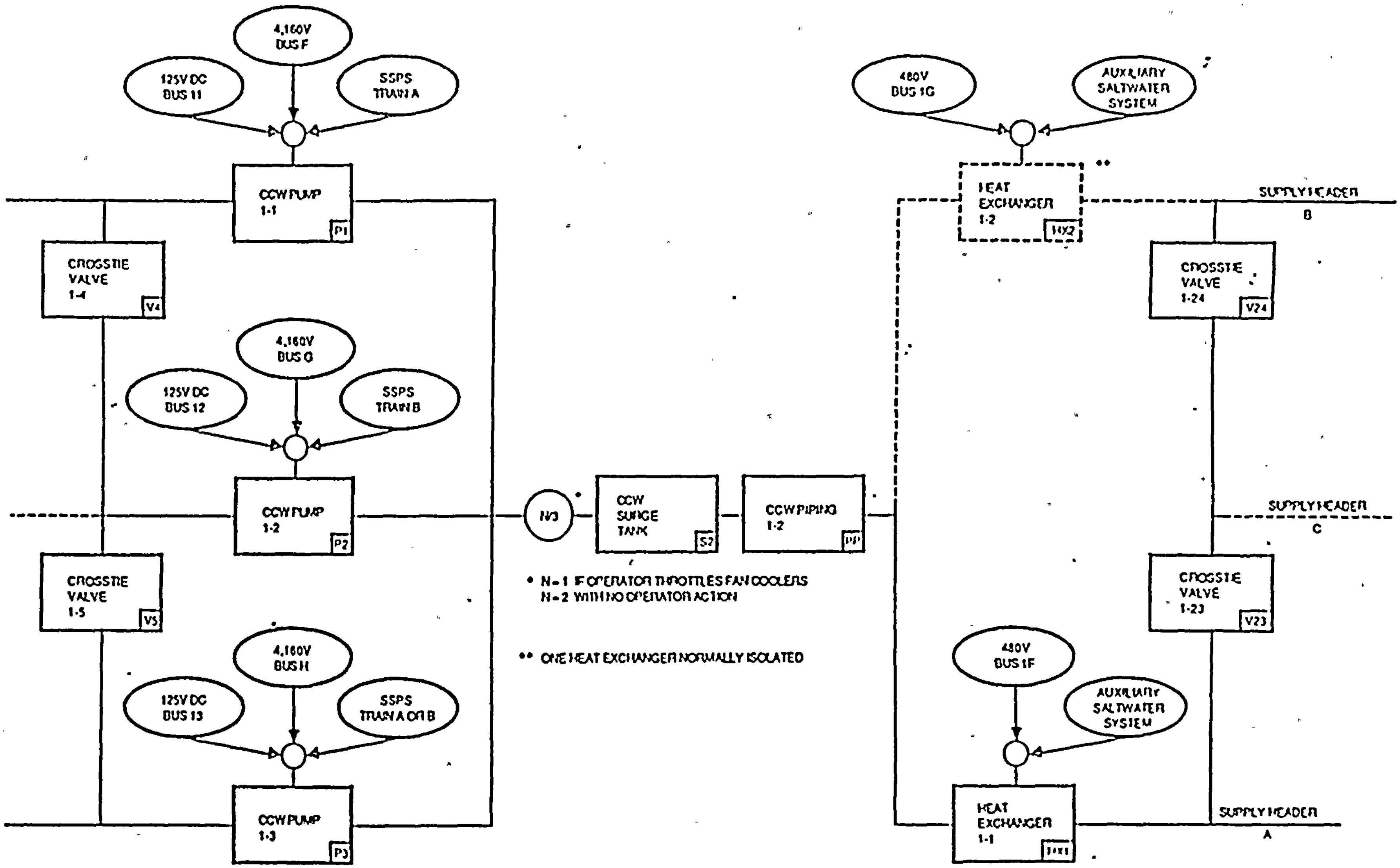


Figure 2.2. Reliability block diagram for top event CC - Component Cooling Water System.

Table 2.1
Component Cooling Water System Loads

	Loop A	Loop B	Loop C
Containment fan coolers	2	3	
Residual heat removal heat exchangers	1	1	
Residual heat removal pump seal water coolers	1	1	
Centrifugal charging pump oil and seal water coolers	1	1	
Safety injection pump oil and seal water coolers	1	1	
Component cooling water pump oil coolers and stuffing boxes	2	1	
Post-LOCA sampling cooler	1		
Spent fuel pool heat exchanger			1
Reactor coolant pump			1
Seal water heat exchanger			1
Letdown heat exchanger			1
Excess letdown heat exchanger			1
NSSS sample heat exchangers			3
Failed fuel detector heat exchanger			1
Steam generator blowdown sample heat exchangers			5
Reactor coolant pump thermal barriers and motor oil coolers			4
Reciprocating charging pump coolers			1
Boric acid evaporator condenser, distillate cooler, vent condenser, and sample cooler			1
Waste concentrator condenser, distillate cooler, vent condenser, and sample cooler			1
Auxiliary steam drain receiver vent condenser			1
Waste gas compressors			2

Table 2.1 (Continued)

	Loop A	Loop B	Loop C
Reactor vessel support coolers			4
Sample panel coolers			1

Table 2.2
Top Event Definitions and Success Criteria
Component Cooling Water System Function

Top Event Designator	Top Event Definition	Top Event Success Criteria
CC	CCWS provides cooling water to vital components during 24 hours following an initiating event.	1. Post accidental injection and recirculation phase: Two CCW pumps and one CCW heat exchanger must provide cooling flow to loads on two vital CCW loops A and B, if the operator does not reduce flow to containment fan coolers or to header C. If the operator throttles flow to the fan coolers or header C, or header C is isolated automatically by a containment high-high pressure signal (Phase B), one of three CCW pumps and an operable heat exchanger are sufficient for system success. 2. Under normal plant cooldown conditions: All the three loops are operated with two or three pumps and two heat exchangers. (If one of the heat exchangers is operative, orderly shutdown is not affected, but the cooldown time is extended.) 3. Under normal operation. All the three loops are used, with one or two pumps and one heat exchanger. If ocean temperature exceeds 64°F, the second heat exchanger is also placed in service.

Technical Specifications
LCOs:
1. May operate 72 hours with one vital loop of CCW inoperable; if two vital loops are inoperable, must be in at least hot standby within the next six hours and in cold shutdown within the following 30 hours.
2. When ocean water temperature exceeds 64°F two CCW heat exchangers must be in operation within eight hours.

Table 2.3
Boundary Conditions for Top Event, CC

Split Fraction ID	Boundary Condition
CC1	All support available (N/3 pumps starts and/or runs).
CC2	Loss of 4kV Bus H (N/2 pumps runs).
CC3	Loss of 4kV Bus G (N/2 pumps starts and/or runs).
CC4	Loss of 4kV Buses F and G (1/1 pump runs).
CC5	Loss of 4kV Buses F and G (1/1 pump starts and runs).
CC6	LOSP - All support available (N/3 pumps starts and runs).
CC7	LOSP - Loss of one 4kV Buses F, G, or H (N/2 pumps starts and runs).
CCI	Initiating event frequency (all pumps fail).
CCF	Guaranteed failure.

Note: N-1 if operator throttles fan coolers.
N-2 if operator fails to throttle fan coolers.

Table 2.4
Unavailability Values (Split Fractions) for the
Component Cooling Water System Function

Top Event	Case	Calc.	TTL	HW	HWI	HWD	MN	TS	HE	Comment #
CC	CC1	PG&E	1.878-5	1.840-5	1.835-5	5.555-8	3.808-7	----	----	
	CC2	PG&E	5.689-4	3.981-4	3.978-4	3.547-7	1.708-4	----	----	
	CC3	PG&E	5.849-4	4.141-4	4.137-7	3.547-7	1.708-4	----	----	
	CC4	PG&E	2.674-2	1.450-3	1.449-3	6.622-7	1.019-2	----	7.656-3	
	CC5	PG&E	2.865-2	3.373-3	3.373-3	6.622-7	1.019-2	----	7.656-3	
	CC6	PG&E	2.431-5	2.255-5	1.955-5	3.003-6	1.763-6	----	----	
	CC7	PG&E	6.625-4	4.437-4	4.355-4	8.139-6	2.189-4	----	----	
LPCC	CCI	PG&E	1.965-4	2.231-4	2.019-4	2.114-5	----	----	8.037-6	1
	CCF	PG&E	1.0							

1. The CCI value is indicated here. CCI=.85*TTL, where .85 is the capacity factor of Diablo Canyon Unit 1.

3. RESULTS OF THE BNL REVIEW

3.1 General

In spite of the fact that the CC split fractions were not subjects for quantitative audit calculations, BNL performed a quite thorough qualitative review of the unavailability modelling of this top event. The thorough qualitative review was done because the CCWS is an important support system impacting the safety of the majority of plant operations, including cold shutdown.

Special attention was directed to the determination of the initiator frequency, when the CCWS is completely lost, because the DCPRA uses a "non-plant-specific experience-based" value for this initiator based upon fault tree analysis.

An approach, similar to that applied in reviewing the Auxiliary Saltwater System was used: check the adequacy of the DCPRA modelling for "system-specific" effects derived from applicable experience. For that purpose BNL obtained information from a recent study[3] investigating the operating experience of the CCWSs at U.S. PWRs. From this study (which is based mainly on analyzing NPRDS events) one can extract information about the nature and the main characteristics of generic CCWS failures. In addition, BNL performed a survey of CCWS failure events at PWRs by using the RECON[4] data base to obtain information about the characteristics of those events in which the CCW function was completely lost or had the potential for such a complete loss. After having ascertained the nature and characteristics of these failures, an evaluation was made as to how well the DCPRA model reflects this experience. Finally, an attempt was made to determine a Diablo Canyon-specific "Loss of Component Cooling Water," LOCCW initiator frequency based upon industry experience as a prior and updated accordingly.

3.2 Results of the Survey on the CCW Systems Failures

The CCWS is a continuously operating system, like the Auxiliary Saltwater System (ASW), but in contrast with the ASW, it is a closed system circulating treated water. Its predominant failure mode was found (based on 1179 NPRDS records by Reference 3) to be: leakage (37%), associated mainly with both pumps and valve failures. The second failure mode (12%) was found to be: loss of function and failure to meet specification. Valve does not close (9%), does not open (5%), incorrect signals (9%), plugging (4%), noise/vibration (3%), short circuit (2%), and other failures (together 11%) were found to represent the other characteristic failure modes of the CCWS. The majority of the CCWS failures resulted in degraded operation of the system or in a loss of redundancy. Valves (~53%), pumps (~21%) and load heat exchangers (~12%) were found to be the components having most of the failures (roughly reflecting their occurrence frequency in the CCWS design). Pump failures were dominated by seal and bearing failures (resulting in leakage), while valve failures were dominated by valve operator failures and wear of the valve seats.

For the present study the distribution of pump and valve failure modes is very important. These were found to be:

Pump failures: leakage (49%), fail to run (23%), vibration (11%), fail to start (5%), low output (4%), other (8%).

Valve failures: leakage (30%), spurious operation (27%), fail to open (25%), fail to close (2%), other /unknown (16%).

The description of events (found by the BNL survey) which resulted in or had the potential to result in a complete loss of CCWS is given in Appendix A. Failures which lead to the complete loss of the CCW function typically involved:

a. Loss of an operating CCW heat exchanger while the other was in maintenance. The loss was caused either by a closed outlet valve or loss of shell side (service water) cooling flow (clogging, leak).

The events of the latter type are essentially failure events "linked" with the Service Water System ("linked initiators").

b. Loss of the CCW pumps (in the reported case: due to flooding by human error).

The recovery times of the CCW failure events (as estimated by the time evolution of the various events) indicate a distribution similar to that of the service water, extending from a representative 1-2 hours to more predictable time periods of a few hours or of even one or more days (fixing corroded CCW heat exchangers).

3.4 Comments on the CC Top Event Modelling

The review of the unavailability modelling of the CCWS was based upon the latest version of the DCPRA information recently provided by PG&E[5] and the information obtained from the CCWS failures described above.

a. The review found that the DCPRA model of the CCW used the same or even smaller failure rate values for the continuously running CCW pumps as was used for standby pumps (this is against the industry wide experience on the CCWS mentioned in the previous section). Compare, e.g., the pump fails to run failure mode:

   S3PCCR, 1 of 3 CCW pumps fail to run: 2.91-5/hour.

   While for standby systems:

   S2PAMR, 1 of 2 Auxiliary Feedwater pumps fail to run; 2.86-5/hour

   S2PCSR, 1 of 2 Spray pumps fail to run; 3.48-5/hour

   S2PRHR, 1 of 2 RHR pumps fail to run; 3.11-5/hour

   S2PS1R, 1 of 2 SI pumps fail to run; 3.48-5/hour

   Similarly:

   S3PCCS, 1 of 3 CCW pumps fail to start; 1.76-3/d. This value should be compared with:

   S2PAMS, 1 of 2 Auxiliary Feedwater pumps fail to start; 2.04-3/d

   S2PCCS, 1 of 2 Spray pumps fail to start; 2.54-3/d

   S2PRHR, 1 of 2 RHR pumps fail to start; 2.22-3/d

   S2PSIS, 1 of 2 SI pumps fail to start; 2.59-3/d

The CCW pump "fails to start" failure rate itself seems to be rather low, considering that the normal start of the CCW pumps go through interlocks which prevents the start of these pumps if the lube oil pressure is below 6 psig. This latter requirement, however, involves the operation of lube oil motors and heat exchangers which themselves are subject to failures.

b. The DCPRA is tacit about the other failure modes of the pumps, such as leakage, vibration, and low (insufficient) output, which are characteristic failure modes of the CCW pumps, mentioned previously.

c. The DCPRA is tacit about one of the most important failure modes of the CCW heat exchanger, the clogging of the shell side (see also Review of the Auxiliary Saltwater System, Letter Report-04). This failure causes most of the outages of the CCW heat exchangers. The DCPRA simply modelled a CCW system having only a single, maintenance free CCW heat exchanger with a rarely occurring "tube or shell rupture" failure mode. This approach is seemingly conservative but it should be backed up by some verifying calculations. The neglect of any failure of the CCW heat exchangers in the initiator frequency calculation, however, is clearly in disagreement with the experience (see Table A.2).

3.5 Determination of the Initiator Frequency, LOCCW, Based on Industry Experience

In order to avoid the pitfalls of determining the initiator frequency of "Total Loss of Component Cooling Water-LOCCW" events, based on unavailability modelling of the CCWS (i.e., fault trees), an attempt has been made by BNL to determine this frequency based on industry experience.

The approach used to obtain a Diablo Canyon-specific value is similar to that applied to obtain an initiator frequency for the Loss of Saltwater System (Letter Report-04). Using a double Bayesian updating technique,[6] a plant-specific posterior mean frequency was calculated by using the Diablo Canyon

experience and a prior distribution consisting of appropriately selected observed LOCCW events, whose potential occurrence was deemed possible at the Diablo Canyon plant.

a. For the updating calculation, events without the non-applicable (N/A) signs in Table A.2 and the reactor years listed in Table A.1 of Letter Report-04 (except those of Diablo Canyon Units 1 and 2) were taken as "experience". For "evidence", zero number of LOCCW events during the operation times of both Diablo Canyon units was taken. By assuming lognormal prior and posterior frequency distributions and by using "best estimate" parameter for the prior in the second stage updating, the obtained Diablo Canyon specific posterior mean, median, standard deviation, 5th and 95th percentile values are given below:

Total Loss of Component Cooling Water, LOCCW*, Events/ry

Mean	Stand. Dev.	5th Percentile	Median	95th Percentile
6.49-3	7.44-1	1.45-3	4.93-3	1.68-2

*LOCCW is applied as designator for these events instead of LPCC used in DCPRA. PG&E considers only the total loss of CCW pumps, as the sole originator of these events.

b. To estimate the recovery probability of LOCCW events, all the events listed in Table A.2 were used. Those events which were omitted from the frequency calculations were also included in the sample to represent some fraction of LOCCW events which are non-recoverable within (say) 16 hours.

Figure 3.1 shows in semi-logarithmic representation the cumulative distribution of LOCCW events as a function of the time to recover, the best fitting curve, $P(T \geq t)$ (providing the probability that the time to recover a LOCCW event, "T", will be longer than some given time "t"), as well as the 90% uncertainty bounds.

The maximum likelihood estimate of the parameter of an exponential recovery probability density function is

$\lambda = N/\Sigma t_i = .16$/hour,

where $t_1, t_2, \ldots t_N$ represent the individual recovery times in the sample and $1/\lambda = \bar{t}$ is the mean time to recovery.

Based on an optimistic estimate of the heat capacity of the water available in the CCW system given a LOCCW event ($t_1 \sim \frac{1}{2}$ hour) and the time necessary to develop an RCP seal LOCA with appreciable leak rate leading to core uncovery given unavailable cooling ($t_2 \sim 1.5$ hours), the critical time for non-recovery of an LOCCW event was taken to be $t_1 + t_2 \sim 2$ hours. At this point in time the probability of non-recovery of an LOCCW event was estimated from the best fitting curve in Figure 2.3 to be $P(T \geq 2) = 0.74$. (To apply this non-recovery factor for all of the initiating events is optimistic, because, it is applicable only - strictly speaking - for that fraction of the initiating events when the circulation of the CCW does not stop. For the other fraction of initiating events, when the CCW circulation stops, sizeable RCP seal failure and core uncovery may occur earlier than two hours.)

c. A fraction of the initiating events (see Table A.2) represent "linked" initiators, i.e., events when one of the CCW heat exchangers was in outage and the other heat exchanger was lost because of a failure of its associated service water system train. In the case of Diablo Canyon, this "linked" ($L = \frac{1}{2}$) fraction of the total events has to be multiplied by the conditional probability that given loss of both ASW trains at Unit 1, the Unit 2 trains also become unavailable: $R_E(2|1)$. The "experience" value for this latter quantity was taken from Table 2.4 of Letter Report-04: $R_E(2|1) = .538$.

Thus, the mean initiator frequency of LOCCW events (non-recoverable within some time t) can be calculated by the expression:

$$LOCCW(T \geq t) = .85 * P(T \geq t) * LOCCW_{Mean} * [(1-L) + L * R_E(2|1)],$$

where the quantity .85 is the capacity factor of Diablo Canyon Unit 1 and the other quantities were defined above.

By substituting their numerical values, the mean frequency of LOCCW initiator is:

$$LOCCW(T \geq 2) = .85 * .74 * 6.49\text{-}3 * [\tfrac{1}{2} + \tfrac{1}{2} * .538] = 3.14\text{-}3 \text{ events/ry}.$$

This frequency is one order of magnitude higher than that obtained in the DCPRA by fault tree calculation.

3.6 Conclusion

The BNL review identified some discrepancies in the modelling of the CCW system in the DCPRA. If these apparent discrepancies are determined to be real ones as the review progresses, it will mean that the CC top event split fractions, in general, and the calculated initiator frequency associated with the total loss of the CCWS, in particular, will have been underestimated in the DCPRA.

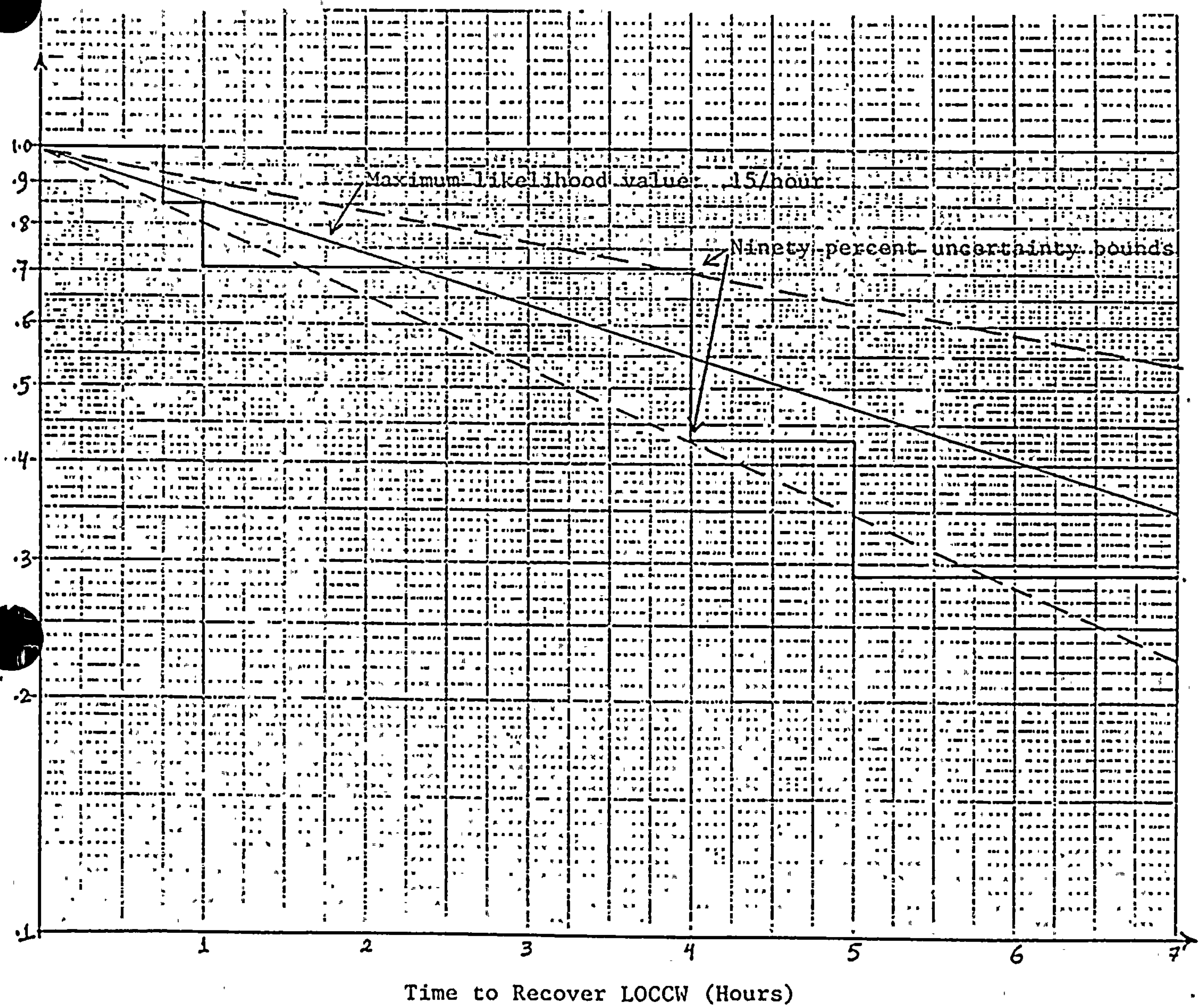


Figure 3.1. Exponential model for non-recovery of LOCCW events.

4. UNAVAILABILITY ANALYSIS OF THE EQUIPMENT NECESSARY TO MAINTAIN REACTOR COOLANT PUMP SEAL COOLING, TOP EVENT: SE

4.1 General

The unavailability analysis of the equipment necessary to maintain RCP seal cooling is strongly correlated with the analysis of the unavailability of CCWS. Therefore, it was deemed to be appropriate to include it with the review of the CCWS.

4.2 Equipment Description, Definition and Boundary Conditions of Top Event, SE

Top event SE represents the unavailability of the equipment providing cooling to the RCP seals to keep intact their integrity. The equipment consists of seal cooling injection pathways associated with a seal cooling injection source and backup pathways with the RCP thermal barrier cooling acting as a backup cooling source. The seal injection water can be supplied by any one of the three charging pumps. The cooling for the thermal barrier heat exchanger is provided by circulation of CCW. The split fractions for SE are evaluated for both non-seismic and seismic initiating events.

Four different boundary conditions were modelled. They are as follows:

a. For event sequences in which there is a guaranteed chance for success; the split fraction designator is SEO. Its value is:

   SEO=0.0. (Guaranteed success)

   This is assumed to be true if CCW flow to Loops A, B, and C is available.

b. If the CCW is unavailable, the seal cooling can only be recovered by manual operator action (ZHESE1); such as restoring seal injection by providing cooling to the charging pumps (i.e., to the charging pump heat exchangers) from the fire water sprinkler system as described in the plant procedures. The charging pump, otherwise should be operable. The pump suction is from the RWST or from the Volume

Control Tank. This means that the success of boundary condition 2 requires the success of top event CH. In addition, it requires the successful trip of the RCPs within five minutes after the loss of CCWS (i.e., it requires the success of top event RP). If the centrifugal charging pumps are not available(quotation from p.6-142 of Ref.1) "a makeshift system for temporary cooling of the positive displacement charging pump (that is, wet rags and portable fans) could also be established, although such actions are not currently covered by procedures." The designator of this split fraction is: SE1. Since the unavailability of seal injection paths and the fire water system is much less than the failure frequency of the operator recovery action only the operator action, was included for non-seismic quantification of this split fraction:

SE1=2HESE1=9.907-3.

c. When either the CCWS is unavailable for thermal barrier cooling (all support systems are available) or when the CCWS Loop C is isolated (e.g., P-signal occurred due to steam line break inside the containment or power is lost to two vital buses, prompting the operator to isolate Loop C) so that thermal barrier cooling, as well as, cooling to the positive displacement charging pump is lost, injection flow still can be maintained by a charging pump (cooling to the charging pumps via CCW Loops A or B is available). The success of this boundary condition requires the success of top event CH (i.e., the cooling flow from the RWST by an operating charging pump should be available). The designator of the corresponding split fraction is SE2. By the same reason as discussed for boundary condition 2 above, for non-seismic quantification of this split fraction DCPRA use a value of:

SE2=0.0.

d. Split fraction SEF is used in conditions where seal cooling is guaranteed to be unavailable; e.g., if CCWS Loop C is isolated and the charging pumps fail, or CCWS is unavailable and RCPs are allowed to run. The value of this split fraction is:

SEF=1.0. (Guaranteed failure)

5. UNRESOLVED QUESTIONS IN REVIEWING THE UNAVAILABILITY ANALYSIS OF THE RCP SEAL COOLING/CCW SYSTEM

a. In order to validate the DCPRA unavailability analysis for the seal injection and the fire water system paths, BNL requires the following:

   1. A schematic flow diagram of the present status of the RCP seal cooling design at the Diablo Canyon plant. The flow diagram should indicate the injection and seal leakoff systems, all components (valves, heat exchangers, joints, rubber line sections, etc.) in the pathways which served the basis of the seismic analysis, as well as of the hardware unavailability estimate, that led to the statement used in calculating the split fractions of SE1 and SE2 (that the unavailability of injection path plus charging pump cooling paths and the RCP seals are negligible compared with the human failure probability).
   2. Some details of the hardware unavailability calculation of RCP seal equipment: supercomponents and associated failure rates.
   3. Frequency of RCP seal LOCA initiator, i.e., its fractional contribution to the small LOCA (isolable and unisolable) initiator frequency.

b. The assumptions, the basis and details of estimating the value of the operator failure probability, ZHESE1=9.907-3. It is not clear whether it is connected with the core uncovery time analysis given in Appendix A.3 of the DCPRA or it is based on effective time-testing of the provisional cooling lineup process?

c. Given the centrifugal charging pumps are not available, it is not clear to BNL whether the DCPRA gave credit to the availability of the positive displacement charging pump. (See the description of split fraction, SE1, in the previous section.) If yes, in which sequences?

d. Table 6-26 (DCPRA) states that FS11 deals with loss of auxiliary saltwater due to flooding. Table 6-61 (DCPRA) states that FS11 represents loss of CCW pumps due to flooding. Please provide the full/exact definition of this initiator and describe how the quantification of this initiator was determined.

APPENDIX A

Information on Failures of the Component Cooling Water System

This appendix provides the documentation of information used to determine the frequency of the initiator "Total Loss of Component Cooling Water, LOCCW" for Diablo Canyon Unit 1, based on generic plant experience.

The information includes:

a. Characterization of Component Cooling Water Systems (from Ref.3) for plants which have experienced "Total Loss of CCW" events (Table A.1).
b. A list of failure events obtained by a survey of the RECON[4] data base, when the CCWS is completely lost due to failures of the system itself or due to linked failures with the Service Water System (Table A.2).
c. A detailed description of the events listed in Table A.2, and of the events occurred at Surry Units 1 and 2, when the Charging Pump Cooling Water System was lost. The Surry events were omitted from Table A.2, because the Surry units have CCWS of limited design purpose; this system cools only the charging pumps.

Table A.1
Component Cooling Water System Summaries for Plants Which Have Experienced "Total Loss of CCWS" Events

Plant, System Vendor	Pumps	HXs	Surge Tanks	Loads	Comments
Salem 2, Westinghouse	3	2	1	RHR HX, RCPm and t.b, LDHX, SWHX, XLDHX, RHR-P, SI-P, Chg.-P	No cross connection between Units 1 and 2.
Turkey Point 3, Westinghouse	3	3	1	RHRHX, RCPm and t.b, Non-Reg. HX, XLDHX, SWHX, Misc., RHR-P, SI-P, Chg.-P, SFPHX, Cont. CRD clr	Some cross connection at loads between Unit 3 and 4.
Indian Point 2, Westinghouse	3	2	1	RHX, SFPHX, SWHX, XLDHX, Non-Reg. HX, RHR-P, SI-P, Recirc.-P, Chg.-P, Misc., RCPm and t.b	4-ACCW-P's for recirc.-P loop.
Calvert Cliffs 1 and 2 Combustion Engineering	3	2	1	SDHX, LPSI-P, HPSI-P, LDHX, Misc., RCPm and SC, CRDM clg (cooling)	
San Onofre 2 and 3 Combustion Engineering	3	2	2	SDHX, LDHX, SFPHX, HPSI-P, LPSI-P, CS-P, CCW-P, RCPm and SC, Misc., Cont. Air Circ., CR-Chiller, CEDM clr.	
Surry 1 and 2 Chg.P CW Westinghouse	2	2	1	Chg.-P	

Table A.1 (Continued)

Abbreviations	
CEDM	Control Element Drive Mechanism
Chg.-P	Charging Pump
CR	Control Room
CS	Containment Spray Fan Coolers
Cont.	Containment
CCW	Component Cooling Water
CRDM clg.	Control Rod Drive Mechanism Cooling
CRD chg.	Control Rod Drive Cooling
CEDM clr.	Control Element Drive Mechanism Cooler
HPSI	High Pressure Safety Injection (CE)
LPSI	Low Pressure Safety Injection
LD	Letdown
HX	Heat Exchanger
Misc.	Miscellaneous Loads
Non-Reg.	Non-Regenerative
P	Pump
RCPm and t.b	Reactor Coolant Pump Motor and Thermal Barrier
Recirc	Recirculation
RHR	Residual Heat Removal
RHX	Residual Heat Exchanger
SC	Seal Cooler
SDHX	Shutdown Heat Exchanger
SI	Safety Injection
SFP	Spend Fuel Pool
SWHX	Service Water Heat Exchanger
XLD	Excess Letdown

Table A.2

"Total Loss of the Component Cooling Water System" Events

Event	Plant	Reference	Recovery	Description	Comments
1,2	Calvert Cliffs 1,2	LER-317/84-5	16 hrs.	At Unit 1, CCHXs 11 and 12 outlet channel heads had three areas with apparent through wall weepage due to corrosion. Similar failures at Unit 2 CCHXs 21 and 22 (CCHXs were made from cast iron).	N/A
3	Salem 2	LER-311/85-18	≥ 4 hrs.	CCHX (No.22) service water outlet valve failed to the closed position (vibration caused the valve actuator to separate from the valve stem). The redundant CCHX (No.21) was in maintenance.	
4	San Onofre 2	LER-361/84-46	1 hr.	Train "A" CCWHX was out of service for cleaning. Train "B" CCWHX indicated fault condition (high differential pressure).	
5	Indian Point 2	LER-247/84-011	See notes	While at cold shutdown for a refueling outage, all component cooling pumps were disabled due to flooding of the pump compartment. Water entered the compartment through an opening in the service water piping after a valve had been removed for maintenance.	**
6	Turkey Point 3	LER-250/86-18	5 hrs.*	CCWHX "B" was taken out of service for cleaning. Subsequently intake cooling water inlet temperature increased such that the three CCWHXs were required to be in service.	N/A

Table (Continued)

Event	Plant	Reference	Recovery	Description	Comments
7	San Onofre 3	LER-362/86-11	3/4 hr.	CCWHX "B" was taken out of service for cleaning. The salt water flow through CCWHX "A" was blocked due to fouling with marine growth.	Linked initiator

Notes:
- 1st motor recovery: 3 hours.
- 2nd motor recovery: 4 hours.
- 3rd motor recovery: 6 hours.

Comments:
N/A - Not applicable at Diablo Canyon.
* - Estimated.
** - This event may be classified as the flooding initiator, FS11, in the DCPRA, however it yields the same consequences: RCP seal LOCA.

[illegible]

Description of Operating Events Involving the Total Loss of Component Cooling Water System (Table A.2)

Calvert Cliffs 1 LER-317/1984-005

Power level - 100% on 5/2/84, during Unit 2 refueling outage a through wall hole occurred during removal of the graphite layer on one #22 component cooling heat exchanger (CCHX) channel head. The graphite layer was being removed in preparation for coal tar epoxy application. On 5/3/84, a second hole was created during graphite removal, prompting notification to the Nuclear Regulatory Commission. A visual examination was subsequently conducted on the operating #11, #12, and #21 (CCHX) and service water heat exchanger (SRW HX) channel heads. The #11 and #12 CCHX outlet channel heads had three areas with apparent through wall weepage. On 5/6/84, Unit 1 shutdown and all Unit 1 and Unit 2 CCHX and SRW HX were opened as conditions permitted. Due to the size, location, and number of below minimum wall areas found on the channel heads, several repairs were pursued. Encapsulations were installed on #12 and #22 CCHX channel heads, while new channel heads were installed on #11 and #21 CCHX. Bolted plate patches were installed on #12 and #22 SRW HX to correct the deficiencies. Numbers 11 and 21 SRW HX did not need any repairs. However, all CCHX and SRW HX channel heads were coated with coal tar epoxy to prevent future corrosion. New channel heads for all CCHX and SRW HX will be installed during the next outage of sufficient duration. An expanded surveillance program for cast iron components in the salt water system is being developed.

Salem 2 LER-311/1985-018

Power level - 100% on 8/27/85, No.22 component cooling water heat exchanger (CCHX) service water outlet valve (22SW356) failed to the closed position. Attempts to jack the valve open failed to adequately restore service water flow to the heat exchanger. Because the redundant CCHX (No.21) was out of service for maintenance at the time, Tech. Spec. 3.0.3 was entered, and a controlled shutdown was initiated. The malfunction of 22SW356 was attributed to a vibration induced failure which caused the valve actuator to separate from the valve stem. The vibration resulted from the prior removal of the

cavitrol tube bundle from No.22 CCHX service water control valve (22SW127), due to plugging and deterioration. Investigation revealed that operation with this tube bundle removed has caused turbulence downstream of the control valve. Due to the close proximity of this valve to the heat exchanger outlet valve (22SW356). The turbulence caused 22SW356 to vibrate which resulted in actuator damage. The valve actuator was replaced, tested and No.22 CCHX restored to an operable status. A new cavitrol tube bundle for 22SW127 is presently scheduled for delivery by 11/85. Replacement of this component should alleviate the vibration problem associated with 22SW356.

San Onofre 2 LER-361/1984-046

Power level - 100%. On 8/15/84, at 1130, with both Units 2 and 3 in Mode 1 the local readout for salt water cooling flow to the train "B" component cooling water (CCW) heat exchanger indicated a fault condition. The train 'A' CCW heat exchanger indicated a fault condition. The train 'A' CCW heat exchanger was out of service for cleaning. Because a high differential pressure existed across the train 'B' CCW heat exchanger, it was conservatively assumed that train 'B' saltwater cooling flow was less than the flow required for system operability. Train 'B' CCW was declared inoperable, and LCO 3.0.3 was invoked on Unit 2. Emergency chiller E-335 was declared inoperable since train 'B' CCW was supplying its cooling water. Loss of E-335 renders two vital inverters inoperable in each unit, and LCO 3.0.3 was also invoked for Unit 3. Shutdown of both units was initiated. A train 'B' salt water cooling pump in the Unit 2 intake was started, and the differential pressure across the heat exchanger decreased. At 1230 the salt water cooling flow indication was restored. Salt water cooling flow was determined to be above the minimum required flow, and LCO 3.0.3 was exited. The salt water cooling flow indication was restored by switching readout channels. It is suspected that the initial fault indication was due to reading an inoperable channel.

Indian Point 2 LER-247/84-011

Date of event - 081384. Power level - 100%. On August 13, 1984, at 1050, while at cold shutdown for a refueling maintenance outage, two operating

component cooling water pumps and subsequently the standby pump automatically tripped on receipt of an over current protection signal. The over current condition was caused by wetting of the component cooling water pump motors with service water. Leakage through a service water valve permitted service water flow into the component cooling water pump compartment through an opening in the service water piping being prepared for a test. The central control room was promptly notified of water conditions in the compartment and the CCR operators immediately secured the operating service water pumps which stopped the flow. The water was pumped and drained from the compartment. No.21 component cooling pump was flushed with fresh water, dried and returned to service at 1344.

Turkey Point 3 LER-250/1986-018

Power level - 100%. While Unit 3 was at 100% power, a unit shutdown was commenced due to exceeding administrative guidelines for intake cooling water (ICW) system operation. These guidelines were established by engineering based on a postulated failure of temperature control valve, TCV-2201 during a design basis event , which could degrade the ability to provide the required ICW system flow through the CCW heat exchangers during a design basis event. These guidelines establish limits on ICW inlet temperature, component cooling water (CCW) heat exchanger cleanliness and lineup, and ICW flow rates for unit operation. On April 16, 1986, the 3B CCW heat exchanger was taken out of service for cleaning. Plant conditions were evaluated at that time and it was determined that the administrative guidelines were met. Subsequently, ICW inlet temperatures increased such that three CCW heat exchangers were required to be in service for Unit 3 operation. At that time, the 3B CCW heat exchanger was still out of service which placed Unit 3 outside of the administrative guidelines requiring a Unit 3 shutdown. A Unit 3 shutdown was commenced and was stopped when the 3B CCW heat exchanger was placed back in service. Cause of event: while the 3B CCW heat exchanger was being cleaned, ICW inlet temperatures increased such that three CCW heat exchangers were required by the special administrative guidelines, to be in service for Unit 3 operation.

San Onofre 3 LER-362/1986-011

Power level - 100% at 1550 on August 4, 1986, saltwater cooling (SWC) flow through train a component cooling water heat exchanger (CCWHX) decreased, due to fouling with marine growth, to below the postulated design basis flow rate required for removal of CCW heat loads (critical CCW loop), and was therefore declared inoperable. At this time Train B CCWHX was operating with reverse SWC flow to remove similar fouling which had previously taken place. At 1605, operators commenced realignment of Train B CCWHX SWC flow to the normal direction in order to return one train of CCW to its design configuration and thereby increase heat removal capability of that train. During the realignment, both trains of the SWC system were considered to be inoperable contrary to technical specification limiting condition for operation (LCO) 3.7.4, and LCO 3.0.3 was entered. Train B SWC system was returned to operable status within thirty minutes, and at 1635, LCO 3.0.3 was exited. As corrective action, operating procedures will be revised to minimize the effect of marine fouling on the operability of the SWC system.

Events Not Included in Table A.2:

Surry 1 LER-280/84-011

Power level - 100%. On 5/18/84 operations personnel performing a system walkdown following maintenance discovered the intended heat sink for the charging pump component cooling water system was isolated. The charging pump component cooling water isolated to intermediate seal cooler 1-SW-E-1B and service water isolated to intermediate seal cooler 1-SW-E-1A. A review of plant logs and operator interviews has confirmed that both intermediate seal coolers were isolated during two separate events. The first event started 5/16 at 2045 hours, when 'B' cooler was improperly placed in service and 'A' cooler was removed from service until 2125. The second event started 2140 hours on the same day when 'A' cooler was again removed from service with 'B' cooler remaining improperly valved in service. Both coolers were isolated for a total of 40 minutes during the first event and 32 hours for the second event. Due to the complexity of the maintenance involved, the existing procedures were not adequate to provide the necessary valve alignments.

Immediate corrective actions involved placing 'B' intermediate seal cooler in service to provide a necessary heat sink and making 'A' cooler available as a backup. To prevent recurrence, maintenance operating procedures were written to ensure control of removal and return to service of the intermediate seal coolers.

Surry 2 LER-281/86-010

Power level - 100%. On 7/11/86 with Unit 1 in refueling shutdown and Unit 2 at 100% power, operators were attempting to return the 'A' charging pump component cooling water pump to service following emergency maintenance. At 15.18 hours, the redundant 'B' pump, which had been supplying cooling water to the charging pump seal coolers, lost discharge pressure. This resulted in both pumps being inoperable. It is assumed that air introduced into the system during maintenance on the 'A' pump caused the 'B' pump to become vapor bound. The 'A' pump was vented, water was added to the system, and the pump was returned to service at 18.25 hours. Subsequently, operability of the 'B' pump was demonstrated, and it was also returned to service.

Surry 2 LER-281/188-009

Power level - 100%. On April 20, 1988 at 12.27 hours, with Unit 1 in a refueling outage and Unit 2 at 100% reactor power, the "A" and "B" component cooling water (EIIS-CC) heat exchangers (EIIS-HX) (CCHX) were declared inoperable. The "C" and "D" CCHXS had previously been removed from service for maintenance. Unit 2 entered a six hour clock to hot shutdown in accordance with technical specifications 3.0.1. An engineering review of the potential dependence of CCHXS on the station vacuum priming (VP) system had determined that five VP valves (EIIS-ISV) which isolate the CCHXS service water (SW) piping from the VP lines, were not seismically mounted. In a seismic event, the potential would have existed for rupture of the VP piping and air ingress into the CCHX, breaking the siphon effect on the SW, and causing a loss of SW to the heat exchangers. The seismic supports were installed and the "A" and "B" CCHXS were returned to service at 17.10 hours on April 20, 1988 and T.S. 3.0.1 was exited. Additional engineering evaluations will be performed to assess the necessary design changes to permit future CCHX

operation with vacuum priming in service. The VP valves will remain normally closed pending the results of the engineering evaluations.

REFERENCES

1. Final report on the Diablo Canyon Long-Term Seismic Program, Pacific Gas and Electric Co., Diablo Canyon Power Plant, Docket Nos. 50-275 and 50-323, July 1988.

2. Units 1 and 2 Diablo Canyon Power Plant, "Final Safety Analysis Report Update," Pacific Gas and Electric Co., December 1988.

3. J. Higgins, R. Lofaro, M. Subudhi, R. Fullwood, J. Taylor, "Operating Experience and Aging Assessment of Component Cooling Water Systems in Pressurized Water Reactors," NUREG/CR-5052, July 1988.

4. DOE/RECON, Nuclear Safety Information Center (NSIC), 1963 to present.

5. PG&E letters to NRC signed by J.D. Shiffer, No. DCL-88-297, December 9, 1988, and No. DCL-89-010, January 16, 1989.

6. C. Park, "Bayes: A Two-Stage Bayesian Update Procedure for Data Specialization for the Plant-Specific Risk and Reliability Analysis," BNL Internal Memorandum, March 19, 1987.