14.3 BORON DILUTION EVENT

14.3.1 IDENTIFICATION OF EVENT AND CAUSE

The CVCS regulates both the chemistry and the quality of coolant in the RCS. Changing the boron concentration in the RCS is a part of normal plant operation, compensating for long-term reactivity effects such as fuel burnup, xenon buildup and decay, and plant startup. During refueling operations, borated water is supplied from the refueling water tank (RWT).

Boron concentration in the RCS can be decreased either by controlled addition of demineralized water or by using a purification ion exchanger with a deborating resin. During normal operation, concentrated boric acid solution and demineralized water is introduced into the volume control tank in concentrations corresponding to the required concentration for proper plant operation. When the specified amount has been injected, the makeup controller automatically shuts the demineralized water and boric acid control valves. A purification ion exchanger with a deborating resin is normally used for boron removal when the boron concentration in the RCS is low (less than 50 ppm) and the feed and bleed method becomes inefficient.

The CVCS is equipped with the following indications which could inform the operator when a change in boron concentration in the RCS is occurring:

a. Volume control tank level;
b. Makeup controller flow; and,
c. CVCS valve position lineup.

A Boron Dilution event is defined as any event caused by a malfunction or an inadvertent operation of the CVCS that results in a dilution of the active portion of the RCS. The active portion of the RCS is defined as that volume of water that circulates through the core. For example, when in shutdown cooling (SDC), no credit is allowed for the volume of water in the SG and other stagnant portions of the RCS. A dilution of the RCS can be the result of adding borated water, which has a boron concentration that is less than the system boron concentration, or by the removal of boron using a purification ion exchanger with a deborating resin.

14.3.2 SEQUENCE OF EVENTS

The analysis of the Boron Dilution event covers the six modes of operation (Table 14.3-1). The modes of operation are defined in Technical Specification Table 1.1-1. A Boron Dilution event can approach the DNBR and LHGR SAFDLs and the RCS Pressure Upset Limit. In all cases, operator action is required to prevent exceeding these limits by securing the dilution and borating, if necessary, to maintain the required shutdown boron concentration.

The calculated time-to-criticality is dependent upon the critical and shutdown boron concentrations, the RCS coolant mass and the flow rate of the dilution stream. In addition, for the dilution front model, a range of SDC flow rates is required.

Assume the boron concentration is exactly the amount needed to maintain the required Technical Specification shutdown margin. Also assume that under the worst conditions the operator has 30 minutes in the refueling mode and 15 minutes in the other modes of operation from the time of initiation of the event to secure the dilution to prevent losing the minimum shutdown margin. The DNBR and LHGR SAFDLs and the RCS Pressure Upset Limit criteria will be met if the entire shutdown margin is not lost.

14.3.2.1 Power Operation and Startup

An inadvertent Boron Dilution event at power and startup (Modes 1 and 2) can be postulated as a result of various malfunctions of, or inadvertent operation of, the CVCS. The sequence of events starts with the decrease of the boron concentration in the RCS. All three charging pumps are on and adding 150 gpm of unborated (demineralized) water into the RCS. The effect of decreasing the boron concentration is to add positive reactivity. With the reactor initially critical, the core power, heat flux, and RCS temperatures will increase the pressurizer pressure and level. Although no credit is taken for them in the analysis, the pressurizer pressure and level control systems will maintain programmed pressure and level. The combination of the pressurizer sprays and RCS letdown will accommodate these slow increases in pressure and level respectively. The SG temperature and pressure will slowly increase with the increasing average RCS temperature. This is a similar sequence to a slow reactivity addition due to a CEA withdrawal.

The increasing fuel and moderator temperatures will result in a negative reactivity feedback due to the Doppler and the MTC being generally negative. The negative reactivity feedbacks will partially offset the positive reactivity insertion due to the dilution, thus further slowing down the power rise.

If the dilution is not secured, the reactor will be shut down by either the TM/LP or the VHPT. The action of the pressurizer control system will prevent the pressure from exceeding the High Pressurizer Pressure Trip setpoint. Operator action is required to secure the dilution.

14.3.2.2 Hot Standby, Hot Shutdown

For the Hot Standby (Mode 3) and Hot Shutdown (Mode 4) cases, the analysis assumes all three charging pumps are on (as in Section 14.3.2.1 above) and assumes a boron concentration to meet the required shutdown margin, and shutdown to critical boron concentration ratios are as in Table 14.3-1.

Mode 3 assumes RCPs are operating and mix the entire RCS loops.

While in Hot Shutdown the limiting shutdown to critical boron ratio occurs while on SDC. The active volume of the RCS includes only that volume to the top of the Hot Leg plus the SDC system. Rapid mixing cannot be assumed in the reactor vessel head or the SG.

14.3.2.3 Cold Shutdown

Two cases are run for Cold Shutdown (Mode 5): a three-pump case and a two-pump case. The three-pump case uses the same volume as the hot shutdown case. For the two-pump case, Cold Shutdown (Mode 5), the NSSS could be partially drained due to repairs or inspections on the RCS (e.g., RCS pump seal replacement, SG inspection, etc.). Therefore, the analysis assumes an active volume of water which is sufficient to fill the RCS to the bottom of the hot leg plus fill the SDC System. Technical Specifications require at least one train of SDC to be in operation. Since the Technical Specifications only allow 88 gpm when the pressurizer level is below 90" in Mode 5, the analysis uses 100 gpm when the level is at the bottom of the hot leg.

14.3.2.4 Refueling

The analysis for Refueling (Mode 6) uses an active volume in the RCS that is the same as cold shutdown. The refueling boron concentration is defined in terms of a ratio of refueling to critical concentration. Changes in the boron concentration which occur each cycle, can be easily evaluated by comparing the ratio to the minimum allowable ratio presented in Table 14.3-1.

14.3.3 CORE AND SYSTEM PERFORMANCE

14.3.3.1 Mathematical Models

Since the NSSS response to a Boron Dilution event is basically the same as a slow CEA Withdrawal event, only the time to criticality is calculated. The rate of change of boron concentration as a function of time can be described by the below equation. The boron in the active volume will be uniformly mixed when sufficient flow exists. Instantaneous mixing is assumed when an RCP is operating. Therefore, the time to lose the prescribed shutdown is:

$$\frac{dC}{dt} = \frac{w}{M} Cx \frac{\rho_{chgg}}{\rho_{RCS}}$$

or

$$t_c = \frac{M}{W} x \frac{\rho_{RCS}}{\rho_{chgg}} In \frac{C_o}{C_c}$$

where:

M	=	active volume
C_o	=	initial boron concentration
C_c	=	critical boron concentration
W	=	charging volume flow rate
t_c	=	time to lose a prescribed shutdown margin
ρ_{RCS}	=	density of active volume
ρ_{chgg}	=	density of charging water

The ratio of shutdown boron to critical boron is:

$$\frac{C_{sdm}}{C_{RCS}} = e \left[\frac{t_{sdm} W}{M} \bullet \frac{\rho_{chg}}{\rho_{RCS}} \right]$$

where:

C_{sdm}	=	shutdown boron concentration
C_{RCS}	=	critical boron concentration
t_{sdm}	=	criterion for minimum time to lose prescribed shutdown margin

The dilution front model is used when the RCS flow is much slower than would occur with at least one RCP running. Typical loop transient times of several minutes are associated with these low flow conditions. The assumption of instantaneous mixing is no longer valid in these low flow conditions; however, the dilution flow is assumed uniformly mixed with the RCS coolant in the vessel downcomer and the lower plenum regions prior to reaching the core inlet.

The time for the first dilution front to reach the core is calculated by dividing the RCS mass from the mixing location to the bottom of the core by the shutdown cooling + dilution flow. The time for subsequent front is calculated by dividing the mass of the RCS and shutdown cooling systems by the shutdown cooling + dilution flow. The time to criticality is determined by iteratively tracking the number of dilution fronts.

14.3.3.2 Input Parameters and Initial Conditions

The input parameters and initial conditions used in the analysis are listed in Table 14.3-1.

The instantaneous mixing and dilution front models are dependent upon the mass of liquid in the active volume, the dilution stream mass flow rate, and the initial to critical boron ratio. The shutdown margin requirement, inverse boron worth and time in cycle are inherently included in the boron ratio. The dilution front model is also dependent upon the RCS flow rate, which is set equal to the shutdown cooling flow rate.

14.3.3.3 Results

Table 14.3-2 contains the minimum time to lose the prescribed shutdown margin for Modes 3-6 of operation. The results show that the operator has sufficient time to take appropriate action to mitigate the consequences of this event for each operating mode.

For Modes 1 and 2, an inadvertent charging of unborated water at the maximum rate would result in a maximum rate of reactivity addition that is within the range evaluated for a CEA Withdrawal event and is therefore not as limiting.

14.3.4 CONCLUSION

In Modes 1 and 2, the RPS initially mitigates the consequences of a Boron Dilution event; after which the operator has sufficient time to terminate the dilution. In all other modes, sufficient time is provided to allow operator action to mitigate the consequences before shutdown margin is lost.

The worst time in life for this event is at BOC when boron concentration is highest and MTC is least negative. Therefore, increased burnup has no adverse effect on this transient.

14.3.5 NRC ACCEPTANCE LIMIT

The acceptance criteria for this event are that the times between initiation of a boron dilution event and loss of shutdown margin are not less than 15 minutes for Modes 2, 3, 4 (Reference 1), and 5, and 30 minutes for Mode 6 (Reference 2). The SER (Reference 2) also states that the analysis of boron dilution for power operation is acceptable because the operator has adequate time to terminate the boron dilution event due to the TM/LP trip and VHPT.

Standard Review Plan Section 15.4.6 requires plants licensed to these requirements to demonstrate that Control Room operations will have a positive alarm indicating the onset of a boron dilution event. Generic Letter 85-05, dated January 31, 1985 and titled "Inadvertent Boron Dilution Events," documents the NRC determination that the consequences of this event do not warrant backfitting this requirement to plants (such as Calvert Cliffs) that are not currently licensed to the Standard Review Plan for this event.

14.3.6 REFERENCES

1. Letter from R. A. Clark (NRC) to A. E. Lundvall, Jr., dated December 12, 1980, Issuance of Amendment No. 48 to Facility Operating License No. DPR-53
2. Letter from S. A. McNeil (NRC) to J. A. Tiernan, dated May 4, 1987, Issuance of Amendment No. 108 to Facility Operating License No. DPR-69

TABLE 14.3-1

INITIAL CONDITIONS AND INPUT PARAMETERS FOR THE BORON DILUTION EVENT

PARAMETER		
Minimum Ratio of Shutdown to Critical Boron Concentration	**Ratio**	**SDM % $\Delta\rho$**
Power Operation (Mode 1 and 2)	---	---
Hot Standby (Mode 3)	1.05	-3.5
Hot Shutdown (Mode 4), RCP Running	1.04	-3.5
Hot Shutdown (Mode 4), SDC	1.17	-3.5
Hot Shutdown (Mode 5), 3 Charging Pumps	1.16	-3.0
Hot Shutdown (Mode 5), 2 Charging Pumps	1.11	-3.0
Refueling (Mode 6), 3 Charging Pumps	1.28	-6.263
Refueling (Mode 6), 2 Charging Pumps	1.18	-6.263
RCS Volume and Charging Flow	**Volume ft^3**	**Method**
Power Operation (Mode 1 and 2)	---	---
Hot Standby (Mode 3)	8861	Instant Mix
Hot Shutdown (Mode 4), RCP Running	8861	Instant Mix
Hot Shutdown (Mode 4), SDC	4513	Dilution Front
Hot Shutdown (Mode 5), 3 Charging Pumps	4513	Dilution Front
Hot Shutdown (Mode 5), 2 Charging Pumps	3657	Dilution Front
Refueling (Mode 6), 3 Charging Pumps	3657	Dilution Front
Refueling (Mode 6), 2 Charging Pumps	3657	Dilution Front

TABLE 14.3-2

RESULTS OF BORON DILUTION EVENT

MODE	TIME TO LOSE PRESCRIBED SHUTDOWN MARGIN (MIN)	CRITERION FOR MINIMUM TIME TO LOSE PRESCRIBED SHUTDOWN MARGIN (MIN)[a]
Hot Standby	16.5	15
Hot Shutdown	16.5	15
Cold Shutdown – three pumps	21.8	15
Cold shutdown – two pumps	20.0	15
Refueling	30.9	30

[a] Assumed time between initiation of event and termination of the dilution by the operator.