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PRIMARY SYSTEM BORON
DILUTION ANALYSIS

MASTER

R. J. Crump/C. J. Naretto/R. A. Borgen/H. C. Rockhold

NOTE: THIS REVISION COMPLETELY SUPERSEDES ALL PREVIOUS
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RESEARCH, ENGINEERING AND CONSTRUCTION REPORT ENGINEERING ANALYSIS DIVISION

RELIABILITY AND STATISTICS BRANCH

PRIMARY SYSTEM BORON

DILUTION ANALYSIS

R. J. Crump, C. J. Naretto, R. A. Borgen and H. C. Rockhold

AUTHOR

CHECKED BY:

Melan E. Stewart

APPROVED BY:

F. J. Ballerz

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TABLE OF CONTENTS

1.0	Introduction	1
2.0	Method of Analysis	2
2.1	Failure Likelihood Ranking	2
2.2	Failure Effects Ranking	2
2.3	Dilution Path Analysis Table	3
3.0	Results	4
4.0	Assumptions and Ground Rules	6

LIST OF FIGURES

Figure 1.	Fault Tree for Possible Boron Dilution Paths	14
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LIST OF TABLES

Table 1.	Dilution Path Analysis	7
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1.0 Introduction

This report documents the results of an analysis conducted to determine the potential paths through which non-borated water or water with insufficient boron concentration might enter the LOFT primary coolant piping system or reactor vessel to cause dilution of the borated primary coolant water.

No attempt was made in the course of this analysis to identify possible design modifications nor to suggest changes in administrative procedures or controls.

2.0 Method of Analysis

The methodology used in the course of this analysis was to examine all potential dilution paths discovered on the fault tree, assigning a relative likelihood of occurrence to each path, and then determining the effect of each dilution path upon primary system boron concentration. The following two modes of plant operation were considered (1) plant in a shutdown mode (control rods inserted) and (2) plant at power; operating and fully pressurized.

2.1 Failure Likelihood Ranking

A numerical value of 1, 2, or 3 was assigned to each potential dilution path to indicate its relative likelihood of occurrence. The failure likelihood statements of (1) anticipated, (2) unlikely, and (3) extremely unlikely are to be thought of only in a relative sense, that is, those assigned a "1" are more likely to occur than those assigned a "2" or "3". The implication that they will frequently occur in the operation of LOFT is not intended. There was no attempt made to quantify the results.

2.2 Failure Effects Ranking

The following are the three effect categories based solely on the amount of non-borated water or water with insufficient boration that could potentially enter the primary system:

- A. Dilution paths in this category have the potential for causing significant dilution of the boron concentration level in the primary coolant.
- B. Dilution paths in this category have the potential for causing moderate dilution of the boron concentration level in the primary coolant (i.e. everything that wasn't either A or C).
- C. Dilution paths in this category have the potential for causing insignificant dilution (or no dilution) of the boron concentration in the primary coolant.

2.3 Dilution Path Analysis Table

A discussion of each possible dilution path is contained in Table 1. The number in the first column refers to the particular dilution path identified on the fault tree (Figure 1), followed in each subsequent column by an explanation of each potential dilution path, and the assigned effect category and likelihood.

3.0 Results

There were 39 dilution paths identified; of these, eight were considered as anticipated and having the potential for significantly reducing boron concentration in the primary system. They were identified with the letter "A" in the effect category column and the number "1" in the failure likelihood column. The following are the eight dilution paths:

- A. Introduction of non-borated water into the primary coolant system by the inadvertent alignment of either charging pump AC-P-4A or -4B to the batch tank AC-T-51 instead of the mix tank AC-M-8 (reference drawing LOFT-650-P-128). The above can occur during normal plant operation. Injection path is through the regenerative heat exchanger to the suction side of the primary coolant pumps.
- B. Similar to the above; charging pump(s) are aligned correctly but the boron concentration in the mix tank is not of the correct concentration or the demineralized water inlet valve inadvertently left open and not being detected.
- C. Same as (A) above except for occurrence during shutdown mode instead of normal operating mode.
- D. Same as (B) above except for occurrence during shutdown mode instead of normal operating mode.
- E. When the blowdown suppression tank is being filled during shutdown, demineralized water is injected into the tank via valves CV-P128-62, V-2345-LVF, V-2145-GVG and CV-P138-20. If valve CV-P120-97 was inadvertently opened, a large source of demineralized water could be introduced directly into reactor vessel via the lower plenum injection point.

- F. Introduction of service water into the pressure reduction and decontamination sump after the fire sprinkler system in containment has been activated. The most probable cause is the occurrence of a fire during plant operation which would precipitate a plant shutdown and initiate residual heat removal through operation of the LPIS.
- G. Introduction of service water into the pressure reduction and decontamination sump by inadvertently opening V-544, service water to decontamination sump spray header.
- H. Introduction of service water into the pressure reduction and decontamination sump by inadvertently opening CV-P6-98, service water to decontamination solution spray pump suction.

4.0 Assumptions and Ground Rules

The following assumptions and ground rules were used in this analysis:

1. All potential paths would be identified even though the likelihood of occurrence was essentially zero.
2. The analysis would only consider the boron dilution within the reactor vessel, primary coolant system piping, pressurizer and steam generator.
3. The borated water storage tank is assumed to start with a boron concentration in water of 3000 ppm.
4. For the purpose of this analysis non-borated water was defined as water with no boric acid. Water with insufficient boration was defined as borated water with a concentration less than the primary coolant loop boron concentration.

TABLE I
DILUTION PATH ANALYSIS

DIAMOND NOTE NUMBER	DIAMOND EXPLANATION	RISK CATEGORY	
		EFFECT CATEGORY	FAILURE LIKELIHOOD
1	The primary component cooling water system operating pressure is approximately 100 psig whereas the primary system operating pressure is approximately 2250 psig. Thus, any leakage of coolant due to a tube failure within the pumps would be from the primary system into the primary component cooling water system; therefore, non-borated water would not be injected into the primary system's borated water and thus is an unlikely dilution path.	C	2
2	The operating pressure for the secondary coolant system and primary system is approximately 1000 psig and 2250 psig, respectively. Thus any leakage of the steam generator tubes would be from primary into the secondary system. Therefore this is an unlikely dilution path.	C	2
3	The operating pressure for the primary coolant injection system (PCIS) and primary system is approximately 2500 psig and 2250 psig respectively. The PCIS is only operated upon loss of coolant to prevent bearing wear. Water with insufficient boration to enter the primary system during nuclear operation, the operator would have to inadvertently actuate the system. If this should occur, the PCIS positive displacement pump could introduce a small amount of water with insufficient boration that could be trapped in the lines between the primary pumps and the 6"-ECC-34-YD into the primary system.	C	1
4 & 10	The demineralized water system (DWS) has the possibility of deborating the BWST if control valve CV-P128-62 (normal closed/fails closed) and V-2345-LVF (locked closed) are inadvertently opened or have internal leaks. This deborated water then could later be introduced into the reactor vessel or primary system upon ECC demand.	A	3

TABLE I (Continued)
DILUTION PATH ANALYSIS

DIAMOND NOTE NUMBER	DIAMOND EXPLANATION	RISK CATEGORY	
		EFFECT CATEGORY	FAILURE LIKELIHOOD
5	There is the possibility that the sample lines contains a trapped sample of water with insufficient boration such that when a sample is required from the pressurizer sprayline (CV-P139-30), some non-borated water could be introduced into 2"-CP-10 at the suction side of the primary pumps. Since the sampling system is only used for the analysis of primary system coolant which is borated, it is unlikely that any fluid within the sample lines would not be borated to the correct concentration level.	C	2
6	If the purification system was used to inject coolant into pressurizer spray nozzle, some water with insufficient boration trapped in the purification system could be injected into the pressurizer. Since the purification system is only used to rid impurities within the primary coolant which is borated, it is unlikely that any fluid within the purification system would not be borated to some level of boron concentration close to the required concentration.	C	1
7 & 8	Intentionally left blank.		
9	When the purification system is being used to remove impurities from the primary coolant system, some water with insufficient boration may be trapped in the purification system and injected into the suction of the primary pumps through 2"-CP-10. Since the purification system is only used to clean up the primary coolant which is borated, it is unlikely that any fluid within the purification system would not be borated to some level of boron concentration close to the required concentration.	C	1
11	During shutdown the primary component cooling water system (PCCWS) may be operated during reactor shutdown. Thus, any leakage of coolant due to a tube failure within the primary pumps would be from the PCCWS into the primary system but is an unlikely dilution path.	B	2

TABLE I (Continued)
DILUTION PATH ANALYSIS

DIAMOND NOTE NUMBER	DIAMOND EXPLANATION	RISK CATEGORY	
		EFFECT CATEGORY	FAILURE LIKELIHOOD
12 & 13	<p>The charging system is used during normal nuclear operations for makeup or increasing or decreasing primary coolant boron concentration. This is performed by using either of the charging pumps AC-P-4A or -4B to pump fluid into the primary system. Following are three possible methods for introduction of non-borated water or water with insufficient boron concentration into the primary system:</p> <ul style="list-style-type: none"> A. Operator inadvertently aligning either of the charging pumps to the batch tank (which contains demineralized water) instead of the mix tank (which contains borated water) when requiring an increase in primary system boron concentration. B. Charging pumps aligned correctly to mix tank but the boron concentration in the tank is not correct. C. Charging pumps aligned correctly to mix tank but the locked closed demineralized water inlet valve V-2281-LVF is inadvertently left open following mix tank fill. This event would be detectable since tank contents would be dumped onto operating floor through tank overflow line. <p>For a real significant dilution of the overall primary coolant system to occur, multiple fills of the batch or mix tanks must be dumped into the primary system or the valve from the demineralized water system to the mix tank (V-2281-LVF, which is normally locked closed) is inadvertently left open and the resulting tank overflow is not detected.</p>	A	1
14 & 15	<p>The charging system is primarily used during shutdown for makeup of primary system coolant. Following are three potential methods for injecting non-borated water or water with insufficient boron concentration into the primary piping system:</p> <ul style="list-style-type: none"> A. Same as #12A and 13A. B. Same as #12B and 13B. C. Same as #12C and 13C. <p>For a real significant dilution of the overall primary coolant system to occur, multiple fills of the batch or mix tanks must be dumped into the primary system or the valve from the demineralized water system to the mix tank (V-2281-LVF, which is normally locked closed) is inadvertently left open and the resulting tank overflow is not detected.</p>	A	1

TABLE I (Continued)
DILUTION PATH ANALYSIS

DIAMOND NOTE NUMBER	DIAMOND EXPLANATION	RISK CATEGORY	
		EFFECT CATEGORY	FAILURE LIKELIHOOD
16	It is possible that non-borated water contained in hydrostatic pressure testing devices could enter the primary piping system if these devices were inadvertently left connected to the system. It should be considered that the quantity of non-borated water contained in the hydrostatic testing devices is very small compared to the normal system inventory.	C	1
17	Should tube failures exist within the steam generator following reactor shutdown, secondary coolant which is non-borated could be introduced into the primary system.	B	2
18	At blowdown, the primary coolant pumps are deactivated, PC-P-3 is activated at this time to supply coolant to the primary pump bearings to prevent damage. The injection pump could introduce a small amount of water with insufficient boration that could be trapped in the lines between the primary pumps and 6"-ECC-34-VD into the primary system.	C	1
19	The BST is filled initially with demineralized water by the opening of valves CV-P128-62, V-2145-GVG, V-2345-LVF, CV-P120-108 and CV-P138-20 (boric acid is also added). There exists the possibility of a small trapped sample of non-borated water within the LPIS "A" piping being later introduced into the reactor vessel following blowdown. This trapped sample would be between the junction of the LPIS crosstie and the junction of BST fill line.	C	1
20	Possible introduction of non-borated water used as pressure instrumentation calibration source into primary piping system via pressurizer instrumentation. Notice should be taken of the fact that a very small volume of non-borated water is used in the calibration of pressure instruments.	C	1
21	There exists a potential for the injection of water with insufficient boration into the primary piping system from the primary coolant purification system into the pressurizer. Trapped water with insufficient boration could be introduced into the pressurizer during this operation since this is the primary means for maintaining the same boron concentration in the entire primary piping system when the primary coolant pumps are de-activated.	C	1

TABLE I (Continued)
DILUTION PATH ANALYSIS

DIAMOND NOTE NUMBER	DIAMOND EXPLANATION	RISK CATEGORY	
		EFFECT CATEGORY	FAILURE LIKELIHOOD
22	Possibility of water with insufficient boration to be introduced into the primary piping system during shutdown by entrapped fluid draining back into the pressurizer. Occurrence is highly unlikely as the blowdown suppression tank into which the vents drain is at a lower elevation than the vent points.	C	3
23 & 29	Possibility of demineralized water used to calibrate pressure instruments being introduced into borated water system. Note that volume of demineralized water is extremely small.	C	1
24, 25, 26 & 27	During shutdown it is possible for water with insufficient boration trapped in the primary system vent and drain lines to drain back into the system. Occurrence is highly unlikely as the vent and drain points are at a higher elevation within the facility than the blowdown suppression tank into which they drain.	C	3
28	Should the "A" portion of the ECCS be inoperable, the "B" portion of the system would be activated. Water with insufficient boration could be introduced into the reactor vessel via a leak in heat exchanger ECC-H-24B allowing primary component coolant to mix with the borated water of the ECC system. Normally the ECC system is at a higher pressure than the PCC system which would preclude flow of the latter into the former system.	C	3
30	It is possible to introduce a trapped sample of water with insufficient boration into the primary coolant system while taking a sample of same. Note that a very small quantity of water with insufficient boration is involved. Also, since the sampling system is used only for the analysis of primary system coolant which is borated it is unlikely that fluid in the sampling system would not be borated to the proper concentration.	C	1
31	There is a possibility of non-borated water from the primary component cooling system entering the borated emergency core cooling system via a leak in heat exchanger ECC-H-24A when ECC-P-64A is activated. Water with insufficient boration can then be injected into reactor vessel through the lower plenum injection point following a LOCE. Such an occurrence would require flow against an inverse pressure gradient which is highly unlikely.	C	3

TABLE I (Continued)
DILUTION PATH ANALYSIS

DIAMOND NOTE NUMBER	DIAMOND EXPLANATION	RISK CATEGORY	
		EFFECT CATEGORY	FAILURE LIKELIHOOD
32	During shutdown, if valve CV-P120-97 was inadvertently opened, demineralized water could be injected into the reactor vessel when the demineralized water pump is being operated to fill the BST. Filling of the BST requires valves CV-P128-62, CV-P120-108, V-2145-GVG and V-2345-LVF to be intentionally opened by an operator; thus, if valve CV-P120-97 is then opened inadvertently, a direct path for non-borated water is available to reactor vessel.	A	1
33	During long term core cooling non-borated water may be introduced into the pressure vessel when demineralized water leaks past the QOBV seals, dumps into the BST and is injected into it by the low pressure injection pumps.	C	1
34	Secondary system high pressure relief valves discharge into pressure reduction and decontamination sump. Thus, secondary system water may be injected into the pressure vessel via LPIS pumps during post-shutdown cooling.	A	2
35	Service water from the fire sprinkler system in containment, if the system is activated, will enter the filter sump. From the filter sump, water can be directed into the condensate sump or the pressure reduction and decontamination sump. Water is drawn from these sumps by LPIS pumps for post-shutdown cooling and therefore non-borated water could be introduced directly into the pressure vessel.	A	1
36	Non-borated water could be introduced into the primary system via the sample lines if a leak exists within the pressurizer sample cooler (PCS-H-1) at the same time a sample of the primary coolant is taken following shutdown.	B	2
37	The primary component cooling system operating pressure is approximately 100 psig. The primary cooling system operating pressure is approximately 2250 psig. Thus, any leakage of cooling water due to a tube failure within the pressurizer sample cooler PCS-H-1 would be from the primary system to the primary component cooling water system. Non-borated water would not be injected into the primary system due to the adverse pressure gradient. This is an unlikely dilution path.	C	2

TABLE I (Continued)
DILUTION PATH ANALYSIS

DIAMOND NOTE NUMBER	DIAMOND EXPLANATION	RISK CATEGORY	
		EFFECT CATEGORY	FAILURE LIKELIHOOD
38	If V-544 is inadvertently opened, service water would be admitted directly into the pressure reduction and decontamination sump via 3"-IW-87-E. Water is drawn from this sump by LPIS pumps for post shutdown cooling and therefore diluted water could be introduced directly into the pressure vessel.	A	1
39	If CV-P6-98 is inadvertently opened, service water would be admitted directly into the pressure reduction and decontamination sump via line 4"-DS-1-E or the decontamination solution spray pump recirculation line 1"-DSV-15-E. Water is drawn from this sump by LPIS pumps for post shutdown cooling and therefore diluted borated water could be introduced directly into the pressure vessel.	A	1

FIGURE 1.
FAULT TREE FOR POSSIBLE BORON DILUTION PATHS.

NON-BORATED H₂O
ADDED INTO PRIMARY
PUMP SYSTEM
DURING SHUTDOWN

A1
PAGE 1.