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September 27, 1985

TMI Program Office
Attn: Dr. B. J. Snyder
Program Director
US Nuclear Regulatory Commission
Washington, DC 20555

Dear Dr. Snyder:

Three Mile Island Nuclear Station, Unit 2 (TMI-2)
Operating License No. DPR-73
Docket No. 50-320
Revision 2 To Boron Hazards Analysis

In response to your letter, dated August 6, 1985, which forwarded approval of the Defueling Water Cleanup System (DWCS) Technical Evaluation Report (TER), Revision 2 of the "Hazards Analysis: Potential for Boron Dilution of Reactor Coolant System" is forwarded for your information.

The basic analysis assessed the potential for boron dilution of the TMI-2 reactor coolant system during a variety of pre-defueling recovery activities. This analysis has been expanded in scope to include DWCS operation. Revision 2 consists of the addition of Appendix E, "Defueling Water Cleanup" and revised "Purpose" and "Applicability/Scope" sections. Substantial portions of the base document (e.g., static conditions in level control mode) remain applicable.

8510040293 850927
PDR ADOCK 05000320
P PDR

Sincerely,

F. R. Standerfer
Vice President/Director, TMI-2

FRS/RDW/eml

Attachment

cc: Deputy Program Director - TMI Program Office, Dr. W. D. Travers

D009
1/1

4430-84-0077

GPU Nuclear
TMI-2 DIVISION

HAZARDS ANALYSIS

POTENTIAL FOR BORON DILUTION OF REACTOR COOLANT SYSTEM

Prepared by:
TMI-2 Licensing and Nuclear Safety Dept.
Risk Assessment Section
September 1985 • Rev. 2

4430-84-0078
Revision 2
September 1985

HAZARDS ANALYSIS:

POTENTIAL FOR BORON DILUTION OF REACTOR COOLANT SYSTEM

Risk Assessment Section

Director, Licensing and Nuclear Safety

Risk Assessment Manager

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List of Tables and Figures

1.0 PURPOSE

The purpose of this analysis is to assess the potential for boron dilution of the TMI-2 reactor coolant system. Revision 0 of this analysis identified methods of isolating the RCS that provide a high degree of assurance that a dilution event will not occur. Revision 0 considered several plant operations that have been important to recovery operations to date. The isolation methods recommended in Revision 0 were implemented through appropriate plant procedures.

Revision 1 of this analysis was issued primarily to consider the effects of criticality analyses which indicated that a higher boron concentration (4350 ppm B) was applicable under some circumstances than was assumed in the Revision 0 (3500 ppm B). Other changes in Revision 1 included the addition of references that described the mixing characteristics of a potential dilution inflow and a more refined analysis of dilution/mitigation capability. Modifications made in Revision 1 are indicated by a vertical line with the number "1".

The purpose of this revision is to consider the boron dilution potential associated with operation of the Defueling Water Cleanup System (DWCS). The DWCS analysis is provided as a new appendix, Appendix E; modifications to preexisting sections of the report are indicated by a vertical line with the number "2". It should be noted that, due to schedular constraints, only minor editorial changes were made in report sections other than Appendix E. Thus, the main body of the report has not yet been modified to include specific additional issues as requested by various groups (e.g., Design Engineering, TAAG, SRG); it is planned that an additional revision will be made to include these issues. The DWCS analysis in Appendix E is not affected by modifications to be made in other sections of this report. 2

2.0 APPLICABILITY/SCOPE

A new filtration and ion exchange system for processing RCS water will be added to aid defueling operations. This system is termed the "Defueling Water Cleanup System" (DWCS). Two modes of DWCS operation may be used in defueling. The first mode utilizes only dedicated DWCS components for filtration and ion exchange; the second mode uses dedicated DWCS components for filtration and the SDS System for ion exchange. This revision considers the potential for RCS boron dilution that is associated with DWCS operation as well as the dilution potential associated with other plant conditions. 2

The main body of this report covers plant operations during static conditions while in the level control mode as described by TMI-2 Operating Procedure OP 2104-10.2. Additional plant maneuvers/conditions are covered in the appendices, as indicated below.

RCS Feed and Bleed (OP 2104-10.2; Section 4.2)	Appendix A	
IIF Fill (OP 2104-10.2 Section 4.3.2)	Appendix B	
Refueling Canal Fill (OP 4210 Ops 3250.01)	Appendix C	
IIF Processing (OP 2104-8.18)	Appendix D	
DWCS Processing	Appendix E	2

3.0 SUMMARY OF RESULTS

References 16 and 17 indicate that the minimum acceptable boron concentration until the start of core alterations is 3500 ppm. Reference 13 indicates that a concentration of 4350 ppm will assure subcriticality in the presence of intentional fuel disturbances. The probability of occurrence of a dilution event is a function of the ability to isolate the RCS and not of the acceptable boron concentration. The probability of a large dilution rate event occurring during static conditions was found to be very small ($\sim 3 \times 10^{-4}$ per year); the probability of a small rate dilution was somewhat larger ($\sim 5 \times 10^{-3}$ per year). The probability of a dilution occurring during particular plant maneuvers varies because the number of potential dilution paths varies; the probability of a dilution occurring during each maneuver is presented in the appropriate appendix. If a dilution event were to occur, the probability of terminating it before it becomes a safety concern is a function of the minimum acceptable boron concentration. However, because there is significant margin between either minimum acceptable boron concentration and the actual RCS concentration of 5050 (± 100 ppm), an 1
appropriate detection/mitigation program can be developed for either minimum concentration. Considering the detection/mitigation capabilities along with the occurrence probability, the probability of an inadvertent dilution causing a criticality was found to be negligible (about 10^{-4} per year) for planned operations until the start of defueling.

Isolation boundaries for the RCS during static conditions and various plant maneuvers have been recommended. The isolation boundaries in this report generally reflect the input of the Safety Review Group and Site Operations and are incorporated into appropriate plant procedures. Sampling and inventory monitoring frequencies have also been recommended. These recommendations were incorporated into SER commitments or are already consistent with plant practice (N.B. After start of SDS processing, GPUN committed to a more frequent sampling frequency than that recommended in this report in order to reduce uncertainties about mixing of the potential diluent.)

Detailed conclusions and recommendations are presented in Sections 5.0 and 6.0, respectively.

4.0 ANALYSIS

4.1 Introduction

Boron dilution of the reactor coolant system is a concern at TMI-2 because of its potential to cause a criticality with possible personnel and public safety implications.[1] Thus, RAS has performed a plant specific analysis of the boron dilution potential at TMI-2. Section 4.2 provides a summary of the analysis approach. Section 4.3 summarizes the assumptions used and the limitations of the analysis. Section 4.4 provides the details of the calculation.

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1 To gain a perspective on the significance of this issue, a summary of industry experience is helpful. Based on actual industry experience, the probability of an unplanned boron dilution of a PWR during maintenance and refueling has been estimated as 0.09 per reactor-year (Reference 1). The NRC estimates the probability of an inadvertent criticality due to a boron dilution event to be 2×10^{-3} to 2×10^{-4} per year depending on the neutron monitoring in use at a plant (Reference 2). Of additional interest at TMI-2 is the probability of an unplanned dilution of a borated tank, which has been estimated, based on industry experience to be about 0.1 per year (Reference 1). Equipment failures were the cause of 20% of the RCS boron dilution events; 80% were the result of personnel error. Interestingly, 81% of the boron dilution events were "other than those postulated in the design analyses in the PWR FSARs ..." (Reference 1).

4.2 Analysis Approach

The boron dilution analysis can be summarized by the following tasks:

(I). Identify the potential points of water injection to the RCS.

These points were identified by review of current P&IDs and knowledge of temporary connections. Dilution through any part of the RCS was considered, e.g. core flood tanks, pressurizer, RC pump seals and vessel nozzles. The secondary side of the steam generators was also considered a potential RCS injection point. Details of this task are provided in Section 4.4.1.

(II) Track each potential RCS injection point to potential dilution sources.

Each injection point identified in Task I was tracked to determine potential boron dilution sources for that point. The potential boron dilution sources found in this manner may be isolated either by barriers near the sources themselves or by barriers associated with the RCS injection point. Details of the task are provided in Section 4.4.2.

(III) Identify isolation barriers for each dilution source.

Isolation barriers were identified for the injection points identified in Task I. (An equivalent isolation barrier could be used if there are operational problems with the barrier forming the basis of this analysis.) An additional measure of protection could be gained by isolating the dilution sources as well as the injection points. The details of this task are presented in Section 4.4.3.

(IV) Determine probability of failure of isolation barrier configuration.

An analysis was performed to assess the probability of failure of various dilution barriers identified in Task III due to hardware faults and human error. This analysis is presented in Section 4.4.4.

(V) Estimate total plant boron dilution potential

The total plant boron dilution potential was estimated considering the number of injection paths, the reliability of each isolation barrier, and credit for operator error in detecting and terminating a boron dilution event. This analysis is presented in Section 4.4.5.

4.3 Assumptions and Limitations

- Recent analyses have indicated that an RCS boron concentration of 4350 ppm should be the basis for some recovery operations. At other times, 3500 ppm remains the minimum acceptable boron concentration. The actual RCS boron concentration is being maintained at an administrative limit of 5050 ppm (± 100 ppm); recent monthly average boron concentrations have been over 5100 ppm. Thus, it was assumed that the initial boron concentration for a postulated 1
dilution event is 5050 ppm and that terminating a dilution event prior to reaching 3500 or 4350 ppm, as appropriate, assures that there is not a safety impact from the event.

- The analysis was performed for RCS operation in both static conditions during the level control mode and for various plant maneuvers. Potential dilution through an open vessel head was judged to have a negligible probability for the scope of this analysis because of (i) the low probability of an in-containment fire coupled with personnel error that 1
would direct flow over the RCS, (ii) the low probability of inadvertent containment spray actuation and, (iii) the presence of the IIF work platform which would inhibit a dilution event through the vessel head.

- The analysis does not take into account water that may be stored in piping. However, the approach used in the analysis whereby isolation is generally achieved "close" to the RCS minimizes this potential concern.

- To calculate dilution times, Rev. 0 assumed that a potential dilution flow would mix uniformly with the borated volume in the reactor vessel; no credit was taken for water in the RCS loops. Since then, the mixing characteristics of a potential dilution inflow have been analyzed in more detail (References 11 and 12). These analyses indicate that the dilution inflow is likely to float to the upper plenum and IIF regions through the cold fit-up gap rather than proceeding down the CSA annulus and through the core. This effect is due to the density difference between the lighter dilution inflow and the borated water in the vessel. These analyses indicate that the core region is likely to be the last area of the vessel to see a dilution flow; thus, the uniform mixing assumption represents a bounding condition. 1

- To assure compliance with SER commitments, double barrier isolation of all dilution paths with appropriate administrative control must be demonstrated. In fact, many more closed valves, pulled spoolpieces, elevation differences, etc., may be in place which prohibits dilution through a particular path. In some of these cases, neither verification of barrier position nor administrative control could be assured and no credit was given to these barriers. Thus, the analysis may be somewhat conservative for many potential dilution paths.

- The quantification performed in this analysis was based on point estimates of hardware failure and human error probabilities; i.e. error bands were not propagated through the calculation. This approach has been used in other analyses (e.g. Reactor Safety Study Methodology Applications Program) for drawing conclusions about relative and dominant risks.

4.4 Calculation

In this section, the details of the boron dilution analysis are provided. They include identification of RCS injection points, identification of potential dilution sources of the RCS, estimates of the failure probability of individual isolation barriers, and an estimate of the total plant boron dilution probability.

4.4.1 Potential RCS Dilution Points

Points of potential dilution of the RCS were identified based on a review of P&ID's. At this stage, dilution through any part of the RCS was considered, e.g., core flood tanks, pressurizer, RC pump seals and vessel nozzles. The points of potential dilution of the RCS primary side are listed in Table 4.4-1 and shown schematically as Figure 4.1.

The secondary side of the steam generators was also considered a point of potential RCS dilution. Although the steam generator tubes provide a boundary from the primary system, they were not credited as a dilution barrier because their integrity above elevation 313' has not been demonstrated for several years. Instead, the approach used in this analysis was to prevent the addition of unborated water to the steam generator itself. Isolation of the steam generator is illustrated in Figure 4.2. We have concluded that the number of barriers isolating the generators and their small exposure to operator error result in a negligible contribution to the probability of RCS dilution from the steam generator secondary side. Additional details of the steam generator analysis are provided in RAS Calculation 0430-84-007.

Dilution through the top of the open vessel was not explicitly analyzed because the probability of such an event was judged to be exceedingly small. This judgment was based on the following considerations: (i) the vessel will only be open for a short interval between removal of the head and installation of the IIF work platform, (ii) dilution with fire fighting equipment requires the occurrence of a fire and misoperation of the equipment and (iii) dilution via the building sprays requires multiple component failures or human errors.

4.4.2 Potential Dilution Sources

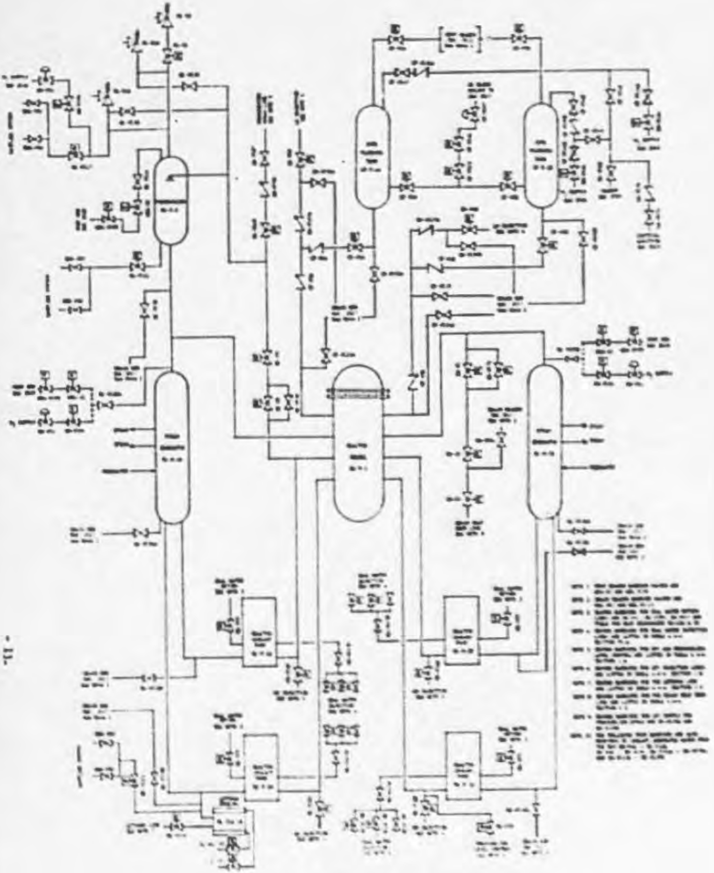
After the potential RCS dilution points were identified, flowpaths to these points were traced back through the plant until a potential dilution source was reached. These sources consist of tanks, coolers, demineralizers, evaporators, heaters, closed cooling water systems and the fuel pool, i.e., any collection of water that could be a potential source of boron dilution. These dilution sources are shown in Table 4.4-2. No consideration was made of the fact that some sources may only be filled to a partial capacity or may have water borated to some level below the minimum acceptable boron concentration; it is assumed that they could be full of unborated water or other liquid at some time. (An exception is the BWST which was judged not credible to dilute because of the amount of water that would have to be added without detection.) When tracing potential paths from a dilution source, flow was considered possible through either direction of a pipe. Credit was not given to complete prevention of flow by a check valve because small dilution flows may not be adequate to assure seating of the valve; however, a check valve was credited as preventing full backflow through a pipe. Paths leading to drains, atmospheric vents, local sampling points, hose nozzles and sumps were assumed not to be potential dilution paths to the RCS and were not tracked further. The tracking of the flow paths to the dilution sources is presented in RAS Calculation 4430-84-07.

One method of reducing the RCS boron dilution probability is to isolate the sources shown in Table 4.4-2. However, since most sources could communicate with several RCS injection points, isolation of a single source could require more than a dozen isolation barriers. Therefore, because fewer barriers were required, isolation was generally recommended at an RCS injection point. Isolation in this manner has the effect of isolating all RCS dilution sources, regardless of their volume and minimizes concern about unborated water in piping. (As noted in Section 4.4.5.2 isolation of several sources which have the volume to dilute the RCS and are at sufficient elevation to gravity feed into the vessel would be an added preventative measure.)

TABLE 4.4-1

POTENTIAL DILUTION POINTS TO RCS PRIMARY

DILUTION POINTS	ELEVATION	ASSOCIATED VALVE
ASME Code Relief Valve	355'	RC-R1A
ASME Code Relief Valve	355'	RC-R1B
EMOV with PORV	355'	RC-V2
Pressurizer Spray Line	353'	RC-V3
Pressurizer Drain Line	310'	RC-V106
Pressurizer Vent Line	355'	RC-V114
Pressurizer Sampling Line	310'	RC-V117
Pressurizer Sampling Line	310'	RC-V122
Pressurizer Drain Line	353'	RC-V142
LPI Pressurizer Spray Line	353'	RC-V149
Pressurizer Drain Line to RC Drain Tank	356'	RC-V155
Steam Generator 1A Primary Drain	301'	RC-V104A
Steam Generator 1B Primary Drain	301'	RC-V104B
S.G. 1A N_2 Primary Blanketing Supply and Vent	365'	RC-V100A
S.G. 1B N_2 Primary Blanketing Supply and Vent	365'	RC-V100B
Reactor Coolant Pump Cold Leg Drains	314'	RC-V110A, C & D
Let Down Nozzle (RCP-1A Cold Leg Drain)	314'	RC-V121 & RC-V110B
Reactor Vessel Gasket Leakage Recovery Drain	322'	RC-V124
Decay Heat Drop Line	314'	DH-V1 & V171
Core Flood & LPI Nozzle A	316'	CF-V1A & DH-V6A
Core Flood & LPI Nozzle B	316'	CF-V1B & DH-V6B
Core Flood Nozzle A Drain	316'	CF-V121A
Core Flood Nozzle B Drain	316'	CF-V121B
LPI Nozzle B Drain	316'	CF-V119
Core Flood Tank 1A Drain	310'	CF-V102A
Core Flood Tank 1B Drain	310'	CF-V102B
HPI Injection Nozzle	314'	MU-V16A,B,C,D & V18
RC Pump Seal Injection Returns	316'	MU-V33A,B,C,D
RC Pump Seal Injection Supply	316'	MU-V415A,B,C,D
Decay Heat Line Drain	316'	DH-V159A & B
Core Flood Tank Vent	342'	CF-V3A, 3B
Core Flood Tank Bleed Line	334'	CF-V2A, 2B
Core Flood Tank Fill Line	338'	CF-V147, V148
Steam Generator Tubes		



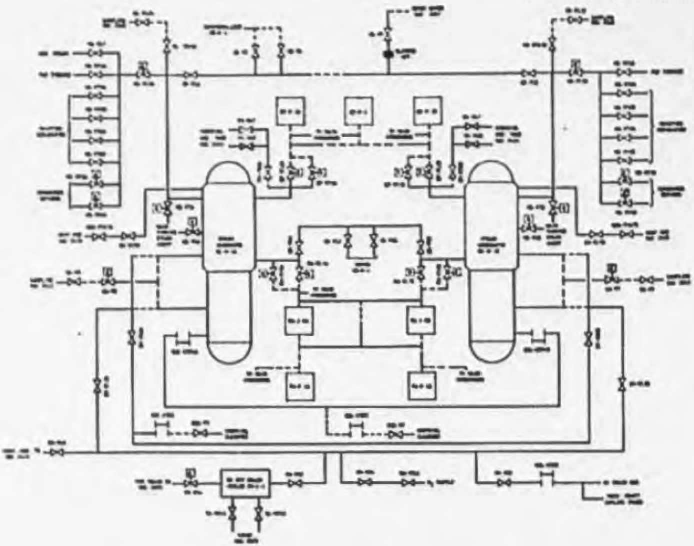


FIGURE 4.2 - RCS SECONDARY SIDE DILUTION POINTS AND SELECTED ISOLATION BARRIERS

TABLE 4.4-2

POTENTIAL DILUTION SOURCES FOR RCS DILUTION POINTS

	Capacity (Gallons)	Centerline Elevation (Feet)	Capacity above Alarm Setpoint[1]
Core Flooding Make-Up Tank (CA-T-8)	560	333'0"	NA
Main Condensers (CO-C-1A, 1B)	25,610 ea.	282'7"	7,964
Sodium Hydroxide Storage Tank (DH-T-2)	14,785	331'0"	1,473
Decay Heat Rem. Coolers (DH-C-1A, 1B)	932 ea.	284'6"	NA
Demin. Water Storage Tank (DW-T-1)	50,000	313'6"	25,758
Vacuum Degasifier (DW-T-2)	1,575	318'0"	NA
Unit #1 Demin. Water Storage Tank	1,000,000	329'6"	NA
Make-Up Tank (MU-T-1)	4,500	312'0"	3,967
Letdown Coolers (MU-C-1A, 1B)	111 ea.	286'3"	NA
RCP Seal Water Coolers (MU-C-2A, 2B)	41 ea.	312'0"	NA
Spent Fuel Coolers (SF-C-1A, 1B)	418 ea.	313'8"	NA
Spent Fuel Demineralizer (SF-K-1)	246	309'0"	NA
Fuel Transfer and Storage Pools	690,000	327'0"	NA
Reactor Bldg. Sump	2,514	279'6"	NA
RC Bleed Tanks (WDL-T-1A, 1B, 1C)	82,286 ea.	291'6"	NA
Misc. Waste Holdup Tank (WDL-T-2)	19,518	312'0"	NA
RC Drain Tank (WDL-T-3)	7,240	289'0"	1,140
MU&P Demineralizers (MU-K-1A, 1B)	570 ea.	309'0"	NA
Condensate Store. Tanks (CO-T-1A, 1B)	250,000 ea.	321'6"	98,485
Gland Steam Condenser (GS-C-1)	244	307'0"	NA
Feedwater Drain Coolers (FW-C-1A, 1B)	2,163 ea.	294'8"	NA
Feedwater Heaters (FW-J-5A, 5B)	7,932 ea.	336'0"	NA
Feedwater Heaters (FW-J-6A, 6B)	13,965 ea.	311'0"	NA
Int. CCW Coolers (IC-C-1A, 1B)	645 ea.	313'0"	NA
Nuc. Service CCW Coolers (NS-C-1A, 1B)	1,949 ea.	313'0"	NA
Ammonium Hydroxide Feed Tank (AM-T-1)	150	283'0"	106
Hydrazine Feed Tank (AM-T-2)	150	283'0"	106
Ammonium Hydroxide Mix Tank (AM-T-7)	60	283'6"	NA
Boric Acid Mix Tank (CA-T-1)	7,590	338'0"	6,415
Lithium Hydroxide Mix Tank (CA-T-3)	50	335'0"	NA
Sod. Thio. & Caust. Mix Tank (CA-T-5)	200	334'0"	NA
Sulphuric Acid Mix Tank (CA-T-9)	200	336'0"	NA
Off-Spec. Water Rec. Bat. Tank (CC-T-1)	85,978	324'6"	80,020
Regeneration Tank (CO-T-2)	1,866	289'6"	NA
Mixing & Storage Tank (CO-T-3)	1,911	289'6"	NA
Hot Water Tank (CO-T-4)	936	288'0"	NA
Reactor Coolant Evaporator (WDL-Z-1)	3,541	291'6"	NA
Debor. Demineralizers (WDL-K-1A, 1B)	1,517 ea.	312'0"	NA
Clean-up Demineralizers (WDL-K-2A, 2B)	253 ea.	286'0"	NA
Evap. Cond. Demin. (WDL-K-3A, 3B)	248 ea.	286'0"	NA
Aux. Bldg. Sump Tank (WDL-T-5)	3,155	286'0"	NA

TABLE 4.4-2

POTENTIAL DILUTION SOURCES FOR RCS DILUTION POINTS (Continued)

	Capacity (Gallons)	Centerline Elevation (Feet)	Capacity above Alarm Setpoint [1]
Neutralizer Tanks (WDL-T-8A, 8B)	9,616 ea.	291'0"	NA
Evap. Cond. Tanks (WDL-T-9A, 9B)	11,040 ea.	291'6"	NA
Spent Resin Storo. Tanks (WDS-T-1A, 1B)	3,861 ea.	284'6"	NA
Concentrated Waste Tank (WDS-T-2)	9,646	334'9"	8,224
Reclaimed Boric Acid Tank (WDS-T-3)	9,646	291'0"	8,224
Clarif. Coagulator Floc Tank (WT-T-1)	350	311'0"	NA
Clearwell Tank (WT-T-2)	50,000	289'0"	NA
Caustic Feed Tank (WT-T-6)	340	309'0"	NA
Sodium Sulphite Store. Tank (WT-T-11)	50	309'0"	NA
Mixed Bed Demineralizers (WT-K-3A, 3B)	1,249 ea.	284'0"	NA
Clean Water Receiving Tank (CC-T-2)	133,689	322'6"	130,137
SDS Monitor Tanks (SDS-T-1A, 1B)	12,000 ea.	322'0"	10,530
Processed Water Store. Tanks (PW-T-1,2)	500,000 ea.	322'0"	NA
Mech. Draft Cooling Tower (CW-C-2)			NA

---

1 Represents the maximum volume of liquid that could be removed from dilution source before a level alarm is activated. "NA" means that no alarm is in use.

4.4.3 Isolation Barriers

Preventing flow through all of the RCS injection points in Table 4.4-1 will prevent dilution of the RCS through piping interfaces during static conditions. To prevent potential inflow, the TMI-2 Safety Evaluation Reports (SERs) have committed to a double barrier configuration consisting of a combination of removed spoolpieces, closed valves, heat exchanger tubes or pumps (with elevation or head difference). Thus, a first priority of this analysis was to ensure that the SER commitment was met. Where possible, we employed the additional constraint that the barriers be "independent" which, from a reliability viewpoint, minimizes concern about common mode failures due either to physical affects or operator error (Reference 9).

In the level control mode, with no water processing (static conditions), it was found that there are 404 paths that require closure to isolate all of the RCS injection points. The isolation of the 404 RCS injection paths is achieved with a total of 125 components which are identified in Table 4.4-3. Table 4.4-3 represents a set of components which have been agreed to by RAS, SRG and Site Operations and have been placed on a 24 hour checklist for isolation of the RCS during static conditions. This checklist is Appendix C to Operating Procedure 2104-10.2. (Also included in Appendix C to 2104.10.2 are valves recommended in Appendices A and B which isolate during IIF fill and feed/bleed.)

In Table 4.4-4, the suggested isolation barriers are grouped according to the functional area of the RCS with which they are associated. This grouping illustrates the double barrier isolation achieved for each potential dilution path.

Table 4.4-3

<u>Isolation Barriers to be Placed on 24-hour Checklist During Static Conditions</u>

BS-V3A	CF-V146	IC-V3	MU-V144C	SNS-V23	WDL-V523
BS-V3B	DH-V3	IC-V4	MU-V169	SNS-V50	WDL-V543A
BS-V136	DH-V4A	IC-V5	MU-V224A	SNS-V53	WDL-V543B
BS-V139A	DH-V4B	MU-V8	MU-V224B	SNS-V128	WDL-V994
BS-V139B	DH-V5A	MU-V10	MU-V226	SNS-V140	WDL-V996
CA-V104	DH-V5B	MU-V12	MU-V289	SNS-V150	WDL-V1091
CA-V107	DH-V7A	MU-V13	MU-V294	SNS-V158	WDL-V1092
CA-V111	DH-V7B	MU-V16A	MU-V319	WDG-V2	WDL-V1125
CA-V112	DH-V100A	MU-V16B	MU-V376	WDG-V199	WDL-V1152
CA-V136	DH-V100B	MU-V16C	MU-V378	WDL-V22	WDL-V1171
CA-V138	DH-V109	MU-V16D	MU-V439	WDL-V288	
CA-V140	DH-V120	MU-V18	NM-V52	WDL-V298	
CA-V173	DH-V128A	MU-V25	NM-V104	WDL-V37	
CA-V175	DH-V128B	MU-V27	OC-V117	WDL-V59	
CF-V1A	DH-V134A	MU-V28	OC-V122	WDL-V65A	
CF-V1B	DH-V134B	MU-V36	OC-V123	WDL-V81A	
CF-V2A	DH-V187	MU-V37	SF-V122	WDL-V81B	
CF-V2B	DH-V101A	MU-V107A	SF-V133	WDL-V118A	
CF-V107	DH-V101B	MU-V107B	SF-V186	WDL-V118B	
CF-V114A	DH-V195	MU-V127	SF-V214	WDL-V153A	
CF-V114B	DH-V227	MU-V133	SF-V217	WDL-V521A	
CF-V115	DH-V230	MU-V144A	SA-V182	WDL-V521B	
CF-V145	DH-V465	MU-V144B	SNS-V20	WDL-V521C	

Table 4.4-4

Double Barrier Isolation Configurations for Potential Dilution Paths

(The barrier combinations in this table are composed of various combinations of the valves listed in Table 4.4-3)

I. NOZZLES

A. HPI:
1. MU-V16A -- MU-V144A
2. MU-V16A -- MU-V144B
3. MU-V16A -- MU-V144C
4. MU-V16A -- MU-V289
5. MU-V16A -- MU-V133
6. MU-V16A -- MU-V127
7. MU-V16A -- CA-V107
8. MU-V16A -- CA-V112
9. MU-V16A -- SF-V182
10. MU-V16A -- MU-V8
11. MU-V16A -- MU-V10
12. MU-V16A -- MU-V319
13. MU-V16A -- CF-V145
14. MU-V16A -- CF-V146
15. MU-V16A -- CA-V175
16. MU-V16B -- MU-V144A
17. MU-V16B -- MU-V144B
18. MU-V16B -- MU-V144C
19. MU-V16B -- MU-V289
20. MU-V16B -- MU-V133
21. MU-V16B -- MU-V127
22. MU-V16B -- CA-V107
23. MU-V16B -- CA-V112
24. MU-V16B -- SF-V182
25. MU-V16B -- MU-V8
26. MU-V16B -- MU-V10

1. NOZZLES (continued)

27. MU-V16B — MU-V319
28. MU-V16B — CF-V145
29. MU-V16B — CF-V146
30. MU-V16B — CA-V175
31. MU-V16C — MU-V144A
32. MU-V16C — MU-V144B
33. MU-V16C — MU-V144C
34. MU-V16C — MU-V289
35. MU-V16C — MU-V133
36. MU-V16C — MU-V127
37. MU-V16C — CA-V107
38. MU-V16C — CA-V112
39. MU-V16C — SN-V182
40. MU-V16C — MU-V8
41. MU-V16C — MU-V10
42. MU-V16C — MU-V319
43. MU-V16C — CF-V145
44. MU-V16C — CF-V146
45. MU-V16C — CA-V175
46. MU-V16D — MU-V144A
47. MU-V16D — MU-V144B
48. MU-V16D — MU-V144C
49. MU-V16D — MU-V289
50. MU-V16D — MU-V133
51. MU-V16D — MU-V127
52. MU-V16D — CA-V107
53. MU-V16D — CA-V112
54. MU-V16D — SN-V182
55. MU-V16D — MU-V8
56. MU-V16D — MU-V10
57. MU-V16D — MU-V319
58. MU-V16D — CF-V145
59. MU-V16D — CF-V146
60. MU-V16D — CA-V175

A. NOZZLES (continued)

61. MU-V18 — MU-V16A
62. MU-V18 — MU-V16B
63. MU-V18 — MU-V16C
64. MU-V18 — MU-V16D
65. MU-V18 — MU-V133
66. MU-V18 — MU-V127
67. MU-V18 — CA-V107
68. MU-V18 — CA-V112
69. MU-V18 — SR-V182
70. MU-V18 — MU-V8
71. MU-V18 — MU-V10
72. MU-V18 — MU-V310
73. MU-V18 — CF-V145
74. MU-V18 — CF-V146
75. MU-V18 — CA-V175

B. LPI and Core Flood:

1. DH-V4A — DH-V109
2. DH-V4A — DH-V120
3. DH-V4A — DH-V128A
4. DH-V4A — DH-V128B
5. DH-V4A — DH-V7A
6. DH-V4A — DH-V7B
7. DH-V4A — SKS-V53
8. DH-V4A — SKS-V128
9. DH-V4A — SKS-V140
10. DH-V4A — SKS-V158
11. DH-V4A — DH-V238
12. DH-V4A — DH-V465
13. DH-V4A — [illegible]-HX-1A (tubes)
14. DH-V4A — [illegible]-HX-1B (tubes)
15. DH-V4B — DH-V109
16. DH-V4B — DH-V120

B. <u>NOZZLES</u> (continued)

17. DH-V4B -- DH-V128A
18. DH-V4B — DH-V128B
19. DH-V4B — DH-V7A
20. DH-V4B — DH-V7B
21. DH-V4B — SKS-V53
22. DH-V4B — SKS-V120
23. DH-V4B — SKS-V140
24. DH-V4B — SKS-V150
25. DH-V4B — DH-V230
26. DH-V4B -- DH-V465
27. DH-V4B -- MDH-MX-1A (tubes)
28. DH-V4B -- MDH-MX-1B (tubes)

C. Letdown:

1. MU-V376 -- CA-V136
2. MU-V376 -- CA-V140
3. MU-V376 — CF-V107
4. MU-V376 — MU-R3
5. MU-V376 -- MU-V8
6. MU-V376 -- MU-V10
7. MU-V376 — MU-V107A
8. MU-V376 -- MU-V107B
9. MU-V376 -- MU-V169
10. MU-V376 — MU-V224A
11. MU-V376 -- MU-V224B
12. MU-V376 -- MU-V226
13. MU-V376 — MU-V294
14. MU-V376 -- MU-V319
15. MU-V376 -- SF-V214
16. MU-V376 -- WDL-V288
17. MU-V376 — WDL-V298
18. MU-V376 -- WDL-V37
19. MU-V376 -- WDL-V59

C. NOZZLES (continued)

20. MU-V376 — WDL-V65A
21. MU-V376 — WDL-V81A
22. MU-V376 — WDL-V81B
23. MU-V376 -- WDL-V318A
24. MU-V376 -- WDL-V318B
25. MU-V376 — WDL-V153A
26. MU-V376 — WDL-V521A
27. MU-V376 — WDL-V521B
28. MU-V376 -- WDL-V521C
29. MU-V376 -- WDL-V523
30. MU-V376 -- WDL-V543A
31. MU-V376 -- WDL-V543B
32. MU-V376 -- WDL-V994
33. MU-V376 -- WDL-V996
34. MU-V376 — WDL-V1091
35. MU-V376 — WDL-V1092
36. MU-V376 — WDL-V1125
37. MU-V376 -- WDL-V1152
38. MU-V376 -- WDL-V1171
39. MU-V376 — WDL-T-1B
40. MU-C-1A (tubes) -- IC-V3
41. MU-C-1A (tubes) -- IC-V4
42. MU-C-1A (tubes) -- IC-V5
43. MU-C-1B (tubes) — IC-V3
44. MU-C-1B (tubes) -- IC-V4
45. MU-C-1B (tubes) -- IC-V5

D. Decay Heat Dropline:

1. DH-V3 -- DH-V100A
2. DH-V3 -- DH-V100B
3. DH-V3 -- SNS-V53
4. DH-V3 -- SNS-V128
5. DH-V3 -- SNS-V140

I. NOZZLES (continued)

6. DH-V3 — SNS-V158
7. DH-V3 — MDH-HX-1A (tubes)
8. DH-V3 — MDH-HX-1B (tubes)
9. DH-V3 — DW-V236
10. DH-V3 — DW-V465

II. CORE FLOOD TANKS

A. Bleed:

1. CF-V1A — CF-V115 — (CF-V107) (check valve)
2. CF-V1B — CF-V115 — (CF-V107) (check valve)

B. Fill:

1. CF-V1A — CF-V146
2. CF-V1B — CF-V145

III. PRESSURIZER SPRAY

A. LPI Supply:

1. DH-V187 — DH-V128A
2. DH-V187 — DH-V128B

IV. REACTOR COOLANT PUMP SEAL WATER

A. Injection (via MU-V330, 378, and 439)[1]:

1. MU-V318 — MU-V144A
2. MU-V378 — MU-V144B

[1] Barrier combinations 31 through 219 provide double barrier isolation of potential injection paths through MU-V330. The same barriers also result in triple barrier isolation of MU-V378 and MU-V439. Further, these barriers act as an additional barrier for paths through MU-V16's.

IV. <u>REACTOR COOLANT PUMP SEAL WATER</u> (continued)

3. MU-V378 — MU-V144C
4. MU-V378 — MU-V289
5. MU-V378 — MU-V133
6. MU-V378 — MU-V127
7. MU-V378 — CA-V107
8. MU-V378 — CA-V112
9. MU-V378 — SH-V182
10. MU-V378 — MU-V8
11. MU-V378 — MU-V10
12. MU-V378 — MU-V319
13. MU-V378 — CF-V145
14. MU-V378 — CF-V146
15. MU-V378 — CA-V175
16. MU-V439 — MU-V144A
17. MU-V439 — MU-V144B
18. MU-V439 — MU-V144C
19. MU-V439 — MU-V289
20. MU-V439 — MU-V133
21. MU-V439 — MU-V127
22. MU-V439 — CA-V107
23. MU-V439 — CA-V112
24. MU-V439 — SH-V182
25. MU-V439 — MU-V8
26. MU-V439 — MU-V10
27. MU-V439 — MU-V319
28. MU-V439 — CF-V145
29. MU-V439 — CF-V146
30. MU-V439 — CA-V175
31. MU-V144A — DH-V5A
32. MU-V144A — DH-V5B
33. MU-V144A — DH-V7A
34. MU-V144A — DH-V7B
35. MU-V144A — DH-V170A
36. MU-V144A — DH-V170B

IV. REACTOR COOLANT PUMP SEAL WATER (continued)

37. MU-V144A — DH-C-1A (tubes)
38. MU-V144A — DH-C-1B (tubes)
39. MU-V144A — DH-V109
40. MU-V144A — DH-V134A
41. MU-V144A — DH-V134B
42. MU-V144A — SF-V122
43. MU-V144A — SF-V133
44. MU-V144A — SF-V186
45. MU-V144A — SF-V214
46. MU-V144A — SF-V217
47. MU-V144A — SF-C-1A (tubes)
48. MU-V144A — SF-C-1B (tubes)
49. MU-V144A — SF-R-1[2]
50. MU-V144A — BS-V3A
51. MU-V144A — BS-V3B
52. MU-V144A — MU-V12
53. MU-V144A — MU-V36
54. MU-V144A — DH-V120
55. MU-V144A — CA-V175
56. MU-V144A — DH-V195
57. MU-V144B — DH-V5A
58. MU-V144B — DH-V5B
59. MU-V144B — DH-V7A
60. MU-V144B — DH-V7B
61. MU-V144B — DH-V109
62. MU-V144B — DH-V120
63. MU-V144B — DH-V120A
64. MU-V144B — DH-V120B
65. MU-V144B — DH-V134A
66. MU-V144B — DH-V134B
67. MU-V144B — DH-C-1A (tubes)
68. MU-V144B — DH-C-1B (tubes)
69. MU-V144B — BS-V3A
70. MU-V144B — BS-V3B

[2] Represents components in vent header system which must fail to allow flow, (e.g., check valves) but cannot be placed on a daily checklist.

IV. <u>REACTOR COOLANT PUMP SEAL WATER</u> (continued)

71. MU-V144B -- CA-V175
72. MU-V144B — DW-V195
73. MU-V144B — SF-V122
74. MU-V144B — SF-V133
75. MU-V144B -- SF-V186
76. MU-V144B — SF-V214
77. MU-V144B -- SF-V217
78. MU-V144B -- SF-C-1A (tubes)
79. MU-V144B -- SF-C-1B (tubes)
80. MU-V144B -- MU-V12
81. MU-V144B — MU-V36
82. MU-V144B -- SF-K-1[2]
83. MU-V144C -- DH-V5A
84. MU-V144C -- DH-V5B
85. MU-V144C -- DH-V7A
86. MU-V144C — DH-V7B
87. MU-V144C -- DH-V109
88. MU-V144C -- DH-V120
89. MU-V144C — DH-V128A
90. MU-V144C -- DH-V128B
91. MU-V144C -- DH-V134A
92. MU-V144C -- DH-V134B
93. MU-V144C — DH-C-1A (tubes)
94. MU-V144C — DH-C-1B (tubes)
95. MU-V144C -- BS-V3A
96. MU-V144C -- BS-V3B
97. MU-V144C -- CA-V175
98. MU-V144C -- DW-V195
99. MU-V144C -- SF-V122
100. MU-V144C -- SF-V133
101. MU-V144C — SF-V186
102. MU-V144C -- SF-V214
103. MU-V144C -- SF-V217

[2] Represents components in vent header system which must fail to allow flow, (e.g., check valves) but cannot be placed on a daily checklist.

IV. REACTOR COOLANT PUMP SEAL WATER (continued)

104. MU-V144C -- SF-C-1A (tubes)
105. MU-V144C -- SF-C-1B (tubes)
106. MU-V144C -- SF-E-1[2]
107. MU-V144C -- MU-V12
108. MU-V144C -- MU-V36
109. MU-V8 -- CA-V136
110. MU-V8 -- CA-V140
111. MU-V8 -- CF-V107
112. MU-V8 -- MU-V10
113. MU-V8 -- MU-V107A
114. MU-V8 -- MU-V107B
115. MU-V8 -- MU-V169
116. MU-V8 -- MU-V224A
117. MU-V8 -- MU-V224B
118. MU-V8 -- MU-V226
119. MU-V8 -- MU-V294
120. MU-V8 -- MU-V319
121. MU-V8 -- SF-V214
122. MU-V8 -- WDL-V288
123. MU-V8 -- WDL-V293
124. MU-V8 -- WDL-V37
125. MU-V8 -- WDL-V59
126. MU-V8 -- WDL-V65A
127. MU-V8 -- WDL-V81A
128. MU-V8 -- WDL-V81B
129. MU-V8 -- WDL-V118A
130. MU-V8 -- WDL-V118B
131. MU-V8 -- WDL-V153A
132. MU-V8 -- WDL-V521A
133. MU-V8 -- WDL-V521B
134. MU-V8 -- WDL-V521C

2 Represents components in vent header system which must fail to allow flow, (e.g., check valves) but cannot be placed on a daily checklist.

IV. <u>REACTOR COOLANT PUMP SEAL WATER</u> (continued)

135. MU-V8 — WDL-V523
136. MU-V8 — WDL-V543A
137. MU-V8 — WDL-V543B
138. MU-V8 -- WDL-V994
139. MU-V8 — WDL-V996
140. MU-V8 — WDL-V1091
141. MU-V8 — WDL-V1092
142. MU-V8 — WDL-V1125
143. MU-V8 — WDL-V1152
144. MU-V8 — WDL-V1171
145. MU-V8 -- WDL-T-1B[2]
146. MU-V209 -- MU-C-2A (tubes)
147. MU-V209 -- MU-C-2B (tubes)
148. MU-V209 -- DW-V227
149. MU-V133 — MU-V13
150. MU-V133 -- MU-V27
151. MU-V133 -- MU-V28
152. MU-V133 — MU-V169
153. MU-V133 -- MU-T-1[2]
154. MU-V127 -- CA-V138
155. CA-V107 — CA-V104
156. CA-V107 -- CA-V111
157. CA-V112 -- CA-V104
158. CA-V112 -- CA-V113
159. MU-V10 -- CA-V136
160. MU-V10 — CA-V140
161. MU-V10 — CF-V107
162. MU-V10 -- MU-V169
163. MU-V10 -- MU-V294
164. MU-V10 -- SF-V214
165. MU-V10 -- WDL-V288
166. MU-V10 — WDL-V293
167. MU-V10 — WDL-V37
168. MU-V10 — WDL-V59

2 Represents components in vent header system which must fail to allow flow, (e.g., check valves) but cannot be placed on a daily checklist.

IV. REACTOR COOLANT PUMP SEAL WATER (continued)

169. MU-V10 — WDL-V65A
170. MU-V10 — WDL-V81A
171. MU-V10 — WDL-V81B
172. MU-V10 — WDL-V110A
173. MU-V10 — WDL-V110B
174. MU-V10 — WDL-V153A
175. MU-V10 — WDL-V521A
176. MU-V10 — WDL-V521B
177. MU-V10 — WDL-V521C
178. MU-V10 — WDL-V523
179. MU-V10 — WDL-V543A
180. MU-V10 — WDL-V543B
181. MU-V10 — WDL-V994
182. MU-V10 — WDL-V996
183. MU-V10 — WDL-V1091
184. MU-V10 — WDL-V1092
185. MU-V10 — WDL-V2125
186. MU-V10 — WDL-V1152
187. MU-V10 — WDL-V1271
188. MU-V319 — CA-V136
189. MU-V319 — CA-V140
190. MU-V319 — CF-V107
191. MU-V319 — MU-V169
192. MU-V319 — MU-V256
193. MU-V319 — SF-V214
194. MU-V319 — WDL-V288
195. MU-V319 — WDL-V298
196. MU-V319 — WDL-V37
197. MU-V319 — WDL-V59
198. MU-V319 — WDL-V65A
199. MU-V319 — WDL-V81A
200. MU-V319 — WDL-V81B
201. MU-V319 — WDL-V110A
202. MU-V319 — WDL-V110B

IV. REACTOR COOLANT PUMP SEAL WATER (continued)

203. MU-V319 — WDL-V153A
204. MU-V319 — WDL-V521A
205. MU-V319 — WDL-V521B
206. MU-V319 — WDL-V521C
207. MU-V319 — WDL-V523
208. MU-V319 — WDL-V543A
209. MU-V319 — WDL-V543B
210. MU-V319 — WDL-V994
211. MU-V319 — WDL-V996
212. MU-V339 — WDL-V1091
213. MU-V319 — WDL-V1092
214. MU-V319 — WDL-V1125
215. MU-V319 — WDL-V1152
216. MU-V319 — WDL-V1171
217. CF-V145 — CF-V134A
218. CF-V146 — CF-V134B
219. CA-V175 — CA-V173

B. Discharge:

1. MU-V25 — MU-V289
2. MU-V25 — MU-V37
3. MU-V25 — DW-V227
4. MU-V25 — MU-C-2A (tubes)
5. MU-V25 — MU-C-2B (tubes)

V. NITROGEN PRESSURE AND BLANKETING

A. Steam Generators and Pressurizer:

1. NM-V104 — NM-V52 — (elevation difference)

B. Core Flood Tanks:

1. CF-V114A -- MU-V104 -- (MU-V52)
2. CF-V114B -- MU-V104 -- (MU-V52)

VI. SAMPLING LINES

A. Pressurizer:

1. RC-V117 -- SNS-V20 -- (SNS-V23)
2. RC-V117 -- SNS-V50 -- (SNS-V150)
3. RC-V122 -- SNS-V20 -- (SNS-V23)
4. RC-V122 -- SNS-V50 -- (SNS-V150)

B. Letdown:

1. RC-V123 -- SNS-V20 -- (SNS-V23)
2. RC-V123 -- SNS-V50 -- (SNS-V150)

VII. VENTS

A. Steam Generators and Pressurizer:

1. WDG-V2 -- WDG-V199 -- (elevation difference)

B. Core Flood Tanks:

1. CF-V3A -- CF-V3A -- (WDG-V2)
2. CF-V1B -- CF-V3B -- (WDG-V2)

VIII. DRAINS

A. RCS Drain Lines:

1. WDL-V22 -- WDG-V1125

IX. DEMINERALIZED WATER

A. Building Spray System:

1. DW-V101A — BS-V139A — (BS-V3A)
2. DW-V101B — BS-V139B — (BS-V3B)
3. DW-V4A — BS-V134
4. DW-V4B — BS-V134

4.4.4 Failure Probability per Pathway

Because of the possibility that some pathways may have additional barriers in place at various times, or that could not be accounted for, it was assumed that the boron dilution probability for a pathway is equivalent to the failure probability of the identified isolation barrier configuration for that pathway. This probability is a function of hardware faults and human error. Hardware faults are the easier of the two to estimate:

TABLE 4.4-5

HARDWARE FAILURE PROBABILITIES FOR VARIOUS TYPES OF DILUTION BARRIERS

BARRIER	HARDWARE FAILURE PROBABILITY	SOURCE OF ESTIMATE
Removed Spoolpiece:	Negligible	RAS
Closed MOV; AOV:[1]		
Leak	6.3×10^{-3}/yr	NPRD A02/A03
Rupture	8.8×10^{-5}/yr	WASH-1400, Table III 2-1
Circuit Short to Power	8.8×10^{-5}/yr	WASH-1400, Table III 4.2
Closed Manual Valve:		
Leak	6.3×10^{-3}/yr	NPRD A02/A03
Rupture	8.8×10^{-5}/yr	WASH-1400, Table III 4.2
Pump:[2]		
Circuit Short to Power	8.8×10^{-5}/yr	WASH-1400, Table III 4.2
Heat Exchanger; Coolers:		
Leak	2.1×10^{-2}/yr	NPRD A02/A03

1 MOV - Motor Operated Valve; AOV - Air Operated Valve
2 Pump required because of elevation/pressure differential; a pump is not considered a barrier if gravity feed is possible.

Human error is the more difficult to assess. The assessment is complicated because of the variety of "performance shaping factors" that exist over the range of conditions that must be encompassed by this analysis. For example, some valves which are used as isolation barriers may be similar in appearance, location, position, etc., to other valves which are manipulated for various recovery operations; thus the potential for operator error in these cases is higher than for isolation valves which are in remote locations and could not logically be associated with recovery operations. A detailed analysis is not feasible for each particular isolation barrier. Rather a generic analysis was performed for each type of barrier using characteristics that apply to all barriers of that type. Thus, in many cases the results may be conservative for a particular barrier.

The human error of concern is that plant personnel will accidentally defeat an isolation barrier. Three categories of error can be postulated to defeat an isolation barrier.

Type I: Operator erroneously selects an isolation barrier when he intends to interact with another component.

Type II: Operator fails to completely or correctly implement procedure.

Type III: Errors in the preparation of plant procedures.

Other possible errors exist when an operator interacts with a valve but their probabilities have been judged to be small relative to those of the above categories. One such error is the "reversal" error, i.e. an operator cycles the desired valve as directed but closes it instead of opening it, or vice versa. For this to result in an incorrect valve position, two errors would have to occur. First, the valve would have to be in an incorrect or unexpected position initially and second, an operator must fail to recognize that it was already in the position he desired. This error was estimated to have a negligible probability in NUREG/CR-1278 (Chapter 14). The other possible error is referred to as "stuck valve", e.g., the possibility that a valve may not be fully shut after an attempt to shut it. The detection of this type of error is a function of the valve type, (e.g., rising stem), or whether there is position indication. In NUREG/CR-1278, the probability of a valve sticking in this manner was estimated as 0.001 per demand; failure to detect this error for a valve with neither a rising stem or position indicator was estimated (Table 14-2, NUREG/CR-1278) as 0.01/demand. This error would be more likely to be detected in valves with position indication. Thus, the probability of this type of error should be no higher than 10^{-5}/demand per valve which is small in relation to the Type I selection error. At TMI-2, there is the unique case in which the detection of partially open valves may be difficult because checking requires a man rem exposure; thus some valves are not checked routinely in order to keep exposure as low as reasonably achievable. With the passage of time, fewer of these valves will be considered to have ALARA concerns which will assure that the probability of this type of error remains negligible.

TYPE I

The following table provides information used to determine the applicable human error probabilities for a Type I error. The asterisk indicates the generic value used for this study.

TABLE 4.4-6

PROBABILITY OF SELECTION (TYPE I) ERRORS

DEVICE	PERFORMANCE SHAPING FACTOR	PROBABILITY OF OF ERROR	SOURCE OF ESTIMATE
MOV; AOV	Valve controls identified by labels only	3×10^{-3}/demand	Table 20-12 NUREG/CR-1278
	Valve controls in well delineated functional groups	1×10^{-3}/demand*	Table 20-12 NUREG/CR-1278
	Valve controls part of well-defined mimic layout	5×10^{-4}/demand	Table 20-12 NUREG/CR-1278
Manual Valve	Clearly and unambiguously labelled; set apart from all valves with any similarities in size, shape, state, presence of tags	1×10^{-3}/demand	Table 20-13 NUREG/CR-1278
	Clearly and unambiguously labelled, part of a valve group with similarities in one of the following: size, shape, state, presence of tags	3×10^{-3}/demand	Table 20-13 NUREG/CR-1278
	As above, but with "level 3" tagging**	1×10^{-3}/demand*	Table 20-15 NUREG/CR-1278
	Unclearly or ambiguously labelled, part of a valve group that is similar in all of the following: size, shape, state presence of tags	1×10^{-2}/demand	Table 20-13 NUREG/CR-1278
Spoolpiece	Unclearly or ambiguously labelled, set apart from spool pieces that are similar in all of the following: size, shape, presence of tags	5×10^{-3}/demand	Table 20-13 NUREG/CR-1278
	Unclearly or ambiguously labelled, part of a group of pieces that are similar in one of the following: size, shape, presence of tags	8×10^{-3}/demand	Table 20-13 NUREG/CR-1278

TABLE 4.4-[illegible] (continued)

BARRIER	PERFORMANCE SHAPING FACTOR	PROBABILITY OF OF ERROR	SOURCE OF ESTIMATE
	Same as above but occ[illegible] for 90% recovery factors [illegible] each of: (i) the requir[illegible] opening of red tagged and identified valves around th[illegible] spoolpiece; (ii) physical effects such as water flowin[illegible] not flowing in expected locations	8 x 10^{-5}/demand*	RAS
Heat Exchanger		N/A	
Pump	Pump controls identified by labels only	3 x 10^{-3}/demand	Table 20-12 NUREG/CR-1278
	Pump controls in well defined functional groups	1 x 10^{-3}/demand*	Table 20-12 NUREG/CR-1278
	Pump controls part of well defined mimic layout	5 x 10^{-4}/demand	Table 20-12 NUREG/CR-1278

* Generic value forming the basis of the analysis; however, value was sometimes modified to reflect plant specific conditions e.g. number of valves on a control panel.

** The 24 hour checklist procedure, by which red-tagged valves are checked against a 24 hour valve lineup list, was judged equivalent to the "Level 1" tagging scheme defined in NUREG/CR-1278.

TYPE II

The maintenance of the RCS and all plant maneuvers required for the recovery are performed in accordance with written procedures. A Type II error refers to two categories of errors relating to the incorrect use of procedures which could defeat an isolation barrier. Specifically, Type II errors are (i) selecting and implementing an incorrect procedure, referred to as Type IIa and (ii) skipping a step or steps in the correct procedure, referred to as Type IIb. These errors are of particular concern because more than a single isolation barrier may be affected; i.e., a common mode failure.

TYPE IIa

Each operating procedure at TMI-2 is designed to maintain the plant in a safe condition. Thus, the implementation of any single procedure will not result in alignment of a dilution source to the RCS. However, the concern with a Type IIa error is that the valve lineup associated with an incorrect procedure may be partially implemented before the incorrect procedure is recognized. That valve lineup combined with the valve lineup associated with the correct procedure may result in inadequate isolation of the RCS.

There seems to be little information in the human factors literature describing the Type IIa error. The closest error having any relationship to a Type IIa that has been analyzed is one in which the operator must make a diagnostic decision in response to an abnormal event. In those events, the median probability of improper diagnosis by the entire control room staff, given an extended time period for making a decision, can approach 10^{-5} per act. Based on discussions with operating personnel, a TMI-2 procedure can be selected and implemented by a single control room operator; this approach tends to make a Type IIa error more probable than if a procedure selection were confirmed by a second person. However, the selection of an operating procedure is made under low stress, practiced situations, which would tend to minimize the Type IIa error. Further, the implementation of an improper procedure should not cause a boron dilution event in the absence of other errors. Once the selection of an incorrect procedure is identified, it is presumed that the operators will restore the plant to its original configuration before implementing the appropriate procedure. Thus, given the low likelihood of the initial error and the possibility for recovery of that error, a Type IIa error is judged to be small relative to other contributors to the boron dilution probability.

TYPE IIb

A Type IIb error assumes that the correct procedure is in use, but the operator does not follow it; for example, a step is skipped or a section of the procedure is omitted. In many cases, the procedure step that is skipped may simply have been to verify that a barrier was in its proper condition. In other cases, however, the omitted step may have called for closing a valve. If an entire section of a procedure is omitted, several isolation barriers may be affected. The most vulnerable isolation barrier configuration for which the impact of this error would be significant is one involving only MOVs or manual valves because the error of a single individual could result in defeat of the configuration. The least vulnerable is a configuration which relies on physical conditions, e.g., heat exchanger tubes or an elevation difference. These types of configurations will not be defeated by a Type IIb error.

Failure to comply with or follow a procedure is often influenced by the extent of operator confidence in the procedure and whether the operators find it easy to use and comprehensive. From NUREG/CR-1278, the probability of plant personnel omitting an item when implementing a procedure in which a written checklist is used has been estimated as 0.003. This probability can be improved by up to a factor of 10 with the use of "well designed written procedures and checklists", i.e., those that eliminate the following factors that have been found as deficient in many procedures reviewed throughout the industry.

(i) Serious deficiencies in content and format
(ii) Inconsistencies between nomenclature in procedures and on panel components
(iii) Instructions for control actions that don't indicate the expected system response.
(iv) Excessive burden on operator short-term memory
(v) Charts and graphs not integrated with text

(vi) Lack of a clear identification of which procedures apply to which situations

(vii) No formal means of getting operator input into updates of procedure and

(viii) Deficient instructions for assisting operators in diagnosing the problem.

A procedure task force has reviewed key recovery procedures to minimize some of the above deficiencies. Other deficiencies should be minimized by the inhouse review process which includes consideration by an Independent Safety Review Group. Conversely, poor validation of the procedures prior to their implementation for a recovery task can increase the probability of errors in executing a procedure. A suggested method of validation is a trial "walk through"; often such walk throughs detect deficiencies in the procedure. These walk throughs also increase operator familiarity with the procedure which tends to reduce his chance of executing it improperly, increase his confidence in it, and enable him to recognize when a part of the procedure might not have been performed correctly. For this analysis, a generic value of .0003 per act was used to depict the probability that a control room operator would skip a part of a procedure and 0.003 per act that other plant personnel would skip a procedure section. The difference is due to the NUREG/CR-1278 observation that "Reactor operators are more likely to use written procedures (correctly) than are calibration technicians who, in turn, are more likely to use them than maintenance personnel". This distinction is made in the analysis of barriers operated in the control room (or a control panel) e.g., MOVs and pumps verses barriers operated locally, e.g., spoolpieces, manual valves.

A common mode failure probability was judged to exist only for barriers of like kind, e.g., two MOVs, two manual valves. The basis for this is that, generally, individual steps of a procedure do not mix valve types. That is, a single procedure step may call for closing a group of valves, but that step would include only control room valves. A separate step would "Have personnel enter R.B. and perform the following valve lineup", which would involve moving several manual valves. Thus, two different valve types would not be subject to a single error. The resultant error rates are shown on Table 8.4-7.

TABLE 4.4-7
Probability of Incorrect Procedure Use (Type IIb) Error

BARRIER	PROBABILITY OF SINGLE ERROR (PER DEMAND)	DEPENDENCE* FOR TWO BARRIERS	PROBABILITY OF TWO OR MORE ERRORS (PER DEMAND)	SOURCE OF ESTIMATE
MOV or AOV	0.003	N/A	N/A	Table 15-3 NUREG/CR-1278
with good procedures	0.0003			
Manual	0.003	N/A	N/A	Table 15-3 NUREG/CR-1278
Spoolpiece	0.001**	N/A	N/A	RAS
Heat Exchanger	N/A	N/A	N/A	Table 15-3 NUREG/CR-1278
Pump	0.003	N/A	N/A	NUREG/CR-1278
MOV - MOV	N/A	Low	1.5×10^{-4}	
With Good Procedures	N/A		1.5×10^{-5}	Pg. 10-26 NUREG/CR-1278
MOV - Manual	N/A	None	9×10^{-6}	NUREG/CR-1278
with good procedures	N/A		Negligible	
MOV - spoolpiece	N/A	None	Negligible	NUREG/CR-1278
MOV - pump	N/A	None	Negligible	NUREG/CR-1278
MOV - heat exchanger	N/A	None	Negligible	NUREG/CR-1278
Manual - Manual	N/A	Same as MOV; MOV		NUREG/CR-1278

* The authors of NUREG/CR-1278 "...usually assume zero dependence when estimating the error probabilities for carrying out individual steps in a written procedure."

** This was judged to be a factor of 3 less likely than movement of an MOV because replacement of a spoolpiece requires work authorization papers.

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TYPE III

The Type III error applies to a variety of errors that could occur in the preparation of written procedures. For example, an error by the procedure writer in the accuracy or completeness of a valving checklist. From NUREG/CR-1278,

> "There are no means to quantify the probabilities of (these) types of inadequacies in written materials. Such errors reflect failure to test the procedures in a dynamic situation ... as well as failure to anticipate the full scope of situations in which the procedure must be used (the TMI incident)."

Within those limitations, NUREG/CR-1278 did assign a probability of 0.003 to the probability that an item intended for a procedure will either be omitted or misrepresented. At TMI-2, procedures are reviewed independently by the Safety Review Group in addition to the internal checks associated with the originating organizations. A recovery factor of 5 was credited for these reviews detecting a single item being left off of the procedure. Thus the probability of a single item being left off the procedure and not being identified in the review process was judged to be 0.0006.

The possibility for a common mode failure of a complete barrier configuration exists for a Type III error; i.e., the procedure preparer leaves both components of the configuration off of the procedure. In RAS Calculation 4430-84-07, the probability of leaving a complete barrier configuration off of a procedure was estimated as 7.1×10^{-5} per procedure.

Summing Hardware Failure and Human Error Probabilities

The final step in evaluating the probability that particular barrier configurations will be defeated is to sum the contributors from the hardware and human error failure modes.

This was done with the following general equation, which is completed in detail in RAS Calculation 4530-84-07 for each barrier configuration:

$$\begin{aligned} P\,\{\text{both barriers fail}\} &= P\,\{\text{barrier 1 fails}\} \cdot P\,\{\text{barrier 2 fails}\} \\ &\quad + P\,\{\text{Common mode failure}\} \\ &= P_1\,\{\text{Hardware} + \text{Type I} + \text{Type II} + \text{Type III}\} \\ &\quad \cdot P_2\,\{\text{Hardware} + \text{Type}_2 + \text{Type II} + \text{Type III}\} \\ &\quad + P_{cm}\,\{\text{Type II} + \text{Type III}\} \end{aligned}$$

The resulting failure probabilities for various barrier configurations are shown in Table 4.4-8 which includes the range associated with various maneuvers as well as static conditions. Table 4.4-8 also includes the failure probabilities for valves that are exposed to error more than once per year. Thus, a judgment of the number of times each barrier could be exposed to error was made and used to convert "per demand" failure rates to yearly failure rates.

TABLE 8.4-8

PROBABILITY OF FAILURE PER ISOLATION BARRIER CONFIGURATION

BARRIER CONFIGURATION	FAILURE PROBABILITY* (PER YEAR)
MOV, MOV	7.2×10^{-5} to 1.9×10^{-3}
MOV; Manual	7.5×10^{-5} to 2.6×10^{-3}
MOV; Pump**	1.5×10^{-5}
MOV; Heat Exchanger	3.6×10^{-4}
MOV; Spoolpiece	5×10^{-5}
Manual; Manual	8×10^{-5}
Manual; Pump	1.6×10^{-5}
Manual; Heat Exchanger	1.7×10^{-4}
Manual; Spoolpiece	5.1×10^{-5}
Pump; Heat Exchanger	8.4×10^{-5}
Pump; Spoolpiece	2.6×10^{-5}
Heat Exchanger; Spoolpiece	1.4×10^{-4}
Triple Barrier Configurations***	1.2×10^{-7} to 5.5×10^{-5}

* Failure probability varies due to varying number of exposures to operator error and difference between leak and rupture failures.

** Pump required because of elevation/pressure differential; a pump is not considered a barrier if gravity feed is possible.

*** Triple barrier configurations consisted of combinations of the above barriers as well as: tanks which hold an inadequate volume to dilute the RCS, valves which are known to be closed from "operational verification" or "documental evidence", gaseous vent headers and other barriers which are known to be present but are not placed on a 24 hour checklist (e.g., Appendix C to OP 2104-10.2). Less credit was given for these barriers because they are not checked regularly.

4.4.5 Estimate of Plant Boron Dilution Probability

In Section 4.4.3, an estimate was made of the probability of failure of each of the configurations used to isolate the TMI-2 RCS from a boron dilution source. In this section, the total plant boron dilution probability is estimated. To do this, the following factors must be considered:

(i) Volume of unborated water that must be injected into the RCS to have a potential safety impact.

(ii) Dilution rate

(iii) Potential detection and mitigation.

(iv) Total probability of occurrence found by summing all potential dilution paths.

4.4.5.1 Dilution Volume

The amount of unborated water necessary to dilute the RCS concentration to a concentration that is a safety concern is a function of (i) the initial RCS boron concentration (ii) the minimum acceptable boron concentration (iii) the characteristics of the dilution inflow and (iv) the RCS processing status (i.e., static or processing mode).

The RCS is currently being maintained at a boron
concentration of 5050 ppm (± 100 ppm). The measured
average concentration for a recent two week period was 1
5152 ppm (Reference 15). Thus, 5050 ppm is an
appropriate assumption for the initial RCS boron
concentration for a dilution event.

The minimum acceptable boron concentration that assures subcriticality is currently 3500 ppm. Recently completed analyses (Reference 13) indicate that a boron concentration of 4350 ppm may be required to assure subcriticality for some recovery operations, including defueling. Thus, the dilution volume that could result in criticality will vary according to the recovery stage.

The characteristics of the dilution inflow, specifically mixing of the underborated inflow with the RCS volume, affects the dilution volume estimate. Recent insights provided in References 11 and 12 indicate that underborated water is likely to float directly to the internals indexing fixture (IIF) rather than being drawn down through the CSA annulus and then to the core. These references suggest that the core region is probably the last volume that will see a dilution which would suggest that a very large dilution volume would be necessary to dilute the core region. For this analysis, however, it is assumed that inflow into the RCS mixes uniformly with the entire vessel and IIF volume. Volumes in the RCS legs (with the exception of the volume between the dilution inflow point and the vessel itself) are not assumed to mix with the dilution flow. 1

The fourth consideration is estimating the volume to dilute the RCS is the RCS processing status. If the RCS is in a static condition, i.e., with no water processing, the dilution is simply an addition of water to the system. If water is being moved into and out of the RCS (for example, as part of a cleanup) then an exponential mixing equation must be used.

From the above considerations, it was determined that a dilution inflow of approximately 15,900 gallons of unborated water is required to dilute the vessel to 3500 ppm during static conditions and approximately 13,700 gallons during RCS processing. Dilution to 4350 ppm requires 5,800 gallons during static conditions and 5,370 gallons during processing. 1

4.4.5.2 Dilution Rate

A spectrum of dilution rates is possible depending on the driving force associated with each dilution path. However, an upper bound on a credible dilution rate can be estimated by physical considerations such as the affects of line size in limiting flow, pump capacities and elevation differences. The maximum credible rate can also be bounded by probabilistic considerations such as the number of faults required to input unborated water via a particular path. These considerations result in a maximum credible dilution rate to the RCS of about 150 gpm. This flow could occur if there is a misalignment of a flow path connecting one running demineralized water pump to the RCS. A flow of this magnitude could also occur by a path misalignment resulting in gravity feed from several water sources which are at elevations above the RCS injection point and have sufficient capacity to significantly dilute the RCS. (In these cases flow is limited by the minimum pipe size through which the flow must pass.) These water sources are:

Sodium Hydroxide Storage Tank (DH-T-2)
Demin. Water Storage Tank (DW-T-1)
Processed Water Storage Tanks (PW-T-1,2)
Unit #1 Demineralizer Water St. Tank
Fuel Transfer and Storage Pools

Misc. Waste Holdup Tank (WDL-T-2)
Condensate Storage Tank (CO-T-1A)
Condensate Storage Tank (CO-T-1B)
Off-Spec. Waste Receiving Batch Tank (CC-T-1)
Clean Water Receiving Tank (CC-T-2)

In Section 4.4.5.4, the probability of occurrence of the maximum credible flow rate (up to 150 gpm) is estimated as 3×10^{-4} per year during the static conditions. This probability is so small that we judge that no specific mitigation considerations need to be made for this event. (This judgment is based on guidance provided by the NRC for safety goals at nuclear power plants, Reference 10. The guidance has been adopted in this analysis as a guideline for the extent of RCS isolation and dilution detection capability that must be 1
provided.) However, the use of the RCS level indication and alarm, which are described in Section 4.4.5.3, provide a capability to detect a large rate dilution event in time to allow the operators to isolate the RCS before a safety limit is reached. As an additional preventative measure (although the results provided here indicate that it is unnecessary), the probability of gravity feed from the other dilution sources listed could be reduced even further by adding isolation barriers for a source to the 24 hour checklist, draining the source or borating the source, as appropriate. The Fuel Transfer and Storage Pools can be isolated by putting the following valves on the 24 hour checklist to be closed: SF-V150, SF-V125, SF-V157 and SF-V105. Condensate Storage Tank 1A can be isolated by: CF-V9, CO-V71A, CO-V768, CO-V98A and CO-V98B. The Off-Spec Tank, CC-T-1 can be isolated by closing ALC-V004, ALC-V031, ALC-V033, ALC-V006 and ALC-V080. Currently, CO-T-1B, CC-T-2, DW-T-2 and WDL-T-2 do not contain enough unborated water to dilute the vessel.

In Section 4.4.5.4, the probability of a lower rate dilution event is estimated to be more likely than the maximum rate discussed above. A lower dilution rate was found to be more likely than the maximum rate because (i) the probability of component failures resulting in leakage is much greater than for passing full flow (Table 4.4-4), (ii) the probability of dilution through the sampling lines which are manipulated often is high relative to other paths and (iii) the potential exists for dilution via component seal water which is designed for some inleakage (important during plant maneuvers). Therefore, provisions must be taken to assure that the RCS will not be diluted to the minimum acceptable boron concentration by the lower, but more probable rates.

From Reference 10, the maximum flow through the 3/8" diameter sampling lines is no greater than about eight gpm. Reference 7 states that maximum seal water inleakage would not typically exceed a few gallons per day (seal water inleakage would be a concern only during processing). There is no absolute definition in the industry for the distinction between leakage and gross valve failure. In this report it was assumed that passage of 10% or more of maximum flow would be termed "gross" or "rupture" failure. Ten percent of the maximum credible flow is 15 gpm. This flow rate encompasses the potential sampling and seal water flows. Thus, it is recommended that this flow rate be used to set inventory monitoring frequencies during static conditions. (Subsequent to the issuance of Rev. 0, EAS has consulted with the manufacturers of several types of valves used at TMI-2. The manufacturers indicate that the 10% leakage assumption is conservative. It was also noted that the pressure for which the valves were qualified generally exceed the demand placed on them at TMI-2, thus reducing the potential for leakage across the valve.)

4.4.5.3 Detection and Mitigation

Mitigation of a boron dilution event consists of terminating the event prior to reaching the Tech. Spec. boron concentration limit. Mitigation of boron dilution prior to reaching the Tech. Spec. limit requires isolation of the RCS from potential dilution paths, once the dilution is detected. Therefore, credit for mitigation is heavily dependent on the detection capability. At TMI-2, the means of detecting a boron dilution event are summarized below.

<u>Detection Methods</u>

(1) Reactor Coolant Level Monitoring

On SPC Panel 3 in the control room, there is digital RCS level monitoring and pressure indication (which can be used even during drain down to indicate a level based on the weight of water). Level instrument RC-LI-100A and the pressure readout are based on a single level transmitter/instrument, RC-LT-100, connected to the RCS hot leg. The instrument is rated at an accuracy of ± 3 inches for measurement of an absolute water level. However, a level differential of ± 1 inch can be read, which corresponds to an RCS volume of less than 160 gallons. A second level instrument, RC-LI-102, has recently been installed and may be read on SPC Panel 3. Instrument RC-LI-102 monitors the level in the IIF and is physically independent of the instrumentation connected to the hot leg. The RCS level is checked hourly and recorded on the "Station Daily Log Sheet".

1

As a backup to the control room indication, the RCS level can be read on a Barton meter, RC-LI-101A, located at the 282' elevation of the Fuel Handling Building or in a tygon tube located outside the D ring in the Reactor Building.

An RCS level alarm has been installed which will alarm in the control room if the RCS level changes ± 6 inches from the operational level in the IIF.

(ii) Monitoring of Dilution Sources

In Table 4.4.2, a number of water collection points, (tanks, coolers, etc.) that could act as dilution sources were identified. Some of these sources are monitored by low and high level alarms and/or (b) verification of level via "Primary Aux Operator Check Sheet". Level Alarms may be indicated in the control room directly; or a satellite alarm may be in the control room with specific indication on a local panel. The Primary Auxiliary Operator Check Sheet is executed every shift by an auxiliary operator and checked at the end of the shift by a reactor operator and a senior reactor operator.

A review of the Primary Auxiliary Operator Check List showed that many of the dilution sources in Table 4.4-2 were not on that list. Also, Table 4.4-2 shows that many alarm setpoints are not set adequately high to be useful in detecting a loss of the volume of water required to dilute the vessel. There would be some value in alarming all dilution sources in Table 4.4-2 or placing them on a shift checklist. However, the likelihood of detecting a dilution in this manner is very small given the more direct indications available. Further, there are some difficult practical problems associated with this approach, e.g. accounting for water use by TMI-1 from the Unit 1 Demineralized Water Tank. Thus, no credit is given for detecting a dilution event by this method.

(iii) Mass Balance

(a) Per Procedure 4301-S1, Appendix B, a mass balance calculation is performed every 24 hours. In the level control mode two slightly different techniques are used. These calculations will indicate the RCS boron concentration.

(b) Every 24 hours the RCS is isolated for 4 hours to perform a leak test. From discussions with plant personnel, these calculations will detect an inleakage as low as about 0.6 gpm. (However, the use of this test for detecting a dilution event is limited for plant measurers because the isolation of the RCS may itself prevent continued dilution.)

(iv) Equipment Checklist

The position of valves, pumps and breakers that are important to the implementation of certain plant procedures are monitored by control room personnel every 24 hours per Appendix C to Operating Procedure 2104-10.2, "Primary Plant Operating Procedure." This monitoring is accomplished by checking the position as indicated in the control room, checking a log in which changes in status of "red-tagged" components is kept, or directly surveying the components.

(v) Neutron Detection

A potential fifth indication of a boron dilution event is the operable source range neutron detectors, NI-1 and NI-2. These indicators are checked hourly and readings are recorded on the Station Daily Log Sheet. However, there is uncertainty abou the significance of the source range response. Although these indicators may trend increased neutron flux in a range very close to criticality, there may be no significant response as the boron concentration approaches the minimum acceptable RCS boron concentration used as a basis for this analysis. This is because conservatism exist in the referenced criticality analyses making it likely that significant shutdown margin remains at the minimum acceptable boron concentration for most core configurations. Thus, no credit was given for detecting a dilution event by this means prior to reaching the minimum acceptable boron concentration used in this analysis. 1

(vi) RCS Boron Sample

A weekly RCS boron sample is taken as required by Technical Specifications. Depending on the time at which a dilution event would occur, a dilution rate of about 1 gpm could cause a dilution below the minimum acceptable boron concentration before the Tech. Spec. sample is taken. Thus, little credit can be given for this sample detecting inleakage of unborated water. It does, however, provide a periodic check on the 5050 administrative limit and provides some assurance that a phenomenological effect (e.g., stratification) is not occurring.

Given the other means of detecting a dilution event, it is judged that there is not a significant risk reduction gained by increasing the boron sampling frequency during static conditions. However, sampling is a useful means of detecting dilution during some plant maneuvers.

Detection Reliability

The RAS judges that a simultaneous RCS dilution and leak of the same magnitude is not credible. Thus, any dilution event during static conditions will result in a changing RCS level. The failure to "see" this level change is a function of the capability of the level instruments. Redundant instruments, RC-LI-100A and RC-LI-102, provide level readout in the control room. Level is read and logged hourly and a level alarm is set to detect a level deviation of six inches. In the event of failure of the remote indication, RCS level may be read from a local instrument at the 282' elevation of the fuel handling building (RC-LI-101A) or from a tygon tube outside a "D" ring. Instrument RC-LI-101A uses the same tap from the "B" steam generator hot leg as control room instrument RC-LI-100A. Instrument RC-LI-102 uses taps in the internals indexing fixture. The tygon tube is connected to the RCS pump 2A cold leg and thus, is physically independent of the other instrumentation. Under normal circumstances, indication outside of the control room is not relied upon on a regular basis. (Currently, additional level instrumentation, RC-LT-100 and RC-LT-102A, is associated with the SPC system; this instrumentation uses the same transmitters as the control room indication.) Thus, there are three independent channels and one dependent (Barton meter) channel available for use in determining RCS level. The failure causes of multiple channel instrumentation strings can be grouped into two broad categories: combinations of independent causes and common cause failures. These contributions can be quantified and summed to obtain the total probability of losing level indication. 1

A level instrumentation string typically has an unavailability of better than 3×10^{-2}/year; this implies that the probability of the TMI-2 level indication becoming unavailable due to independent faults is less than 3×10^{-5}/year.

Common cause failure modes for losing level indication also exist. However, no credible common cause has been identified at TMI-2 that would result in simultaneous loss of all level indication currently installed. The potential common cause contribution to level indication failure is reduced at TMI-2 over what is normally encountered due to the diversity among channels. Mechanisms that exist for a common cause loss of level indication are:

(1) Loss of power - transmitter RC-LT-100 and associated indicators RC-LI-100 and RC-LI-100A are powered from PNL-2-12R while transmitter RC-LT-102 and associated indicators RC-LI-102 and RC-LI-102A are powered from PNL-2-22R. These panels are supplied by power trains 1A and 1B, respectively. Loss of power to both trains concurrently without common cause (e.g., loss of offsite power) is unlikely. In the event of a loss of offsite power, the need for level indication is reduced because the probability for a boron dilution event conditional upon loss of offsite power is negligible. Additionally, RC-LI-101A (the Barton meter) and the level reading from the tygon tube are not dependent on power so they may still be used for indication. The contribution to the loss of level indication from loss of power can be bounded by 2 x 10^{-5}/year.

(2) Loss of sensing pressure to transmitter or failure of transmitter - the
loss of sensing pressure could occur if any line to the pressure transmitter
is blocked or leaking. This could be caused by closed or plugged valves,
leaking fittings or in the case of RC-LT-100, failure of the nitrogen system.
The root valves, and to a lesser extent the Parker fittings at the
transmitter, are vulnerable to human error. In fact, RC-LT-100 may have been 1
unavailable for a short time period due to an inadvertent closing of its root
valve (LER 50-320-84-047). As a result, plant personnel were alerted to such
a problem and "DO NOT OPERATE" tags are now placed on key valves to minimize
this occurrence. Loss of proper level indication could also result from
blocked sensing lines (e.g., by core debris) or if the transmitter itself
failed. Simultaneous plugging of all sensing lines, however, is not judged to
be credible as substantial differences in tap locations exist. The common
cause contribution from this category is estimated to be less than
4 x 10^{-4}/year.

(3) Miscalibrated instruments - The transmitters and indicators are periodically (once a year on different schedules) calibrated under Procedure 4221-PMI-3620.01. The contribution from miscalibration errors is reduced by the differing equipment design and operating principles, staggered maintenance scheduling, and different personnel performing calibration using clearly written procedures. The contribution to level unavailability from the category is estimated to be 5×10^{-4}/year.

Many of the postulated failure modes discussed would not result in an unsafe failure (i.e., indication failed as is while level is rising). Another factor reducing the unavailability is that of immediate feedback (i.e., conflicting readings among channels) to the operator. Ignoring the beneficial effect of these two factors produces a value for losing all level indication of 9.5×10^{-4}/year. The bounding value of .001 used in this report for unavailability of all RCS level monitoring therefore can be considered as very conservative.

Regular sampling of the RCS is another primary means of detecting a dilution event before it becomes a safety concern. Sample frequency is a function of the minimum acceptable boron concentration, the potential flow rate that must be detected and the mixing characteristics of the dilution inflow. There is no justification for implementing a sampling program during static conditions or to detect the largest potential dilution inflows specified in Section 1
4.4.5.2 given the low probability of occurrence and reliability of the level indication. Under some processing circumstances, however, a sample program should be used to provide detection capability when sensitivity of the level indications may be lost. The recommended sampling frequencies are provided in the appropriate appendices. A sampling program can also be implemented if level indication is unavailable for any reason.

The reliability of the sample is a function of its representativeness and the implementation of proper analysis techniques. The current method of taking an RCS sample is to draw through a path from the RCS sample pump to the sample sink. A recent Licensee Event Report (LER 84-102) indicated that some samples may not have been representative of the RCS because of a misinterpretation of a meter. This problem has been corrected and it is assumed that sampling is now representative. There is also a possibility that a particular sample may be analyzed incorrectly so that an RCS concentration that is low is incorrectly found to be within specifications. Plant personnel indicate there have been two incorrect samples in approximately 250 weekly Tech Spec. samples. Using this experience and assuming that any sample error will result in failure to detect a dilution in progress, the probability of failure to diagnose a dilution event because of erroneous analyses is less than 0.01. 1

As stated previously, no credit was given to the neutron monitors, the weekly Tech. Spec. sample and the once per shift check of dilution sources for detecting a dilution event in progress. Checking the valve lineup is a means for recovering from a valve misalignment and credit was applied in the estimates for barrier failure in Section 4.4-4. The mass balance calculation will provide information on the current RCS boron concentration every 24 hours. Therefore, a conservative estimate of the failure to detect a dilution can be made by considering only the unavailability of the level monitoring and sampling frequency.

Mitigation

Mitigation of an event requires that an operator act upon the detection and take the proper actions to isolate the dilution source or the RCS itself. The following general equation describes the probability of failure to detect and mitigate a dilution event:

P {failure to detect and mitigate} = P {failure to detect} + P {failure to mitigate given that event is detected}

In the previous subsection, the probability of failure to detect a dilution event using level indication or boron sampling was estimated. Failure to mitigate a dilution could occur by operator failure to respond, operator error in responding or hardware faults. Because of valves in series, there are several ways by which the RCS could be isolated from a dilution flow. Thus, the failure to mitigate an event is dominated by operator failure to respond or an incorrect operator response. The operator response is affected by the number of control room demands and the time required for the response. 1

The TMI-2 plant state is now much simpler in comparison to an operating reactor in terms of parameters that must be monitored. Thus, a boron dilution will not result in many control room alarms in a short time period as may be characteristic of an incident at an operating reactor. Rather, it will be identified by a single annunciator, such as a level alarm or an unacceptable mass balance, on which an operator may focus his response. Thus, the estimates provided in NUREG/CR-1278 for operator response to a single annunciator provided the basis for a judgment of the effectiveness of operator response to a dilution. NUREG/CR-1278 noted a difference in operator response to an alarm depending on whether a plant was in a power generation or maintenance condition. The difference between the two operational conditions was that during the maintenance mode, control room personnel might expect alarms that are due to maintenance activities in the plant and thus be less concerned; conversely, during power generation each alarm would be taken more seriously. The difference is a factor of 10; failure to respond to a single alarm during power generation was estimated as 0.0001 and during maintenance as 0.001. At TMI-2 it might be expected that alarms at anytime would be pursued with equal concern because they are not as frequent as in an operating plant. However, for conservatism we assumed that the observed difference in response between the power generation and maintenance modes would correspond 1
to a difference in response during actual maneuvers (e.g., IIF processing) and static conditions, respectively.

An incorrect operator response is due to an operator error in selecting the correct component when a decision is made to act; these errors were described as Type I errors in Section 4.4.4. At TMI-2, isolation of the RCS can be achieved by movement of MOVs from the control room; the error rate judged applicable in Table 4.4-6 to the selection of the wrong valve was 1×10^{-3}/demand. This analysis used this estimate as the "nominal" value for an incorrect operator response. An additional factor that influences the probability of an incorrect operator response is the time in which he must respond to mitigate a dilution. This factor is considered by modifying the nominal operator error probabilities to reflect significant variations in the required action time. That is, as the period to respond becomes shorter, the nominal operator error probabilities are increased until they eventually approach one; as the response time lengthens, operator error probabilities tend to decrease until some plateau is reached. As noted earlier, there is a spectrum of possible dilution rates, each with a corresponding time to dilute the vessel to the minimum acceptable boron concentration. The probability of the largest rate dilution events (greater than 15 gpm up to 150 gpm) is so small that no specific mitigation measures are required, although there is some existing capability for mitigation. The most extreme rate of dilution scenario (.150 gpm inleakage during a feed and bleed type operation with detection by the level alarm) provides about 1 1/2 hours after detection for the operator to isolate the vessel before the concentration reaches 3500 ppm. In our judgment, nominal operator error rates could be increased by a factor of 10 for this unlikely scenario. If the lower boron concentration is assumed to be 4350 ppm, under the same worst case conditions, there would only be about 1/2 hour for action after detection by level alarm. Because of the relatively short operator response time, the operator error rates used for this scenario were increased by a factor of 100 over the nominal error rates. (n.b., The actions that could be taken to terminate this unlikely dilution event are not as extensive as those that could be accomplished in a longer time. Rather than proceed through an isolation checklist, it is recommended that the consideration be given to isolating the demineralized water pumps and the large water sources identified in Section 4.4.5.2, if this event is observed.) For the smaller and more likely dilution rates, the most extreme situation (IIF processing in the automatic mode, thus, limiting the ability of the level instrumentation to detect a change) a sampling frequency can be developed (see Appendix D) to assure adequate time for operator action. The operator error rate in responding to sampling or level indications for the more likely, smaller dilution rate events is the nominal value, 0.001/demand. As a conservatism, no credit is given for a recovery factor that would take into account the long response time allowed for most dilution events and the supervision of senior control room personnel. 1

In summary, the probability of failure to mitigate an event,

P (failure to mitigate given that event is detected)

= P (failure to respond + operator error in responding + hardware faults)

From the previous discussion, several estimates of the probability of failure to mitigate can be developed to bound numerous plant situations. These estimates can be combined with the probability of failure to detect a dilution to form the probability of failure to detect and mitigate a potential dilution.

Condition	P (failure to mitigate given detection) (per demand)	P (failure to detect and mitigate dilution) (per demand)
Static, 3500 ppm	2×10^{-3} to 1.1×10^{-2}	3×10^{-3} to 1.2×10^{-2}
Processing, 3500 ppm	1.1×10^{-3} to 1.0×10^{-2}	1.1×10^{-2} to 2.0×10^{-2}
Static, 4350 ppm	2×10^{-3} to 1.0×10^{-1}	3×10^{-3} to 1.0×10^{-1}
Processing, 4350 ppm	1.1×10^{-3} to 1.0×10^{-1}	1.1×10^{-2} to 1.1×10^{-1}

4.4.5.4 Probability of RCS Dilution

The total probability of dilution of the RCS below a minimum acceptable concentration is the sum of the probabilities of dilution through the individual paths (or, equivalently, of the failure probabilities of individual dilution barriers) multiplied by the probability of the operator failure to detect and mitigate the event. The probability of occurrence of a dilution event of any magnitude during static conditions was estimated as 5.4×10^{-3} per year. This is due almost entirely to the "leakage" probability of 5.1×10^{-3} per year; the rupture or "gross" leakage probability contributes 2.7×10^{-4} per year. (The probability of the gross rupture is so small that we judge that no specific mitigation considerations need be made for this event, based on NRC guidance (Reference 10).)

The contributions are summarized in Table 4.4-9 according to the types of isolation and the number of paths with that isolation. It should be noted that although about 400 barrier configurations are required to isolate the RCS during static conditions, only 325 components are required. This is because many components contribute to the isolation of more than one path. Triple barrier isolation is not required for RCS isolation. However, in many cases, triple barrier isolation occurs during static conditions because Appendix C to 2104-10.2 combines the valves required for "double barrier" isolation during various processing maneuvers with those required for static conditions. Thus, there is additional isolation during static conditions. Triple barrier isolation was recommended for some paths because of the number of potential exposures to human error. Finally, although SER commitments require double barrier isolation to be administratively controlled by Appendix C to 2104-10.2 (or its equivalent for IIF processing), the reliability analysis was able to take credit for barriers which are known to exist but cannot be placed on an isolation checklist. (An example would be a valve in a high radiation area which is known closed by "operational verification" or "documented evidence". Less credit was given for these types of barriers. See RAS Calculation 4430-84-007 for more details).

Table 4.4-9 Total Failure Probability Summed for All Barriers per Isolation Type during Static Conditions

Isolation Type	Total Probability
MOV-MOV-MAN	1.6×10^{-3}
MOV-MAN-MAN	1.1×10^{-3}
MISC. DOUBLE*	9.7×10^{-4}
MISC. TRIPLE*	7.0×10^{-4}
MOV-MAN	3.0×10^{-4}
MAN-MAN-MAN	3.5×10^{-4}
MOV-MOV-MOV	2.9×10^{-4}

* Miscellaneous barriers consist of valves used in conjunction with Heat Exchangers, Relief Valves, Hose Connections, Spool Pieces and Tanks.

Taking into account credit for operator mitigation results in an estimate for the probability of dilution to 3500 ppm during static conditions of 2×10^{-5}/year, which can be termed "negligible." (The probability of dilution to 4350 ppm was estimated to be about 5×10^{-5}/year, which can also be termed negligible.) 1

5.0 CONCLUSIONS

This section summarizes the conclusions from the main report and the appendices.

(1) The use of the valve lists suggested in this report and its appendices assures that the SER commitment for double barrier isolation is achieved.

(2) The probability of a boron dilution event of any magnitude occurring during static, level control conditions with the vessel was estimated as 5.7×10^{-3} per year. This probability was dominated by potential human errors associated with valve 1 positioning.

The additional probability of dilution that is incurred during IIF processing (which may be performed up to about 50 days per year) was estimated at 5×10^{-3} per year. The additional probability of dilution during IIF fill and feed and bleed operations (which are expected to be performed much less frequently, if at all) was estimated as 5.6×10^{-3} and 7.3×10^{-3}, respectively.

(3) The detection mechanisms described in Section 4.4.5.3 allow for significant credit to be given for operator action in terminating a dilution event prior to reaching the minimum acceptable boron concentration. The probability of failure to detect and mitigate a dilution varied according to the RCS water processing conditions and the minimum acceptable boron concentration.

(4) The probability of a boron dilution occurring and diluting the RCS from 5050 ppm to 3500 ppm without being terminated was estimated as 2×10^{-5} per year during static conditions; the probability of a dilution to a minimum concentration of 4350 ppm was estimated as 5×10^{-5}/yr during static conditions. The additional 1 probabilities of dilution that are associated with possible maneuvers range from about 6×10^{-5} to 9×10^{-5} per year for a

minimum RCS concentration of 3500 ppm; the range is 1.0×10^{-4} to 1.3×10^{-4} for a minimum RCS concentration of 4350 ppm. These are consistent with the safety goal guidance provided by the NRC 1
(Reference 18). Thus, we conclude that the potential for boron dilution presents a minimal and acceptable risk to the recovery.

(5) A spectrum of potential dilution inflows to the RCS is possible. Prevention and existing level monitoring instrumentation provide adequate protection for a broad spectrum of potential dilution inflows and plant conditions. However, under some conditions, sampling and/or inventory monitoring (e.g., mass balance) may be required; in these situations, the frequency should be based on a dilution rate of up to 15 gpm.

6.0 RECOMMENDATIONS

The following summarize the major recommendations of the report. More detailed recommendations are in the "Conclusions/Recommendations" section of each appendix.

(1) Assure that the "Isolation Valve List" presented as Table 4.4-3 is implemented and that the barriers on that list, or an equivalent alternative, are placed on a 24 hour checklist. Isolation lists for particular plant maneuvers are provided in the appropriate appendices to this report and should also be implemented and placed on a 24 hour checklist. The appropriate checklists are expected to be Appendix C to 2104-10.2 and Appendix G to 2104-8.18.

(2) Assure that recommended monitoring frequencies for static conditions and planned maneuvers summarized in Table 6-1 are implemented. (Details are provided in the appendices.) 1

(3) a. Assure that the emergency procedure for responding to a dilution event specifies that all processing be terminated and references appropriate actions to isolate the RCS in the event dilution occurs. Appendix C to 2104-10.2 could be used to isolate the RCS.

b. Consideration should be given to adding a step in Emergency Procedure 2202-1.2 to trip off a running demineralized water pump if a dilution event is in progress or if the RCS cannot be isolated in a timely manner. (This action will eliminate the most likely driving force for a dilution.) 1

(4) Assure that operators have the opportunity to "walk-through" all new procedures prior to their implementation.

(5) Assure that the detailed recommendations presented in the "Conclusions/Recommendations" section of each appendix are implemented. 1

TABLE 6.1 RECOMMENDED MONITORING FREQUENCIES FOR DETECTION OF BORON DILUTION

CONDITION / MONITORING	STATIC	FEED AND BLEED[4] Less than "x" gal.	FEED AND BLEED[4] Greater than "x" gal	ITP FILL	ITP PROCESSING	CANAL FILL[3] (TEMPORARY PROCEDURE)
RCS BORON SAMPLING	Weekly	Following processing	After process initiation and prior to "x" gal.	Following fill	See Appendix D, Table D.3	Not applicable/required[1]
CANAL BORON SAMPLING	Not applicable/required	Not applicable/required	Not applicable/required	Not applicable/required	Not applicable/required	Before, dump and filled
RCS LEVEL MONITORING	Hourly Recording; High Level CR Alarm	Hourly Recording; High Level CR Alarm	Hourly Recording; High Level CR Alarm	Hourly Recordings	Hourly Recording; High Level CR Alarm	Hourly Recording and High Level CR Alarm
4 HOUR LEAK TEST	Daily[2]	Daily[2]	Daily[2]	Daily[2]	Daily	Daily[2]
ISOLATION BARRIER CHECK (APP C; 2104-10.2)	Daily	Daily	Daily	Daily	Daily	Daily
DILUTION SOURCE CHECK (PRIMARY AUX. OPERATOR CHECK SHEET)	Shift[2]	Shift[2]	Shift[2]	Shift[2]	Shift[2]	Shift[2]
RCS/RCBT BORON CONC. ESTIMATE (PER 4301-S1)	Daily[2]	Daily[2]	Daily[2]	Daily[2]	Daily[2]	Daily[2]
RCS/RCBT MASS BALANCE (APP.F; 2104-8.18)	Not applicable/required	Not applicable/required	Hourly	Not applicable/required	Hourly	N/A
STEAM GENERATOR LEVEL CHECK	Weekly	Weekly	Weekly	Weekly	Weekly	Not applicable/required

1 "Not applicable/required" indicates that a particular type of monitoring is either not applicable to the procedure or does not significantly reduce the boron dilution potential
2 Current frequency at which action is being performed; frequency may be reduced and not significantly affect the boron dilution potential
3 Recommendations apply to the process of canal fill. After canal fill, monitoring frequencies are as specified in Appendix C
4 "x" = 10,000 gallons if minimum acceptable RCS boron concentration = 3500 ppm; x = 5000 gallons if minimum concentration is 4350 ppm

7.0 REFERENCES

1. NUREG/CR-2798, "Evaluation of Events Involving Unplanned Boron Dilution in Nuclear Power Plants", E. W. Hagen, July 1982.

2. Enclosure (Inadvertent Boron Dilution) in letter to Dr. Robert E. Uhrig Florida Power & Light, from Robert A. Clark, USNRC, dated April 26, 1982. Docket No. 50-335.

3. NUREG/CR-1278, "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications", Final Report, August 1983.

4. WASH-1400, "Reactor Safety Study – An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants", October 1975.

5. NPRD AD2/AD3 Reports, INPO 82-029, "1981 Annual Reports – Annual Reports of Cumulative System and Component Reliability", November 1982.

6. GPU Memo #4420-84-0030, "Spool Piece Identification and Designation", G. A. Kunder to S. Levin, dated February 12, 1984.

7. GPU Memo #4340-84-0197, "Elimination of Potential Boron Dilution Pathways", D. R. Buchanan to S. Levin, dated March 23, 1984.

8. GPU Memo #4400-84-0101, "T&MS Recommendations on RCS Boron Sampling Frequency", J. E. Larson to B. K. Kanga, dated April 13, 1984.

9. GPU Memo #4430-84-0053, "Boron Dilution Pathways Criteria," J. J. Curry to J. E. Larson, dated March 22, 1984.

10. Crane Technical Paper No. 410, "Flow of Fluids Through Valves, Fittings and Pipe," 1980.

11. GPU Memo #4430-84-0232, "Flow Distribution for Boron Dilution Inside TMI-2 Vessel," E. D. Fuller to R. E. Rogan, dated August 27, 1984.

12. GPU Memo #4342-84-0180, "Vent Valve Opening," W. E. Austin to D. R. Buchanan, dated September 21, 1984.

13. "Criticality Report for the Reactor Coolant System of TMI-2," October 1984.

14. GPU Memo# 4400-84-0219, "Maintenance of Subcriticality," R. E. Rogan to Distribution, dated October 25, 1984.

15. GPUN Memo #4000-84-5-656, "TMI-2 Biweekly Significant Events Report for Period Ending October 5, 1984," F. R. Standerfer to P. R. Clark, October 19, 1984.

16. "Methods and Procedures of Analysis for TMI-2 Criticality Calculations to Support Recovery Activities through Head Removal", BAW-1738, June 1982; Add. 1, October 1982; Add. 2, December 1982. 1

17. "TMI-2 Criticality Analyses for a Heavy Load Drop Accident in Support of Recovery Activities through Reactor Vessel Head Removal", BAW-77-114 6499-00, December 1983.

18. Nuclear Regulatory Commission, "Safety Goal Development Program," Federal Register, Vol. 48, No. 50, March 14, 1983. 1

19. Applicable Procedures:

TMI-2 Operating Procedure 2104-8.18, Revision 0 (DRAFT), "IIF Processing Through SDS".

TMI-2 Operating Procedure 2104-10.1, Revision 8, "Operation of the Secondary Plant System", February 21, 1984.

TMI-2 Operating Procedure 2104-10.2, Revision 6, "Primary Plant Operating Procedure", February 13, 1984.

20. Applicable Drawings:

Burns & Roe Drawing #2002, Revision 33, "Main and Reheat Steam".

Burns & Roe Drawing #2004, Revision 26, "Auxiliary Steam".

Burns & Roe Drawing #2005, Revision 36, "Feedwater & Condensate".

Burns & Roe Drawing #2006, Revision 26, "Makeup Water Treatment & Condensate Polishing".

Burns & Roe Drawing #2007, (Sheet 1), Revision 25, "Vac. Degasifier & Demin. Service Water T/B".

Burns & Roe Drawing #2007, (Sheet 2), Revision 23, "Demin. Serv. Water Aux. Cont., Serv., & Reactor Bldg.".

Burns & Roe Drawing #2008, Revision 25, "Feedwater Heater Drains".

Burns & Roe Drawing #2013, Revision 9, "Domestic Water".

Burns & Roe Drawing #2015, Revision 18, "Secondary Plant Sampling System".

Burns & Roe Drawing #2018, Revision 22, "Secondary Services Closed Cooling Water".

Burns & Roe Drawing #2023, Revision 27, "Circulating & Secondary Services Water".

Burns & Roe Drawing #2025, Revision 19, "Chemical Addition".

Burns & Roe Drawing #2026, Revision 30, "Spent Fuel Cooling & Decay Heat Removal".

20. Applicable Drawings (Continued)

Burns & Roe Drawing #2027, Revision 27, "Radwaste Disposal Reactor Coolant Liquid".

Burns & Roe Drawing #2028, Revision 27, "Radwaste Disposal - Gas".

Burns & Roe Drawing #2029, Revision 26, "Intermediate Closed Cooling Water".

Burns & Roe Drawing #2030, Revision 27, "Nuclear Services Closed Cooling Water".

Burns & Roe Drawing #2031, Revision 16, "Sampling Nuclear System".

Burns & Roe Drawing #2033, Revision 26, "Nuclear Services River Water".

Burns & Roe Drawing #2034, Revision 28, "Reactor Building Emer. Spray & Core Flooding".

Burns & Roe Drawing #2035, Revision 20, "Decay Heat Closed Cooling Water".

Burns & Roe Drawing #2036, Revision 19, "Nitrogen for Nuclear and Radwaste Systems".

Burns & Roe Drawing #2039, Revision 19, "Radwaste Disposal - Solid".

Burns & Roe Drawing #2045, Revision 23, "Radwaste Disposal Miscellaneous Liquids".

Burns & Roe Drawing #2048, Revision 18, "Reactor Bldg. Normal Cooling".

Burns & Roe Drawing #2601, Revision 11, "Reactor Coolant Pump Seal Recirc. & Cooling Water".

Burns & Roe Drawing #2606, Revision 9, "OTSG Cleaning System".

Burns & Roe Drawing #2414, Revision 20, "Steam Generator Secondary Side Vents & Drains".

Burns & Roe Drawing #2626, Revision 9, Lab and Penetration Pressurization Gas Systems and Hydrogen for MU Tank".

Burns & Roe Drawing #2632, Revision 9, Radwaste Disposal Reactor Coolant Leakage Recovery".

Burns & Roe Drawing #4006, Revision 17, "Auxiliary Bldg. Emergency Liquid Cleanup System".

20. Applicable Drawings (Continued)

Burns & Roe Drawing #M014, Revision 15, "Fuel Pool Waste Storage System".

Burns & Roe Drawing #M022, Revision 25, "Standby Pressure Control System".

Burns & Roe Drawing #M043, Revision 11, "Mini Decay Heat Removal".

Burns & Roe Drawing #M044, Revision 6, "Temporary Nuclear Sampling" (Sheet 1)

Bechtel Drawing #2-M75-DWC01, Revision 2, "Schematic Diagram IIF Processing System".

Bechtel Drawing #2-M75-DWC02, Revision 2, "Schematic Diagram IIF Processing System".

Bechtel Drawing #2-P70-DWC01, Revision 6, "Defueling Water Cleanup System Reactor Building".

Gilbert Drawing #C-302-692, Revision 22, "Liquid Waste Disposal".

B&W Drawing #42-40-002-01, (Revision # Not Discernible - File #7-00-0216), "Seal System Schematic Throttle Bushing Arrangement".

GPU Drawing #2E-950-21-001, Revision 4, "PS10 Composite Submerged Demineralizer System".

APPENDIX A: RCS FEED AND BLEED

A.1 SCOPE

While in the static, level control mode, it may be advantageous to perform a "feed and bleed" operation before head removal in order to reduce the RCS activity or after head removal if IIF processing could not be conducted. This maneuver would be performed in accordance with Section 4.2 of Operating Procedure 2104-10.2. The boron dilution potential directly associated with this maneuver constitutes the scope of this analysis.

A.2 INTRODUCTION

The flow paths used for feed and bleed are described separately in the calculation. The feed pathway draws from the "A" bleed tank through the MU&P System and injects into the RCS via valves MU-V16A, B, C and D. The bleed path draws from the normal letdown line through MU-V376, the WDL System and into the "C" bleed tank. The feed and bleed operation differs from the static, level control situation in the following aspects:

(i) Makeup valves MU-V376, -V101, which provide isolation under static conditions must be opened for the bleed path.

(ii) Makeup valves MU-V16A, B, C, D and -V16S which provide isolation under static conditions, must be opened for the feed path.

(iii) The ability to interpret a dilution event by monitoring RCS inventory change may be affected since although the level should ideally remain constant, it is subject to fluctuations by the nature of the maneuver.

In performing this analysis it has been assumed that:

1) The initial concentration of boron in the RCS and the "A" bleed tank is 5050 ppmB.
2) The "B" bleed tank is either empty or full of RCS grade water.

3) A "dilution event" involves a drop in boron concentration to a minimum acceptable concentration.

4) All barriers which were in effect during the static, level-controlled mode are also maintained during feed and bleed except those required by the maneuver; i.e., MU-V164, B, C, D, -V376.

5) Feed and bleed may be required before head lift and is not expected to be required after head lift. To estimate exposure of certain barriers to operator error, a frequency of once per year was assumed for feed and bleed operations.

6) Type I selection errors on valves operated from the control room were given a recovery factor of 10 to account for the number of qualified personnel witnessing operations. Type I errors on valves operated from the Radwaste Panel were given a recovery factor of 5 to account for the general use of a mimic board; less credit was given for recovery than for valves operated from the control room. Type I selection errors on manual valves were given a recovery factor of 2 to account for operator recognition of an error from the system effects of the error.

7) Feed rates are about 10 gpm or less (based on experience during draindown).

A.3 CALCULATION

A.3.1 Prevention of Dilution - Bleed

To compensate for the loss of isolation barriers associated with opening valves MU-V376, WDL-V46 and WDL-V963 for the letdown path, a new group of 105 isolation barriers was identified. These barriers are provided as Table A.1. The valves in Table A.1 are summarized in Table A.3. It is recommended that the valves in Table A.3 be added to those in Table 4.4-3 of the main report to form the isolation barrier checklist in OP 2104-10.2.

TABLE A.1

FEED AND BLEED - LETDOWN

ACTION	AFFECTED PATH	COMPENSATION	
MU-V376	MU&P Demineralizers	MU-V226, -V224A, -V224B, MU-V6A, -V6B	
	MUAP Demineralizers	MU-V107A,B; MEF Sytem Off, DW-V300B, MU-K-1	
	Deborating Demineralizers	WDL-V81A, -V81B WDL-V70A, 70B, 72A, 72B, 109A, 109B, 109C, 109D, 110A, 110B, 163A, 163B, 190A, 190B, 532A, 532B	
WDL-V46	SF System	SF-V214 SF-V122, 186, 217, DH-V109	
	MU-T-1 Drain	MU-V169 MU-V12,13,27,28,133,MU-T-1	
	Core Flood Tank Bleed and Sample	CF-V107 CF-V144	
	MWHT	WDL-V533 WDL-V1091	1
	RC Drain Header	WDL-V22 WDL-V1125	
WDL-V963	Recirculation Line	Must be open for processing	
	Nitrogen	Must be open for processing	
	Waste Gas Vent Header and Gas Analyzer	Must be open or processing	
	Letdown Relief Valve Discharge	Must be open for processing	

A.3.2 Prevention of Dilution - Feed

To compensate for the loss of isolation barriers associated with opening MakeUp valves MU-V16A,B,C and D for the makeup (feed) path, a group of new isolation barriers was identified. These barriers are provided as Table A.2. The valves in Table A.2 are summarized in Table A.3. It is recommended that the valves in Table A.3 be added to those in Table 4.4-3 to form the isolation barrier checklist for OP 2104-10.2.

TABLE A.2

FEED AND BLEED - MAKEUP

ACTION	AFFECTED PATH	COMPENSATION
MU-V16A,B,C,D.	MU-P-1A,B,C Discharge	MU-V144A, -V144B, -V144C, MU-V36, -V12, DW-V195, SF-K-1*, BS-V3A,B, DH-V5A,B, DH-V100A,B, -V7A,B, -V128A,B, -V109, -V120, -V134A,B, DH-C-1A,B, SF-V217, -V186, -V214, -V122, SP-C-1A,B
	SPC System	Not Required for Boron Dilution
	CF Makeup	CA-V175 CA-V173
	CF Tanks	CF-V114A,B, -V1A,B, -V115 CF-V145, -V146
	Seal Return Coolers	MU-V289 MU-C-2A,B, MU-V37, DW-V227
	MakeUp Tank	MU-V133 MU-V12,13,27,28,169, MU-T-1*
	CA-T2A, -2B, -3	CA-V107; -V112 CA-P-1 off, CA-P-2 off
	CA-T-1	MU-V127 CA-V138
	Pressurizer Sampling Return	SN-V182 Cut & Capped Pipe
MU-V10	Deborating Demins WDL-K-1A, -1B	WDL-V110A, -V110B WDL-V109A, 109B, 109C, 109D, 70A, 70B, 72A, 72B, 163A, 163B, 81A, 81B, 537A, 537B, 190A, 190B, DW-U313, U314, WDL-U301
		WDL-V543A WDL-V544A
		WDL-V543B WDL-V544B

* Isolates vent header: failure of isolation requires tank overflow.

ACTION	AFFECTED PATH	COMPENSATION
	CA-T-1	CA-V140 CA-P-4A,B off, CA-V135,136,154, CA-T-8*
	DW Connection	MU-V294 DW-V92
WDL-V40	Other WDL Sources	WDL-V176, -V1171 WDL-V175, V59, -V41
WDL-V33A	Isolation of WDL Sources from Recirc. Line	WDL-V65A WDL-V65B, -V206A,B
WDL-V167 WDL-V21A(C)	Boric Acid Pump Discharge	CA-V136 CA-V-133A, -V133B, -V135, -V154, CA-T-8*
	Isolate Sampling from Recirculation line	WDL-V37 SNS-V53, 140, 158, 23, 1, SNS-T-6**, hose next to SNS-V139 or SNS-V139 1
WDL-V31A	Demin. Water Flush	WDL-V523 DW-V223
	Isolation of WDL-T-18 from Injection Path	WDL-V298, 288 WDL-V1668
WDL-V29A (C)	RC Drain Tank	WDL-V1153A, 1153C WDL-V1092
	WDL-T-Vent Header and Gas Analyzer	Must be open for processing
	Waste Gas Discharge Header	Must be open for processing
	Nitrogen Line	Must be open for processing
	Makeup Tank Relief Discharge	MU-R1 MU-V12,13,27,28,209,169, MU-T-1*
	Decon Conn.	WDL-V18A, -V18C SNS-V97, -V128
	BC Evaporator	WDL-V18A, 18C, WDL-V47
	RC Evaporator	WDL-V117 WDL-V521A, 521C

* Isolates vent header: failure of isolation requires tank overflow.
** Tank Volume limits dilution potential.

ACTION	AFFECTED PATH	ISOLATION
	BC Evaporator	WDL-V138 WDL-V65B, -V1370
	WDL-T-9A,B	WDL-V959 WDL-V521A, 521C
	DW Flush through RCF System	RCF System Disconnected & Removed

A.3.3 Mitigation of a Potential Dilution Event

During feed and bleed, the operator may not be able to recognize that a boron dilution event is occurring by a deviation from a constant level indication. Further, since feed and bleed requires the movement of large volumes of water in a matter of hours, many of the administrative controls which are performed once per shift or once per day could not be depended upon to detect a potential dilution event.

In order to provide the capability to detect a boron dilution event during feed and bleed, it is recommended that:

1) Immediately after processing, sample the RCS to reestablish a benchmark for maintenance of the system at an acceptable boron concentration.

2) When processing more than 10,000 gallons and the minimum acceptable RCS boron concentration is 3500 ppm, sample the RCS prior to injection of 10,000 gallons to verify the correctness of the valve lineup. (If the minimum acceptable concentration is 4350 ppm, sample prior to injection of 5000 gallons.) This will allow for corrective action to be taken prior to injection of enough water to dilute the vessel to the minimum acceptable concentration.

3) A mass balance calculation similar to that described in Procedure 2104-8.18, Appendix F, should be performed hourly when more than 10,000 gallons (5000 gallons for a minimum acceptable concentration of 4350 ppm) is being processed. 1

4) Sample the bleed tank selected for makeup prior to processing.

5) Monitor the RCS level every hour during feed and bleed processing to verify RCS level is not changing beyond the normal expected variation.

6) Perform isolation barrier check daily in accordance with Procedure 2104-10.2, Appendix C, to verify barriers have not been breached and provide recovery potential from any misalignment.

7) Perform boron concentration estimate daily in accordance with Procedure 4301-S1.

A.3.4 Probability of Boron Dilution During Feed and Bleed

For feed and bleed operations, there are 392 barrier configurations in addition to those in the baseline analysis (Table 4.4-4). It is assumed that feed and bleed will be performed only once before head lift, therefore the frequency of demand is taken to be once per year per barrier. The number of each barrier type was multiplied by the failure/demand/barrier type as given in Section 4.3 taking the increased frequency of demand into account to yield a failure probability of 7.3×10^{-3}/year. This is the probability that at least one of the barriers will be breached with the potential to cause an RCS boron dilution. Multiplication of the probability of barrier failure by the probability that an operator will fail to detect and properly mitigate the dilution will yield the probability of diluting the RCS boron concentration below a minimum acceptable boron concentration during a feed and bleed operation. This probability has been calculated to be about 8.6×10^{-5}/year for dilution to 3500 ppm and 1.3×10^{-4}/year for dilution to 4350 ppm. 1

A.4 CONCLUSIONS/RECOMMENDATIONS

This section summarizes the conclusions and recommendations discussed in Appendix A.

1) The probability of a boron dilution assuming during feed and bleed operations is estimated as 6.0×10^{-3} yr^{-1} for leak and 5.5×10^{-4} yr^{-1} for rupture. This probability is due to the required isolation of about 390 additional paths for the maneuver. Considering detection and mitigation capability, the probability of dilution to 3500 ppm due to this manuever was estimated as $8.6 \times 10^{-5}/yr.^{-1}$. The 1
probability of dilution to 4350 ppm was estimated as $1.3 \times 10^{-4}/yr.^{-1}$

2) Table A.3 supplements Table 4.4-3 in that it provides isolation of the RCS to compensate for the valves opened by the feed and bleed procedure. Thus, the valves in Table A.3 should be added to Appendix C to 2104-10.2; this will assure compliance with the SER Commitment for double barrier isolation.

3) Sampling of the RCS should be performed after completion of the operation to benchmark the RCS boron concentration. If the minimum acceptable boron concentration is 3500 ppm, sample prior to feeding 10,000 gallons. If the minimum acceptable concentration is 4350 ppm, sample prior to feeding 5000 1
gallons.

4) Monitor the RCS level hourly to detect variations that exceed what may be expected.

5) The current frequencies of executing Appendix C to 2104-10.2, the dilution source check in the Primary Aux. Operators Check Sheet, the boron concentration calculation in 4301-S1 and steam generator level checks are acceptable.

6) A mass balance calculation similar to that described in OP 2104-8.18, Appendix F, should be performed hourly when 10,000 gallons (or 5000 gallons if 4350 ppm is the minimum acceptable concentration) or more is being processed. 1

TABLE A.3 BARRIER LIST FOR FEED AND BLEED

(Feed and bleed is accomplished per Section 4.2 of Operating Procedure 2104-10.2. Procedure 2104-10.2 is structured such that all valves required for isolation during static conditions or for any maneuver covered by 2104-1.02 are placed on a single checklist - Appendix C to 2104-10.2. Thus, the following valves are recommended to be placed on Appendix C to 2104-10.2 in addition to those in Table 4.4-3 of this report. The valves listed here isolate the process flow path.)

CA-V133A
CA-V133B
CA-V135
CA-V154
CF-V144
DW-V92
DW-V223
MU-V6A
MU-V6B
SWS-V1
SWS-V97
WDL-V18A
WDL-V18C
WDL-V41
WDL-V42
WDL-V65B
WDL-V70A
WDL-V70B
WDL-V72A
WDL-V72B
WDL-V109A
WDL-V109B

WDL-V109C
WDL-V109D
WDL-V117
WDL-V130
WDL-V163A
WDL-V166B
WDL-V175
WDL-V176
WDL-V190A
WDL-V190B
WDL-V206A
WDL-V206B
WDL-V532A
WDL-V532B
WDL-V533
WDL-V544A 1
WDL-V544B
WDL-V959
WDL-V1153A
WDL-V1153C
WDL-V117D

APPENDIX B: IIF FILL

B.1 SCOPE

After installation of the Internals Indexing Fixture (IIF), the RCS water level will be raised to approximately 144". This maneuver is performed per Section 4.3.2 of Operating Procedure 2104-10.2. The boron dilution potential directly associated with this maneuver constitutes the scope of this analysis. It is expected that this will be a one time only procedure. After its completion, RCS level adjustments will be made with the IIF processing system or a feed and bleed operation. Thus, the minimum acceptable RCS boron concentration is assumed to be 3500 ppm. 1

B.2 INTRODUCTION

The flow path used for IIF fill will be the same as that used for previous refill and feed maneuvers: i.e., draindown from RC bleed tanks A or C and RCS injection through makeup valves 16A, B, C and D using a WDL pump. The details of the IIF fill maneuver differ from those analyzed for the static, level control situation in the following aspects:

(i) Makeup valves 16A, B, C and/or D which provide isolation under static conditions may be opened for the IIF fill.

(ii) The ability to interpret a dilution event by monitoring any RCS inventory change is affected because the IIF fill produces an increasing level by design.

The IIF fill entails increasing the RCS level from 12 ± 3 inches to 144 ± 3 inches, or the injection of about 11,500 gallons. The instrument accuracy (± 3 inches) corresponds to about ± 475 gallons.

In performing this analysis, it has been assumed that:

1) the initial concentration of boron in the RCS and the source bleed tank is 5050 ppm.
2) The "B" bleed tank is either empty or full of RCS grade water.
3) The dilution event of concern involves a drop in the RCS boron concentration below 3500 ppm.

4) All barriers which were in effect during the static, level-controlled mode are also maintained during IIF Fill except those required by the maneuver e.g. MU-V168.

5) The IIF Fill operation will be performed only once. Therefore, a frequency of barrier valve manipulation of 1 yr^{-1} was assumed.

6) Type I selection errors on valves operated from the control room were given a recovery factor of 10 to account for the number of qualified personnel witnessing operations. Type I errors on valves operated from the Radwaste Panel were given a recovery factor of 5 to account for the general use of a mimic board; less credit was given for recovery than for valves operated from the control room. Type I errors on manual valves were given a recovery factor of 2 to account for operator recognition of an error from the effects of a valve misalignment.

B.3 CALCULATION

B.3.1 Prevention of Dilution

To compensate for the loss of isolation barriers associated with opening the SIF fill path, a group of isolation barriers was identified. This group is provided as Table B.1. The valves in Table B.1 are summarized in Table B.2. It is recommended that the valves in Table B.2 be added to those in Table 4.4-3 of the main report to form the isolation barrier checklist in OP 2104-10.2.

TABLE B.1

ACTION	AFFECTED PATH	[illegible]
MU-V16A,B,C,D, SPC-V96	MU-P-1A,B,C Discharge	MU-V144A, -V144B, -V144C MU-V36, -V12, DW-V195, DH-V5A,B, 100A,B, DH-V7A,B, -V128A,B, DH-C-1A,B, -V109, -V120, DH-V134A,B, SF-V217, 186, 133, SF-C-1A,B, -V214, -V122, SF-K-1, BS-V3A,B,
	SPC System	(Isolation not required for Boron dilution prevention)
	CF Makeup	CA-V115 CA-V113
	CF-Tanks	CF-V145, -V146; CF-V1A,B, -V115, -V114A,B
	Seal Return Coolers	MU-V289 MU-C-2A,2B tubes, -V37, DW-V227
	Makeup Tank	MU-V133 MU-V12,13,27,28, MU-T-1*,169
	RC Bleed Hold-Up Tanks or Deborating Demins.	MU-V8 WDL-V81A,B, WDL-V1091, -V1125, SF-V214, MU-V169, CF-V107, WDL-V914, -V996, -V37, -V1171, WDL-V1152, -V523, -V153A, -V1092, -V85A, -V29B, WDL-V28B, -V521A,B,C, CA-V136, WDL-T-1B,*

* Isolation vent header; failure of isolation requires tank overflow.

ACTION	AFFECTED PATH	COMPENSATION
	CA-T-2A, -2B, -3	CA-V107, 112 CA-P-1 off, CA-P-2 off
	CA-T-1	MU-V127 CA-V138
	MU-K-1A, -1B	MU-V8 MU-V107A,B, -V224A,B, -V226
	RCS Letdown Coolers	MU-V8 MU-V376
MU-V10	Deborating Demins WDL-K-1A, -1B	WDL-V118A, -V118B WDL-V72A, -V72B, DW-V313, -V314 WDL-V532A,B, -V109A,B,C,D, -V70A,B, -V163A,B, WDL-V81A,B, -V190A,B, WDL-V301
	CA-T-1	WDL-S43A WDL-S44A
		WDL-S43B WDL-S44B
		CA-V140 CA-P-4A,B off, CA-V135, -V136, -V154, CA-T-8*
	DW Connection	MU-V294 DW-V92
WDL-V40	Other WDL Sources	WDL-V176, -V1111 WDL-V175, -V59, -V41
WDL-V33A	Isolation of WDL Sources from Recirc. Line	WDL-V65A WDL-V65B, -V206A,B
WDL-V757 WDL-V21C(A)	Boric Acid Pump Discharge	CA-V136 CA-V133A,B, -V135, -V154, CA-T-8*
	Isolate Sampling from Recirculation Line	WDL-V37 SNS-V158, SNS-140, SNS-53, SNS-T-6*, SNS-V23, -V1, Hose next to SNS-V139 or SNS-V139 1

ACTION	AFFECTED PATH	COMPENSATION
WDL-V31A	Demin Water Flush	WDL-V523 DW-V223
	Isolation of WDL-T-1B From Injection Path	WDL-V208, -280 WDL-V1643
WDL-V29C(A)	RC Drain Tank	WDL-V1153C, -V1153A WDL-V1092
	Relief Valve LetDown Line	MU-R3 MU-V107A,B, MU-V228, MU-V224A,B, 376
	WDL-T-Vent Header and Gas Analyzer	Must be open for processing
	Waste Gas Discharge Header	Must be open for processing
	Nitrogen Line	Must be open for processing
	MakeUp Tank Relief Discharge	MU-R1, MU-V12,13,27,28,289,169, MU-T-1*
	Decon Connection	WDL-V18C(A) SNS-V97, -V128
	DC Evaporator	WDL-V117, -V184,C WDL-V521C, 521A, -V82
	RC Evaporator	WDL-V138 WDL-V658, V1170
	WDL-T-9A,B	WDL-V858 WDL-V521C(A)
	DW-Flush Through RCF System	RCF System Disconnected and Removed

8.3.2 Mitigation of Potential Dilution Event

During IIF fill, the operator is not able to determine that a dilution event is occurring by a deviation from a constant level indication. Further, the IIF fill requires increasing the level from 72 ± 3 inches to 144 ± 3 inches at a rate of about 30 gpm. This results in completion of the IIF fill maneuver in about 6 1/2 hours. Thus, because most of the administrative controls described in Section 4.4.5.2 are performed on a shift or daily basis, the only detection of a dilution would be a low level alarm on a dilution source. However, this does not present a significant boron dilution hazard because the total volume added is not enough to dilute the vessel concentration to 3500 ppm.

Thus, the following recommendation are made:

(1) Sample the bleed tank from which the IIF will be filled prior to start of fill.

(2) Sample the RCS after completion of IIF fill to reestablish the 5050 ppm benchmark.

(3) Perform a mass balance of the RCS and source bleed tank every hour to identify discrepancies which could indicate a dilution event in progress.

B.4 CONCLUSIONS and RECOMMENDATION

This section summarizes the conclusion and recommendations for IIF fill.

1) The probability of a boron dilution occurring that is associated with IIF fill is estimated at 5.2×10^{-3} for leaks and 3.9×10^{-4} for ruptures. This probability is due to the required isolation of 263 paths. The detection capability associated with the IIF fill results in a probability of boron dilution to 3500 ppm due to this maneuver to be about 6.6×10^{-5} per year. 1

2) The valves listed in Table B.2 should be added to Appendix C to 2104-10.2. These valves provide at least double barrier isolation of the IIF fill path to compensate for the isolation valves that are opened for the maneuver. The isolation valves in Appendix C to 2104-10.2 that are not explicitly required for the IIF fill must remain closed to assure double barrier isolation.

3) Sample the bleed tank from which the IIF will be filled prior to the start of the fill (since the total fill volume is less than that required to dilute the vessel to 3500 ppm).

4) Perform hourly mass balances of the RCS and bleed tanks during the maneuver.

Table B.2 Barrier List for IIF Fill

(Filling of the IIF is accomplished per Section 4.2 to Operating Procedure 2104-10.2. Procedure 2104-10.2 is structured such that all valves required for isolation during static conditions or for any maneuver covered under 2104-10.2 are placed on a single checklist – Appendix C to 2104-10.2. Thus, the following valves are recommended to be placed on Appendix C to 2104-10.2 in addition to those in Table 4.4-3 of this report. The valves listed here isolate the process flow path.)

MU-V6A	WDL-V317
MU-V6B	WDL-V130
SKS-V26	WDL-V168B
SKS-V97	WDL-V176
WDL-V10A	WDL-V206A
WDL-V10C	WDL-V206B
WDL-V20A	WDL-V532A
WDL-V20C	WDL-V532B
WDL-V29A	WDL-V159
WDL-V29C	WDL-V163
WDL-V41	WDL-V166
WDL-V45	WDL-V1153A
WDL-V46	WDL-V1153C
WDL-V650	WDL-V1170
WDL-V72A	
WDL-V72B	

APPENDIX C: REFUELING CANAL FILL

C.1 SCOPE

After the installation of the internals indexing fixture (IIF), there is a contingency plan to fill the refueling canal if a leak in the IIF seal were to develop. The maneuver would be performed by Operating Procedure 4201-OPS-3254.01. The potential for dilution of the RCS when conducting this maneuver constitutes the scope of this analysis.

The most likely time for an IIF seal leak would have been immediately after installation, which was part of the head lift operation. For head lift, the minimum acceptable RCS boron concentration was 3500 ppm. Although a leak of the IIF did not occur; and therefore, the likelihood of filling the refueling canal is now diminished, this appendix has been 1
updated to include the boron dilution hazard of filling the refueling canal if the minimum RCS boron concentration were 4350 ppm.

C.2 INTRODUCTION

Under this contingency, the refueling canal is to be filled to approximately the top of the IIF. This corresponds to an elevation of 327 feet and requires the transfer of about 105,000 gallons from the BWST. The maneuver may be conducted with pump SF-P-1A, SF-P-1B or FCC-P-2. Whichever pump is used, the required flow path is from the BWST through portions of the decay heat and spent fuel systems and through flexible hosing (connected at FCC-U-2) into the canal.

The canal fill maneuver differs primarily from static conditions in that it is more difficult to detect a dilution event by level change when a flooded canal communicates with the RCS. This is because a one inch increase in water level as read on the RCS level indicators corresponds to roughly 915 gallons when the canal is filled versus about 160 gallons if only the IIF were filled. From a dilution viewpoint, the additional water in the canal has little beneficial effect because it must be assumed that a dilution through a piping interface will not mix with the canal volume before reaching the core.

The loss of level monitoring sensitivity becomes more important for slow dilution events (.15 gpm). This is because, at faster dilution rates the operators may be able to judge that a dilution event is in progress by the unexpected rate at which the canal is being filled or if the dilution rate is by a piping interface, by a surge in the IIF level.

C.3 CALCULATION

There are three aspects of the dilution potential that are associated with the canal fill maneuver: (1) the potential for dilution into the canal fill pathway during the fill itself, (2) the potential for dilution of the RCS from a diluted canal volume after the fill is completed and (3) dilution of the RCS through RCS piping interfaces after the canal is filled.

In the first case, the concern is that a portion of the flow into the canal is unborated water. As mentioned in Section C.2, it is likely that a dilution flow that was comparable to the desired fill flow would be detected by a greatly increased canal fill rate (or a relatively slowly decreasing BWST level). However, flows significantly less than the fill rate would probably go unnoticed in this maneuver. In any event, if a canal sample were taken prior to overflowing into the shallow end, any dilution event could be detected before affecting the RCS.

In the second case, the refueling canal volume acts as an additional mixing volume to inhibit dilution of the RCS. The water in the canal itself is approximately three times that in the reactor vessel. To dilute the volume of both the vessel and canal to a boron concentration of 3500 (4350) ppm would require approximately 60,000 (22,500) gallons, which would correspond to a canal level increase of over 5 (2) feet. It is extremely unlikely that this amount of additional water would go undetected.

The potential of dilution via RCS piping interfaces after the canal is filled represents the third, and most restrictive, case. The probability of a dilution occurrence through piping interfaces is not related to whether the refueling canal is filled. However, the ability to detect such an occurrence is more difficult because of the loss of level instrument sensitivity with the canal filled (or partially filled) with water. Further, the canal volume cannot count as a mixing volume for any unborated water through piping interfaces because it must be assumed that the water above the vessel will not mix before the unborated water will reach the core. In this case, the level increase before a potential dilution to 3500 ppm would be about 13 inches (915 gallons/inch canal volume). At any credible dilution rate (see main report), this would require at least an hour. For the more likely rates, dilution would not occur in less than about 13 hours. However, if the minimum acceptable RCS boron concentration is 4350 ppm, the volume of water required to dilute the vessel to this concentration would result in a level increase of only six inches. Thus, the current level alarm setpoints are not appropriate for detection of a dilution under these circumstances. In the event of canal fill with the minimum RCS concentration specified at 4350 ppm, (1) the level alarm should be reset to ± 2 inches or (2) an RCS sampling program with a frequency of 2 hours or less should be implemented to provide timely notification of a potential dilution during static conditions. If RCS processing must be undertaken with a filled canal, there are additional monitoring requirements associated with each operation. These additional requirements are specified in the appropriate appendix. 1

(Detailed quantification of the dilution potential associated with the canal fill maneuver was not performed because the risk was judged to be negligible, given the low likelihood of occurrence of the contingency canal fill, the low probability of dilution occurring and the detection capability. The dominant risk associated with the maneuver is judged to occur through piping interfaces after the canal is filled because of the loss of sensitivity of the level instrumentation. However, in this case, there will be adequate time for operator response to an event of any credible flow rate (see main report). The probabilities of occurrence of a dilution through piping interfaces are the same as estimated for plant conditions in other sections of this report.

C.4 CONCLUSIONS/RECOMMENDATIONS

(1) Sample the canal prior to filling the deep end to assure that the water with the desired concentration is being added.

(2) Provide isolation of the canal fill pathway. In this regard, Rev. 0 of 4210-OPS-3254.01 was reviewed and verified that, with the exception noted below, isolation of the canal fill path is achieved with the valve lineup presented in the procedure. (N.B. This list does not provide "double barrier" isolation of the fill path. However, this is not required from a reliability standpoint given that injection is into the canal and that a sample will be taken just prior to filling the shallow end. If double barrier isolation is required due to SER commitments, an isolation list which achieves this is available in RAS Calculation 4430-84-007.)

Valve SF-V222 in Section 7.3 of 4210-OPS-3254.01 should be closed to isolate the flow path. No indication of the correct position is shown.

(3) In the event of canal fill with the RCS minimum acceptable boron concentration of 3500 ppm, assure that the RCS level alarm is set to detect a level increase of no more than about 6 inches; this will allow for operator action to isolate the RCS from dilution through piping interfaces. In the event of canal fill with the RCS minimum acceptable concentration of 4350 ppm, (1) the RCS level alarm setpoint should be plus two inches or (2) a sampling program with a frequency of two hours or less should be implemented. 1

APPENDIX D

ANALYSIS OF BORON DILUTION POTENTIAL DURING IIF PROCESSING

D.1 SCOPE

This appendix describes the boron dilution potential directly associated with the operation of the IIF processing system. For the purposes of this analysis, a draft procedure for IIF processing was used (2104-8.10).

Since most of the administrative controls which are in place under 2104-10.2 will also be in place under this procedure, this analysis addresses those operations which diverge from the level control mode, or which in some way influence the controls which were taken credit for in the baseline analysis.

8.2 INTRODUCTION

Operation of the IIF Processing System impacts the baseline (static RCS) assessment in the following ways:

1) Opening of MU-V16B
2) Installation and operation of DWC-P-1
3) Manual maintenance of level in the Reactor Coolant System from the Radwaste Panel

For each of these changes to the baseline assessment for boron dilution, compensating and/or mitigating measures have been evaluated.

To compensate for the opening of MU-V16B and the operation of DWC-P-1, additional valve closures have been recommended and appropriate accident sequences have been postulated.

To compensate for the potential to accommodate and mask a small unborated injection by the level controller, an increased sampling frequency is recommended. No credit has been taken for operation of a boronometer.

Given the post head lift experience, it is anticipated that the IIF processing system will operate no more than 50 days between head lift and start of defueling. This translates to a maximum of about nine batches on a yearly basis. A batch consists of about 30,000 gallons of RCS water. An extended (>8hrs) shutdown isolation list would be implemented at the end of each batch per Section 6.1.10 of 2104-8.1B; a temporary shutdown isolation is implemented on a daily basis during the batch process per Section 6.2 of 2104-8.18. These shutdowns enable operators to make their daily leakrate checks and to handle any temporary abnormalities which may be encountered in the SDS system. One system trip annually was also assumed.

With respect to manual maintenance of level, it was assumed that this maintenance would be performed only on the makeup side from the Radwaste panel and that letdown flow through SDS would remain constant.

In performing this analysis it has also been assumed that:

1) The initial concentration of boron in the RCS and the bleed tank used for makeup is 5050 ppmB.
2) The "B" bleed tank is either empty or full of RCS grade water.
3) A "dilution event" involves a drop in boron concentration to the appropriate RCS minimum acceptable boron concentration of 3500 ppm or 4350 ppm. I
4) All barriers which were in effect during the static, level-controlled mode are also maintained during IIF processing except those barriers involving WDL-V164, B, C, D.
5) Type I selection errors on valves operated from the control room were given a correction factor of 10 to account for the number of qualified personnel witnessing operations.

6) Type I selection errors on valves operated from the Radwaste Panel were given a correction factor of 5 to account for the mimic Board and the potential for operator recognition of errors because a maneuver might have failed following his valve lineup.

7) Type I selection errors on manual valves were given a correction factor of 2 to account for operator recognition of errors because a maneuver might have failed following his valve lineup.

D.3 CALCULATIONS

Operation of the Internals Indexing Fixture Processing System introduces a new pathway which is not present during the normal, level-controlled mode of plant operation. It can be viewed as an extension of the RCS from the vessel through the SDS system, into the RCBT's and back to the vessel via the Make-Up and Purification System. Intrusion of the RCS system is made in two places which must be compensated for by the isolations along the path which makes up the IIF Processing System.

D.3.1 Prevention of Dilution

The additional risk due to the operation of the IIF processing system is composed of two components:

1) Dilution while processing and
2) Dilution after processing has ceased, or between batches.

The total probabilities of leak and rupture dilutions have been ca' lated to be 4.4×10^{-3} yr^{-1} and 5.0×10^{-4} yr^{-1}, respe.. vely. The specific components of these numbers are discussed in the sections to follow. 1

D.3.1.1 Letdown During Processing

The first intrusion is made on the top of the IIF where
reactor coolant is pumped out to the FHB, through the SDS
System, and into the basement of the Auxiliary Building to
WDL-T-1A(C). Compensating valve closures are listed in Table
D.1. Except for the first two hose connections, only the
first isolation boundary is listed on the letdown path. Shown
there are 20 manual and 13 MOV valves, each of which is
combined with 4 MOV's to make 136 barrier configurations.
Three of the four MOV's (29A(C), 28A(C), 963(964)) have an
adjacent manual valve (WDL-V166A(C), 996(994)), which it is
assumed would be cycled during long term shutdown. As 1
mentioned, it is assumed that one trip per year would demand
FCC-V003 as a barrier in combination with each of the 13 MOV
and 20 manual valves.

When the IIF System is operating, the only means of RCS dilution on the letdown (SDS) side of the system is by inadvertent line-up of the WDL pump to the wrong bleed tank, or by letdown to the bleed tank being used for makeup (given that a dilution occurs on the letdown path).

Since the frequency of operation is the driving factor which increases the probability of dilution for letdown, a third valve for these pathways was required to reduce this probability.

The leak and rupture components due to the letdown side during processing are 2.6×10^{-3} yr^{-1} and 2.3×10^{-4} yr^{-1}, respectively. 1

TABLE B.1

IIF PROCESSING - LETDOWN

ACTION	AFFECTED PATH	COMPENSATION
Open FCC-V003 DH-(1 1/2")	From canal drain pump (1 1/2" hose)	FCC-V002 Disconnect pump
	From sump sucker (1" hose)	FCC-V001 Disconnect pump
Open SWS-V1	From Service Water System drain (3/4")	SWS-V6
Open SWS-V2	Flush Conn. (3/4")	Step 4.2.3 of OP 2104-B.18 precludes connection of flushing apparatus during processing
Open CN-V-RC-364	Return line from Monitor Tanks (SDS-T-1A, -1B)	CN-RC-362
	Off-gas line	CN-V-RC-362
	RCS Clean-up manifold sump	CN-V-RC-362
	High-Rad filter manifold sump	CN-V-RC-362
CN-V-RC-363	WG-P-1 discharge	WG-V71
	Flush connection	Step 4.2.3 of OP 2104-B.18 precludes connection of flushing apparatus during processing
	MDHT, RCBT	WG-V71
	WG System	WG-V71, -V95
CN-V-FL-1	Flush Conn.	Step 4.2.3 of OP 2104-B.18 precludes connection of flushing apparatus during processing
	Sample conn. & vent	Not credible for dilution
CN-V-FL-3	Vent & sample conn.	Not credible for dilution
CN-V-FL-14	Sample line & vent	Not credible for dilution

ACTION	AFFECTED PATH	COMPENSATION
CN-V-FL-6	Vent line & sample line	Not credible for dilution
	WG-P-1 discharge	WG-V69
	RBHT & RCBT	WG-V69
	Flush conn.	Step 4.2.3 of OP 2104-B.1B precludes connection of flushing apparatus during processing
	Demin Water	WG-V69
	SDS-T-1A, B	CN-V-RC-366
CN-V-RC-369	Flush conn.	Step 4.2.3 of OP 2104-B.1B precludes connection of apparatus for flushing during processing
	Hi-Rad sample glove box	Not a credible source for dilution
CN-V-IX-25(26)	Flush conn.	Step 4.2.3 of OP 2104-B.1B precludes connection of flushing apparatus during processing
CN-V-IX-29(31)	Flush conn.	Step 4.2.3 of OP 2104-B.1B precludes connection of flushing apparatus during processing
CN-V-IX-30(32)	Tie-in to MDM	Tie-in not made
	Utility water supply	CN-V-IX-50
	Flush connection	Step 4.2.3 of OP 2104-B.1B precludes connection of flushing apparatus during processing
	Monitor tank (SDS-T-1A, B)	CN-V-PF-62
	Flush Conn. for Sampling	CN-V-SA-294, CN-V-PM-196
	RBHT and Radwaste System	CN-V-IX-102

ACTION	AFFECTED PATH	COMPENSATION
SF-V158	Spent Fuel System	SF-V150
	SF Pool	SF-V159
	Fuel Storage Pool	SF-V161
SF-V125	Sample Line	SF-V126
	DH System	SF-V240
	SF System	SF-V240
	DH Letdown	SF-V122
	SF System	SF-V121A
	SF System	SF-V121B
SF-V214	Core Flood Tank Bleed and Sample	CF-V107
	MWHT	WDL-V1091
	RC Drain Header	WDL-V-1125
	MU-K-1A,B, WDL-K-1A,B, MakeUp System	WDL-V81A,B, MU-V8, -V107A,B MU-V226, -V224A,B, -V376
	Makeup Tank	MU-V169
WDL-V364(-V363)	Isolate Letdown Tank from Makeup Line/Tank	WDL-V-28A(C), -V29A(C), -V533 WDL-V166A(C)
	Isolate WDL-T-1B from MakeUp Line	WDL-V28B, -V29B WDL-V166B
	Isolate WDL-T-1B from Letdown Line	WDL-V395

D.3.1.2 Makeup During Processing

The second intrusion to the RCS is made by making up from WDL-T-1C(A) through WDL-V40 and MU-V16B. Compensating valve closures are listed in Table D.2 yielding double valve isolation to any unborated water source. The path is traced from MU-V16B back through the MU&P System and the Liquid Radwaste System to the bleed tank WDL-T-1C(A).

The frequency of manipulation for these compensating valves is assumed to be once per year. That means that no allowance has been assumed for moving valves around on the makeup side of the system during shutdown except at the bleed tank.

The resulting leak and rupture probabilities for the 400 barrier configurations on the makeup side during processing are $1.4 \times 10^{-3}\ yr^{-1}$ and $1.1 \times 10^{-4}\ yr^{-1}$, respectively. 1

TABLE D.2

ACTION	AFFECTED PATH	COMPENSATION
MU-V16A,B,C,D SPC-V86	MU-P-1A,B,C Discharge	MU-V144A, -V144B, -V144C MU-V36, -V12, DW-V195, SF-K-1*, BS-V3A,B, DH-V5A,B, -V7A,B, -V100A,B, -V128A,B, -V109, DH-V120, -V134A,B, DH-C-1A,B, SF-C-1A,B, SF-V217, -V106, -V122
	SPC System	Isolation not required to prevent boron dilution
	CF MakeUp	CA-V175 CA-V173
	CF-Tanks	CF-V145, -V146, CF-V114A,B, -V1A,B, -V115
MU-V151	Seal Return Coolers	MU-V289 MU-C-2A,B, MU-V37, DW-V227
	Makeup Tank	MU-V133 MU-V12,13,27,28,169, MU-T-1*
	Deborating Demins	MU-V8, WDL-V81A,B
MU-V149	CA-T-2A, -2B, -3	CA-V107, 112 CA-P-1 off, CA-P-2 off
	CA-T-1	MU-V127 CA-V130
	MU-K-1A, -1B	MU-V8 MU-V107A,B, -V224A,B, -V326
	RCS Letdown Coolers	MU-V8 MU-V376

* Tank volume limits potential for dilution.

ACTION	AFFECTED PATH	COMPENSATION
MU-V118	Deborating Demins WDL-K-1A, -1B	WDL-V118A, -V118B WDL-V72A, -V72B, DW-V84 WDL-V532A,B, -V109A,B,C,D, -V70A,B, -V163A,B, WDL-V81A,B, -V190A,B, WDL-U301
		WDL-V544A,B WDL-V543A,B
	CA-T-1	CA-V140 CA-V133A,B, -V135, -V136, -V154, CA-T-8 *
MU-V9	DW Connection	MU-V294 DW-V12
WDL-V40	Other WDL Sources	WDL-V176, -V1171 WDL-V175, -V59, -V41
WDL-V33A	Isolation of WDL Sources from Recirc. Line	WDL-V65A, WDL-V65B, -V206A,B
WDL-V167	Isolate WDL-T-1B, -T-1A(C) from Recirc. Line	WDL-V963(964), -V18A, V521C WDL-V996(994), 521A, B, WDL-T-1B*, -V18C, WDL-T-1A(C) *, WDL-V995
	Boric Acid Pump Discharge	CA-V136 CA-V133A,B, -V135, -V154, CA-T-8 *
	Isolate Sampling from Recirculation Line	WDL-V33 SNS-V158, SNS-V140, SNS-V53, -V23, -V1, SNS-V139
WDL-V31A	Demin Water Flush	WDL-V523 DW-V223
	Isolation of WDL-T-1A(C) from Injection Path	WDL-V29A(C), V28A(C) (All 1st isolation barriers used for letdown) ***, WDL-V166A(C)
	Isolation of WDL-T1B from Injection Path	WDL-V29B, -28B WDL-V166B
WDL-V29C(A)	RC Drain Tank	WDL-V1153C(A) WDL-V1042

* Tank volume limits potential for dilution.
*** Triple barrier isolation is required due to human error vulnerability introduced by frequent valve manipulation.

ACTION	AFFECTED PATH	COMPENSATION
	Relief Valve Letdown Line	MU-R3, MU-V107A,B, MU-V226, MU-V224A,B, -V376
	WDL-T-Vent Header and Gas Analyzer	Required to be open for processing
	Waste Gas Discharge Header	Required to be open for processing
	Nitrogen Line	Required to be open for processing
	Makeup Tank Relief Discharge	MU-R1, MU-V12, 13, 27, 28, 289, 169, MU-T-1*
	Decon Connection	WDL-V18C(A); SXS-V93, -V120, WDL-V42 ↑1
	RC Evaporator	WDL-V117 WDL-V521C(A)
	RC Evaporator	WDL-V130 WDL-V65B, V1170
	WDL-T-9A, B	WDL-V959 WDL-V521C(A)
	DW-Flush Through RCF System	RCF System Disconnected and Removed

* Tank volume limits potential for dilution.

On the makeup side of the system, all potential dilution sources are isolated by at least two independent barriers. There are 284 potential injection points, all of which meet the two independent valve closure criteria during operation of the IIF. When the system trips, there is an additional barrier (WD1-V60) for the WD1 barriers all of which are upstream of WD1-V60. Therefore, the more conservative assessment of boron dilution probability comes from the scenario in which the IIF processing system is in operation.

D.3.2 Probability of a Dilution - Impact of Shutdown

The calculation of a boron dilution event initiation after processing has ceased, or between batches has been performed by determining the increase in vulnerability due to starting and stopping the processing system. This determination was made separately for letdown and makeup.

D.3.2.1 Impact of Shutdown on the Letdown Path

When the system is shutdown for an extended (>8 hrs) time, FCC-V003 forms four triple barriers with SWS-V1, SWS-V2; SWS-V1, SWS-V6; FCC-V001, pump; FCC-V002, pump. If SWS-V2 can be added to the temporary shutdown list, then the calculation for temporary shutdown will incorporate extended shutdown for the letdown path except for 33 barrier configurations. Assuming daily temporary shutdowns for each workweek (1 batch takes approximately a week to process), the leak and rupture probabilities of boron dilution through the letdown path during shutdown are 1.1×10^{-4} and 8×10^{-6}, respectively. Triple barrier configurations were needed to keep this probability acceptably low.

D.3.2.2 Impact of Shutdown on the MakeUp Path

Again, the system is assumed to be shutdown ~8 times/year 1
for an extended period (> 8 hours) if the system is operated for a year. On the makeup (injection) side of the system, MU-V168, MU-V9, MU-V10 will be closed in addition to the isolations already in effect for processing. Allowance has been made for manipulation of the valves upstream of MU-V10 in order to prepare the bleed tanks for further processing. That component is included in the calculation for dilution during processing. Therefore, the only additional component to the risk is that due to the manipulation of three valves (MU-V168, -V9, -V10) for each long term shutdown. The leak and rupture probabilities for this component are 1.5×10^{-6} yr^{-1} and 1
2.6×10^{-5} yr^{-1}, respectively. Noting that the rupture probability is almost twenty times the leak probability, one concludes that this failure mode is dominated by human error, owing to the high frequency of valve manipulation.

while the system is shutdown temporarily (<8 hrs), allowance has not been made for the manipulation of processing isolation barriers. Only valves in the process stream will be manipulated, having negligible impact on the risk of dilution. All isolation barriers which were in place during processing will still be in place during temporary shutdown, so the calculation of dilution potential during processing has taken care of this component.

B.3.3 Mitigation

As discussed in Section 4.4.5.3, there are several potential methods for detecting a dilution event. The methods for which reliability credit can be given during IIF processing are discussed below:

(1) Level monitoring: The ability of the level instrumentation to detect a dilution event has some limitations during IIF processing. This is because the water movement into and out of the vessel requires some throttling of the makeup source to maintain a constant level in the IIF. (The throttling may be manual or automatic. From the standpoint of boron dilution prevention, direct operator balancing of the flow is preferred to the action of an automatic level controller. This is because the operator may be able to make a judgment that the degree of throttling is excessive for balancing the process.) 1

This throttling allows the possibility of a dilution inflow being mixed with the desired makeup flow to maintain level. As a worst case, the entire makeup flow could be an unborated water source; this unborated water inflow would remain undetected by the level indicators until it exceeded the IIF processing outflow. If the inflow exceeds the outflow, a rising RCS level will detect the dilution event. Experience with the IIF processing indicates that it will probably not be operated at greater than about 15 gpm, which, coincidentally is the bounding rate for most dilution events as discussed in the main report.

(2) Boron sampling: To compensate for the loss of sensitivity of the level indication during IIF processing, a boron sampling program will provide the capability to detect a dilution event. Because the dilution rate that could be "hidden" from the level indication is a function of the outflow, or IIF processing rate, the sampling frequency varies with the processing rate. (Coincidentally, the most likely range for a dilution event, 0 to 15 gpm, corresponds to the range at which processing will be conducted. If processing exceeded 15 gpm, the boron sampling frequency should be set to detect a dilution inleakage of 15 gpm.) The sampling frequencies recommended are provided in Table D.3. 1

Table D.3 Recommended RCS Sampling during IIF Processing

Process Flow Rate	RCS Minimum = 3500 ppm		RCS Minimum = 4350 ppm	
	Dilution Vol	Sampling Freq	Dilution Vol	Sampling Freq
5 gpm	13,200 gal.	37 hrs.	5,370 gal.	11 hrs.
10	13,200	16	5,370	3
12	13,200	13	5,370	2
15	13,200	9	5,370	1

The above table illustrates the difference in the sampling frequency resulting from different minimum acceptable boron concentration. The frequencies in Table D.3 assume 1

(1) no operator action if the sample results are 4350 ppm or greater (n.b., not to be confused with the assumed initial RCS boron concentration of 5050 ppm)

(2) time allowed for sample analyses is three hours

(3) time allowed for operator action is one hour.

The sampling frequencies can be lengthened if any of these assumptions were relaxed, e.g., a reduced sample analyses time may be possible for some period of operation.

(3) Mass Balance: Per appendix F to 2104-8.18, a water inventory balance between the RCS and the reactor coolant bleed tanks will be performed every hour during processing. Processing will be terminated if there is a mismatch of more than 5000 gallons. This method will detect an inflow of water into the process system and thus is a backup to RCS sampling.

D.4 CONCLUSIONS AND RECOMMENDATIONS

Given the assumptions stated in D.2, it has been calculated that the IIF processing operations can be implemented and carried out safely with an acceptably low risk of diluting the boron concentration below the minimum acceptable RCS boron concentration. The calculated probabilities of leak and rupture dilution initiations are 4.4×10^{-3} yr^{-1} and 5.0×10^{-4} yr^{-1}, respectively. Accounting for operator mitigation of the event, the probability of dilution below 3500 ppm during IIF processing was estimated to be 6.6×10^{-5} yr in addition to the baseline risk; the probability of dilution below 4350 ppm was estimated to be an additional 1.0×10^{-4} per year above the baseline risk.

These probabilities are contingent upon the following recommendations:

1) The valves listed in Table D.4 should be maintained closed during operation of the IIF processing system.

2) The applicable RCS boron sampling frequency from Table D.3 is proceduralized and implemented.

3) Valve SWS-V2 should be added to the temporary shutdown list in Section D.2 of 2104-4.10.

TABLE D.4 BARRIER LIST FOR IIF PROCESSING

(IIF processing is accomplished per Operating Procedure 2104-D.10. Procedure 2104-D.10 is structured such that all valves required for isolation during any maneuver are placed on checklists for periodic verification. Checklists applicable to IIF processing are Appendix C to 2104-10.2 and Appendix G (to be added as developed) to 2104-D.10. Thus, the following valves are recommended to be placed on one of these checklists in addition to those in Table 4.4-3 of this report. The valves listed here isolate the process flow path.

CA-V133A*	SF-V121A	WOL-V29C	WOL-V190A*
CA-V133B*	SF-V121B	WOL-V42*	WOL-V190B*
CA-V135*	SF-V126	WOL-V65B*	WOL-V206A*
CA-V154*	SF-V150	WOL-V70A*	WOL-V206B*
CA-P-1* OFF	SF-V159	WOL-V70B*	WOL-V532A*
CA-P-2* OFF	SF-V161	WOL-V72A*	WOL-V532B*
CW-V-IX-58	SF-V240	WOL-V72B*	WOL-V533
CW-V-IX-102	SWS-V1*	WOL-V109A*	WOL-V544A*
CW-V-PF-67	SWS-V97*	WOL-V109B*	WOL-V544B*
CW-V-PR-196	SWS-V139	WOL-V109C*	WOL-V959*
CW-V-RC-362	SWS-V6	WOL-V109D*	WOL-V963*
CW-V-RC-366	WOL-V18A*	WOL-V117*	WOL-V964*
CW-V-SA-294	WOL-V18C* 1	WOL-V138*	WOL-V995
DW-V84*	WOL-V28A	WOL-V163A*	WOL-V1153A*
DW-V92*	WOL-V28C	WOL-V163B*	WOL-V1153C*
DW-V223*	WOL-V29A	WOL-V166A	WOL-V1170*
FCC-V001		WOL-V166B*	WOL-U301 removed
FCC-V002		WOL-V166C*	WG-V69
(Pumps		WOL-V175*	WG-V71
disconnected)		WOL-V176*	WG-V85** 2

* Valves which have already been incorporated into 2104-10.2, App. C.
**Valve removed and pipe capped

E.1 SCOPE

This appendix describes the boron dilution potential directly associated with the operation of the Defueling Water Cleanup System (DWCS) as described by Operating Procedures 4215-OPS-3525.01 (Reactor Vessel portion), 4215-OPS-3525.03 (FTC/SFP portion) and 4215-OPS-3525.04 (Early Defueling DWCS operation). Since most of the administrative controls required by Operating Procedure 4210-OPS-3200.02 (formerly 2104-10.2) will remain applicable, this analysis addresses only those operations which vary from the static condition, or which in some way influence the controls which were applied during static conditions. The boron dilution potential directly associated with DWCS operation constitutes the scope of this analysis.

When fully operational, the Defueling Water Cleanup System (DWCS) will provide the capability to remove particulate material or radionuclides from reactor vessel water or water in the fuel transfer canal and spent fuel pool A. During early defueling, the SDS System will be utilized in lieu of dedicated DWCS ion exchangers. Except for operation during early defueling, the flow paths used for defueling water cleanup are independent of those used for Feed and Bleed, IIF Fill, and IIF Processing. The DWCS utilizes two closed loop processing flow paths, one for the Reactor Vessel, and a second for the Fuel Transfer Canal (FTC) and the Spent Fuel Pool (SFP). Two submersible pumps (deep well type) have been dedicated to each volume of water (i.e., a total of 6 pumps). The two pumps for the Reactor Vessel cleanup train are installed in wells located in the fuel storage pit (south of the reactor vessel) in the shallow end of the Fuel Transfer Canal. The FTC/SFP loop includes the two pumps located in the deep end of the Fuel Transfer Canal and the two pumps installed in the Spent Fuel Pool. Each pump has a capacity of 200 gpm and recirculates 20 gpm to protect the pump motor from runout. This arrangement allows each loop to filter 200 or 400 gpm from the Reactor Vessel and Fuel Transfer Canal/Spent Fuel Pool depending on whether one or two pumps is operating. The defueling water cleanup processing differs from the static, level control mode of operation in the following aspects:

(1) Reactor coolant water is circulated through filters and, if necessary, through a dedicated DWCS ion exchanger(s). During early

defueling, the SDS System will replace the ion exchange portion of the DWCS until installation of the DWCS ion exchange loops is completed.

(2) After DWCS filtration, process water generally will be returned directly to the vessel. An exception to this is the use of the SDS ion exchangers, either for "early defueling" purposes or to remove radionuclides not removed by the DWCS ion exchange resins.

(3) Although the sampling points used during static conditions will also be available during DWCS operation, sampling points have also been incorporated into the DWCS design which will serve as the primary method of RCS boron sampling during DWCS operation. The various sample points are routed to two sample glove boxes which are located in the Fuel Handling Building. It is planned that the boron concentration of the ion exchanger effluent in the RV Cleanup System will be constantly monitored and displayed at a local control panel.

In performing this analysis it has been assumed that:

1) The initial concentration of boron in the Reactor Vessel is 5050 ppm; the Fuel Transfer Canal/Spent Fuel Pool A is 4350 ppmB.

2) All RCS isolation barriers which were in place during the static, level-control mode as defined in operating procedure 4210-OPS-3200.02, are also maintained during defueling water

cleanup. By procedure, correct positioning of barriers required to isolate the DWCS process stream will be verified on a daily basis. Some of these barriers may be removed if required for operational reasons, e.g., line flushing.

3) Criticality analyses of the defueling canisters in their storage racks have been performed (Reference TER 15737-2-G03-114, "TMI-2 Technical Evaluation Report for Defueling Canisters"). These analyses indicate that an array of canisters will be subcritical in unborated water. Thus, dilution of Fuel Pool A or the fuel transfer canal was not considered to be a safety concern and was not included within the scope of this analysis.

4) Typical operations may not require the DWCS to be operating at maximum capacity, i.e., both filter and ion exchange loops (either dedicated DWCS ion exchange loops or SDS ion exchange loops). Additional valving would be closed if only a portion of the DWCS were operating. For the purpose of estimating the dilution probability, this analysis assumed the DWCS was operating at maximum capacity; thus, the largest number of potential dilution pathways was considered.

5) The SPC Charging Water Storage Tank (SPC-T-4) is assumed to contain RCS grade (5050 ppmB) water at all times when the DWCS is operating. SPC-T-4 is equipped with level sensors which continuously indicate the water level and actuate an alarm when the level reaches 37% (~ 1600 gallons) of capacity.

E.3 CALCULATIONS

Operation of the Defueling Water Cleanup System introduces additional potential dilution pathways which were not present during the static, level-control mode of plant operation. The new pathways into the Reactor Vessel are through the Internals Indexing Fixture (IIF) which rests on the top of the Reactor Vessel. Six separate lines, i.e., two suction lines and four return lines, enter the IIF via the work platform.

Section E.3.1 describes the prevention of boron dilution by the isolation of the process stream. Two methods of DWCS processing are considered. One method uses dedicated DWCS components; the second method uses DWCS filtration in conjunction with SDS ion exchange. Section E.3.2 discusses the capability to detect and mitigate a dilution event during DWCS operation.

E.3.1 Dilution Prevention

This section describes the prevention of boron dilution; prevention is achieved by use of barriers which isolate the DWCS process stream from other fluid sources. Two modes of DWCS operation are considered: one using only dedicated DWCS components, the other using the DWCS in conjunction with the SDS system.

E.3.1.1 Reactor Vessel Cleanup using Dedicated DWCS Components

Processing of RCS water using dedicated DWCS components is shown schematically in Figure E-1. Several potential points at which unborated water could be introduced into the processing stream were identified, e.g., flush lines, reactor coolant bleed tank feed lines, and sampling lines. Double barrier isolation of the process stream has been identified for each of these interface points.

The potential points of introduction of unborated water and their associated isolation barriers are provided in Table E.1. Barriers to dilution through these points have been chosen in Table E.1 based on reliability considerations such as diversity of design and operational requirements such as accessibility for position verification. However, other isolation barriers which have comparable reliability could be substituted. As noted in Table E.1, there are 19 barrier configurations required to isolate the RV processing loop; these configurations are formed with a total of 21 manual valves and 4 air operated valves. The isolation valves identified in Table E.1 are summarized in alpha-numeric order in Table E.3 of Section E.4, "Conclusion and Recommendations".

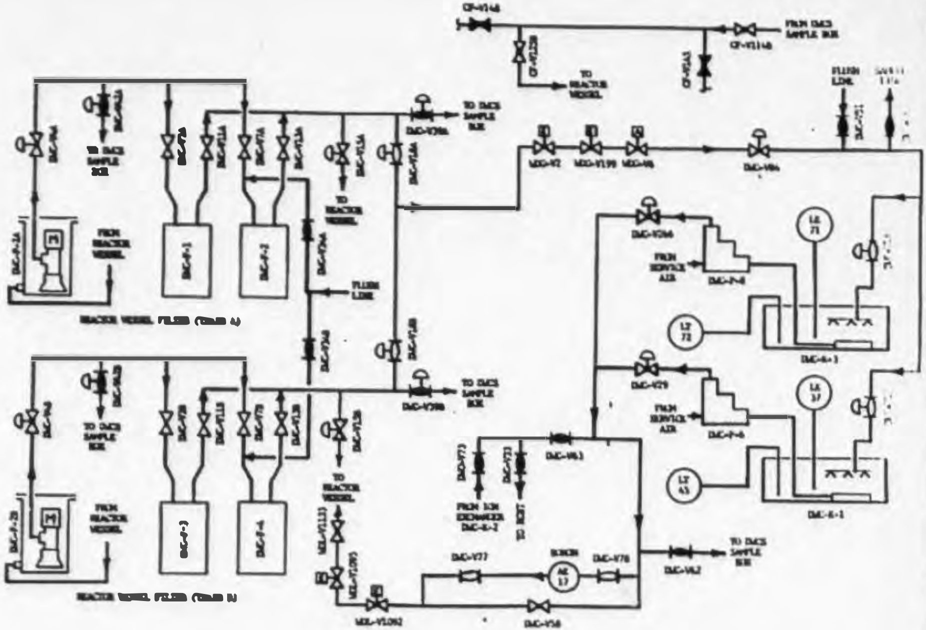

FIGURE E-1 SIMPLIFIED SCHEMATIC OF RV PROCESSING USING DEDICATED DACS COMPONENTS

To estimate the probability of dilution of the processing loop, the following assumptions were made in addition to the assumptions identified in Sections 4.3 and E.2:

(i) The filter loop of the DWC System is assumed to be operating continuously except during filter change over and during system modification or repairs.

(ii) It was assumed that flow will be circulated continually through one ion exchanger. When the ion exchangers (K1, K3) are being utilized, a boronometer (AE-17) which will monitor the boron concentration of the water leaving the ion exchangers may be in service.

(iii) The borated water flush lines are used only during filter/ion exchanger change over or system maintenance to reduce excessive radiation levels.

(iv) Operationally, a third valve must be closed on the sample lines to avoid an erroneous sample. In calculating the dilution probability through these paths credit was given for this barrier. It was not required, however, that its position be verified on a daily basis.

The probability of boron dilution due to the operation of the DMCS was estimated as 2.0×10^{-4} per year; this probability is almost entirely due to the "leak" type of dilution as defined in the main report. The "rupture" dilution event probability was estimated to be 7.3×10^{-8} per year.

TABLE E.[illegible]

DHCS PROCESSING - REACTOR VESSEL

POTENTIAL UNBORATED LIQUID SOURCES	ISOLATION BARRIERS
Reactor Coolant Bleed Tanks (WDL-T-1A, T-1B, T-1C)	DHC-V063 DHC-V033, V073
Borated Water Flush, RV Filters (DHC-F-1, F-2, F-3, F-4)	DHC-V034A, V034B DH-V187
Borated Water Flush, DHC Ion Exchangers (DHC-K-1, K-3)	DHC-V051 DHC-V106, V313, V314 V321, V322, V323
Sample Line, RV Filters (DHC-F-1, F-2, F-3, F-4)	DHC-V041A DHC-V039A, V039B (DHC-V170)*
Sample Line, DHC Pumps (DHC-P-2A, 2B)	DHC-V041B DHC-V042A, V042B (DHC-V165)*
Sample Line, DHC Ion Exchangers Discharge (DHC-K-1, K-3)	DHC-V062 DHC-V180 (DHC-V178, V179)*
Sample Line, DHC Ion Exchanger Feed (DHC-K-1, K-3)	DHC-V065 DHC-V175 (DHC-V173, V174)*
Sample Return Line	CF-V128B CF-V114B

* Valves which are not on 24 hour checklist but are normally closed.

0714x RA

For "early defueling" the Submerged Demineralizer System (SDS) may be utilized in lieu of the DWCS ion exchange loop in accordance with Operating Procedure 4215-OPS-3525.04. A slip stream (≤ 30 gpm) is to be taken from the RV filtration loop and processed through the SDS in a manner similar to IIF processing (see Appendix D). The SDS effluent then flows into the basement of the Auxiliary Building to reactor coolant bleed tank WDL-T-1A(C). A simplified schematic of RV cleanup using this process is shown as Figure E-2. To compensate for the removal of borated water from the reactor vessel, reactor grade water is fed from another bleed tank (e.g., either WDL-T-1C (A)) through WDL-V40 and one of the makeup "16" valves (typically MU-V-16B) to maintain a constant level in the reactor vessel.

The makeup path to the RV is the same as that used in IIF processing; thus, the isolation barrier configurations shown in Table D.2 are still appropriate. The letdown side of the IIF Processing connections have been modified for use of SDS with the DWCS. This modification requires new isolation barrier configurations as shown in Table E.2. The isolation valves identified in Tables D.2 and E.2 are summarized alpha-numerically in Table E.4 of Section E.4, "Conclusions and Recommendations".

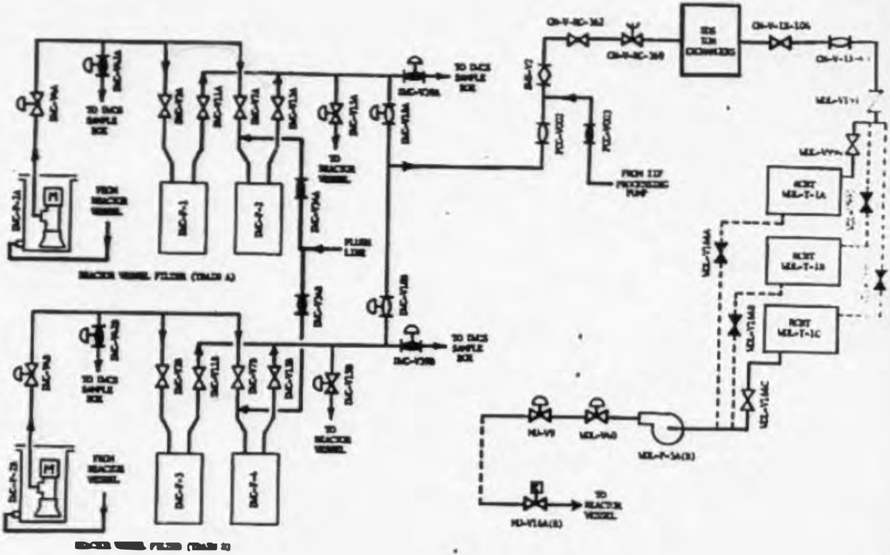

FIGURE E-2 SIMPLIFIED SCHEMATIC OF RV PROCESSING USING DMCS AND SDS COMPONENTS

The total number and type of isolation valves and barrier configurations are largely the same as with IIF processing; only the valve designation numbers change. (Note: Some minor operational changes have been made. For example, FCC-V002 will be open during normal processing while FCC-V003 is closed. Valves SF-V125 and V214 must be closed to give double valve isolation from the Spent Fuel Cooling system and from the modifications being made to support the FTC/SFP cleanup portion of the DWCS system. A new valve, CN-V-IX-63, has been added. This valve must remain open to allow SDS effluent to flow to the WDL-T-1A, 1B and 1C bleed tanks; its failure does not influence the boron dilution probability.) Therefore, the estimate for the dilution probability using the early defueling processing scheme is based on the value calculated in Appendix D for IIF processing and the additional modifications for DWCS operations. The probability of "leak" and "rupture" dilution events are 5.2×10^{-3} yr^{-1} and 5×10^{-4} yr^{-1}, respectively.

E.3.1.3 Fuel Transfer Canal/Spent Fuel Pool (FTC/SFP) Cleanup System

The FTC/SFP Cleanup System is expected to be operating continuously except during filter change, resin change or system modification/repair. Sampling for boron concentration will be performed weekly on both the filter loop and ion exchange loop. Dilution of the fuel transfer canal or the spent fuel pool is not a nuclear safety concern in itself, based on the results of criticality

TABLE E.2

EARLY DEFUELING ION EXCHANGE PROCESSING - LETDOWN

ACTION	POTENTIAL PATH FOR UNBORATED LIQUID	COMPENSATION
Open FCC-V002	From canal drain pump (1 1/2" hose)	FCC-V003 and disconnect IIF processing pump
	From sump sucker (1" hose)	FCC-V001 and disconnect pump
Open SWS-V1	From Service Water System drain (3/4")	SWS-V6 -- SWS-V7
Open SWS-V2	Flush Conn. (3/4")	SWS-V4 and flush line connection. Administratively controlled by 24 hour checklist
CN-V-RC-364	WG-P-1 discharge	CN-V-RC-363 -- WG-V21
	Pre-Filter Inlet	CN-V-RC-363 -- CN-V-FL-1
	DWC Booster pump	CN-V-RC-363 -- DWC-V236
Open CN-V-RC-382	Return line from Monitor Tanks (SDS-T-1A, -1B)	CN-V-RC-380 -- SDS-V052
	Off-gas line (Bottoms pump)	CN-V-RC-380 -- CN-V-VA-245
	RCS Clean-up manifold sump	Not a credible source
	High-Rad filter manifold sump	Not a credible source
Open CN-V-RC-366	Final filter discharge	CN-V-RC-367 -- CN-V-FL-6
	Sample box	CN-V-RC-367 -- CN-V-SA-258
	WG-P-1 pump discharge	CN-V-RC-367 -- WG-V29
	Manifold connection	CN-V-RC-367 -- CN-V-RC-374
CN-V-RC-369	Flush conn.	CN-V-IX-61 -- Hose connection
	Hi-Rad sample glove box	Not a credible source

ACTION	POTENTIAL PATH FOR UNBORATED LIQUID	COMPENSATION
CN-V-IX-25(26)	Flush conn.	CN-V-IX-34 -- Hose connection CN-V-IX-36 -- Hose connection
CN-V-IX-29(31)	Flush conn.	CN-V-IX-38 -- Hose connection CN-V-IX-40 -- Hose connection
CN-V-IX-30(32)	Tie-in to HOH	Tie-in not made
	DWCS Return to FTC/SFP	CN-V-IX-58 -- DWC-V102
	DWC-K1, 2, 3 Return	DWC-V33 -- DWC-V63 DWC-V33 -- DWC-V73
	Flush connection	CN-V-PF-72 -- CN-V-PF-71
	Monitor tank (SDS-T-1A, B)	CN-V-PF-62 -- CN-V-PF-68
	Flush conn. for sampling	CN-V-SA-294 -- CN-V-PM-196
	MWHT and Redwaste System	CN-V-IX-102 -- CN-V-IX-103
	SDS Post Filter	CN-V-PF-70 -- CN-V-PF-72
CN-V-IX-63	Core Flood Tank Bleed and Sample	CF-V107 -- CF-V144
	MWHT	WDL-V1091 -- WDL-V533
	RC Drain Header	WDL-V1125 -- WDL-V22
	MU-K-1A, B	WDL-V46 -- MU-V107A WDL-V46 -- MU-V107B WDL-V46 -- MU-V224A WDL-V46 -- MU-V224B WDL-V46 -- MU-V226 WDL-V46 -- MU-V376
	WDL-K-1A, B	WDL-V46 -- WDL-V81A WDL-V46 -- WDL-V81B WDL-V1060 -- WDL-V81A WDL-V1060 -- WDL-V81B

ACTION	POTENTIAL PATH FOR UNBORATED LIQUID	COMPENSATION
CN-V-IX-63 (continued)	Makeup Tank Drain	MU-V169 -- MU-V12 MU-V169 -- MU-V13 MU-V169 -- MU-V27 MU-V169 -- MU-V28 MU-V169 -- MU-V133
	Spent Fuel System	SF-V214 -- SF-V121A SF-V214 -- SF-V121B SF-V214 -- SF-V122 SF-V214 -- SF-V125 SF-V214 -- SF-V240
WDL-V964 (-V963)	Isolate Letdown tank from Makeup line/tank	WDL-V166A(C) -- WDL-V28A(C) WDL-V165A(C) -- WDL-V29A(C) WDL-V166A(C) -- WDL-V533
	Isolate WDL-T-1B from Makeup line	WDL-V166B -- WDL-V28B WDL-V166B -- WDL-V29B
	Isolate WDL-T-1B from letdown line	WDL-V995 --WDL-V965

analyses for fuel canisters submerged in unborated water. Thus, operation of the FTC/SFP Cleanup System is a concern only to the extent that it could be associated with dilution of the RCS. There are two methods by which this could occur; one occurs if the FTC/SFP acts as a source of underborated water, the second is associated with the dilution of the FTC/SFP Cleanup System process stream.

The possibility that the FTC/SFP would act as an RCS dilution source during DWCS processing is not considered credible. The bases for this conclusion are:

(i) The combined volume of the FTC and spent fuel pool A during defueling operations will be about 290,000 gallons: this volume of water will be borated to at least 4350 ppm. A large amount of water would be required to dilute the FTC/SFP to a concentration which would represent a meaningful RCS dilution source (e.g., dilution of the FTC/SFP to 4000 ppm would require the addition of over 25,000 gallons of unborated water).

(ii) Level in the fuel transfer canal and fuel pool A is checked each shift and

(iii) In the event that the FTC or SFP were diluted, or other water were introduced (e.g., into the shallow end of the FTC), additional component failures (e.g., a suction hose break, failure of the double isolation between the RV and FTC cleanup systems) must occur to dilute the RV.

The other mechanism which could introduce diluted water to the RCS is through the FTC/SFP Cleanup System piping. The concern is the possibility that unborated fluid could enter the FTC/SFP Cleanup System piping, be diverted into the RV Cleanup System piping and flow into the reactor vessel. This was judged not to be a credible scenario for diluting the RCS based on the following considerations:

(i) Double barrier isolation exists between the RV process loop and the FTC/SFP process loop. These isolation barriers will be placed under administrative control and verified to be correctly positioned on a daily basis.

(ii) Mixing would occur between the 200 to 400 gpm process flow and the dilution inflow into the FTC/SFP loop; this mixing would minimize the dilution rate seen by the RCS.

(iii) Although valving which isolates the FTC/SFP from other pathways is not under administrative controls, such valving must be in place to conduct the operation. Thus, additional barriers besides those used to separate the RV and FTC/SFP cleanup loops are typically in place and

(iv) A dilution into the RCS from the FTC/SFP interface would be detected by boron sampling or as a level increase by RV level instrumentation.

No credible Reactor Vessel dilution scenario associated with the FTC/SFP has been identified. The FTC and SFP need not be isolated from a dilution given the criticality analysis of canisters in unborated water. The valves required to isolate the FTC/SFP cleanup loop from the RV cleanup loop were included in the overall isolation scheme for the RV cleanup loop (see Table E.3). Thus, no further actions are needed to prevent dilution of the fuel transfer canal or spent fuel pool A.

E.3.2 Detection and Mitigation of a Potential Dilution Event

As discussed in Section 4.4.5.3, there are several methods to detect a dilution event; mitigation requires termination of the dilution event prior to dilution of the RCS to 4350 ppmB. An analysis has been performed to determine which controls that are available for detecting a dilution in the static condition are applicable during DWCS operation. Operation of the DWCS in each of the two modes was considered. Operation with dedicated DWCS components was considered in Section E.3.2.1; modified DWCS operation which uses a slipstream through SDS while making up from a reactor coolant bleed tank is described in Section E.3.2.2.

E.3.2.1 Detection of a Potential Dilution Event During Operation of Using Dedicated DWCS Components

Normal operation of the DWCS results in circulation of RCS water from the RV through a closed loop and return into the RV. There are no significant holdup points nor is flow balancing between different feed and bleed sources required. Thus, DWCS operations represents an essentially steady state operation and level instrumentation provides an effective means for detecting a boron dilution event.

There is redundant and diverse level indication available during DHCS operation. Level instrument RC-LI-100A uses taps from the Decay Heat Removal System drop line off of the steam generator "B" hot leg and is read in the control room. Level instruments RC-LT-102 and RC-LIS-103 are bubbler type instruments supplied by the same sensing tube which uses taps in the IIF. Level instrument RC-LT-102 provides level indication locally and in the control room; RC-LIS-103 is interlocked with DHCS operation. Instrument RC-LIS-103 will alarm and trip the DHCS pumps at a low level reading of 63 inches (el 327'3") and will alarm at a high level of 69 inches (el 327'9"); the alarms are annunciated both locally and in the control room. The RCS level is checked hourly and recorded on the "Station Daily Log Sheet". As a backup to the Control Room indication and the DHCS local panel indication, the RCS level can be read on a Barton meter, RC-LI-101A, located at the 282' elevation of the Fuel Handling Building or on a tygon tube located outside the D-ring in the Reactor Building. Since normal operation of the DHCS is a closed system, a level alarm will occur only due to the unplanned addition or loss of water due to an abnormal condition, such as a dilution event. (No feed and bleed type of processing will be performed except to make adjustments in boron concentration or to makeup inventory lost by evaporation or defueling operations.)

Since the ability to detect a dilution event through level monitoring will be unaffected by DHCS operation, the weekly Technical Specification sample is used to benchmark the boron concentration once each seven days. Although no additional sampling would be required for normal operation, it is noted that a daily boron sample will be taken while operating the DHCS filter loop and once every twelve hours while operating the ion exchange loop.

The probability of failure to detect a dilution event is estimated as 1×10^{-1} per demand. The bases for this estimate were provided in the bounding analysis for failure to detect a dilution during static conditions (see Section 4.4.5.3). The major aspects of DHCS operation which justify use of the bounding estimate are:

i) Processing with only dedicated DHCS components results in a simple recirculation of RCS water; there is no inherent characteristic which would mask a dilution inflow (e.g., different feed and bleed sources, automatic level controller).

ii) There is redundant and diverse level instrumentation which is read in the control room; backup instrumentation which can be read locally is also available and

(iii) The potential dilution rate into the process stream does not exceed the rate identified for other process conditions. The magnitude of this dilution rate is a function of the dilution source (e.g., size limitations, pumping capabilities) and not of the rate at which RCS water is circulated.

The probability of mitigating a dilution event was estimated as 2 x 10^{-3} per demand for a "leak" (≤ 15 gpm) type dilution, based on the analyses performed in Section 4.4.5.3. (The probability of a "rupture" event occurring was estimated as so low as not to require specific mitigating actions. However, consistent with Section 4.4.5.3, the probability of operator failure to mitigate such an event was assumed to be 0.1 per demand). The relevant aspects of this estimate are the time allowed for the required operator action and the type of required actions. Because the potential dilution rate is comparable to that previously considered for the static case, the time allowed for action prior to reaching 4350 ppm is also comparable to the static condition. The required action would be to terminate DHCS operation and take additional actions to identify the dilution source and isolate the RCS. Termination of DHCS flow into the RV due to low boron concentration has been proceduralized (see operating procedure 4215-OPS-3525.02) and is accomplished by an operator stationed at the local control panel; additional operator actions have been proceduralized in appropriate emergency procedures (e.g., emergency procedure 4210-EAP-1300.01).

Combining the detection failure and mitigation failure probabilities yields a probability of failure to detect and mitigate a dilution event of 3×10^{-3} per demand for "leak" type dilutions (0.1 per demand for "rupture" dilution rates). Combining this probability with the dilution probability as determined in Section E.3.1.1 yields a total probability of diluting the RCS to 4350 ppm of 1.3×10^{-8} per year. Thus, the probability of RCS dilution during operation of the dedicated DWCS RV Cleanup System is considered negligible.

The analysis in this section took credit only for the available level instrumentation. It should be noted that a continuous boron sampling capability may be available by either a boronometer situated in the Temporary Nuclear Sampling System (TNSS), or a boronometer planned to be installed in the ion exchange portion of the RV cleanup system. The reliability of these boronometers has not been estimated. However, given adequate startup testing and calibration against grab samples, it is expected that a boronometer will provide an additional effective detection capability which is comparable to manual boron sampling (see Section E.3.2.2). Thus, a boronometer may substitute for an extended outage of level instrumentation.

E.3.2.2 Detection of a Potential Boron Dilution Event During DWCS Operation in Conjunction with SDS

Early in the defueling process, the ion exchange loop of the DWCS may not be available for Reactor Vessel processing. For this reason, an alternate processing method has been developed. This method takes a slipstream from the filter train of the DWCS, processes it through SDS, and returns it to a bleed tank; simultaneous makeup to the RV is from another bleed tank through the HPI lines. This operation is nearly identical to the IIF processing capability described in Appendix D. Major characteristics of the process are:

1) Reactor Coolant System water is being recirculated through particulate filters at a flow rate of 200/400 gpm; flow to the ion exchange loop will be drawn from the filtration loop at a rate of ≤ 30 gpm, instead of directly from the RV.

2) The capability for automatic level control in the IIF exists using makeup from the reactor coolant bleed tanks (SDS effluent is returned to the bleed tanks). Thus, there is the possibility of masking a dilution inflow in a manner similar to IIF operation; an

undetected dilution at a rate comparable to the rate at which water is removed by the ion exchange loop could occur. (This potential masking effect could also occur as an operator manually balances feed and bleed from the different bleed tanks.)

3) No unique dilution sources or driving forces were identified for this mode of operation. Thus, the potential dilution rates are the same as those analyzed in the main report.

One option to compensate for the potential inability to detect a 15 gpm unborated injection rate with level instrumentation is to institute a boron sampling program. Such a sampling program could be accomplished by taking manual samples with sufficient frequency to detect a dilution before the vessel reaches the Technical Specification limit of 4350 ppm. The frequency of the sampling program would vary according to the process flow rate, which determines the maximum inflow that could be hidden from the level indication. The following table provides sampling frequencies as a function of process flow rate. The assumptions used in developing the table are the same as those used in Appendix Section D.3.3.

Process Flow Rate (gpm)	Dilution Volume (gallons)	Sampling Frequency (hrs)
5	5370	12
6.5	5370	8
10	5370	3
12	5370	2
15	5370	1

The estimated probabilities of failure to detect and mitigate a dilution event were based on the analyses performed in Section 4.5.3. The probability of an erroneous grab sample was estimated as 0.01; the probability of operator error in responding to a "leak" type of dilution was estimated as 2×10^{-3}. Combining these probabilities yields an estimate of 1.2×10^{-6} per demand for failure to detect and mitigate a leak type dilution. In the rupture case, a higher operator error rate of 0.1 was assigned due to the shorter time for operator action; this results in a probability of failure to detect and mitigate of 1.02×10^{-3} per demand. Combining the leak and rupture probabilities with the detection and mitigation probabilities yields a total probability of RCS dilution to 4350 ppm during DWCS processing with SDS ion exchange; this probability estimate is 1.1 × 10[illegible] per year.

Boron sampling could also be accomplished with an on-line boronometer. Such an instrument is currently installed in the discharge of the RV sample pump in the INS system. This boronometer analyzes a sample drawn from the core region or the annulus between the inner vessel wall and the thermal shield. It provides a local readout of boron concentration and a control room alarm if the boron concentration drops below 4950 ppm. Either the INSS boronometer or the regular sampling program provides the capability to detect a boron dilution in the absence of level indication. No specific reliability data was available for INSS boronometer. The failure mode of concern with the boronometer is one in which the boronometer indicates an acceptable sample result but in fact a dilution is occurring; this failure must also be non-detectable normally (or else a manual sampling program would have been instituted to compensate for the failure). It is judged that the boronometer, once checked and calibrated, would have at least a reliability comparable to that used for the manual sampling.

Another means to detect a dilution is to conduct an hourly mass balance to monitor changes in the inventory of the RCS and bleed tanks. The precision of the existing instrumentation on the RV and the bleed tanks results in the ability to determine volume changes to within 300 gallons. No estimate of the reliability of this detection method was made given the reliability of the boron sampling methods.

E.4 CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the conclusions and recommendations of the analysis of the DHCS boron dilution potential. The conclusions noted herein are contingent upon the assumptions used in the analysis and implementation of the specified recommendations.

E.4.1 Conclusions

(1) The probability of RV dilution to 4350 ppm during DHCS processing using only dedicated DHCS components was estimated as 1.3×10^{-5} per year, which can be considered negligible. Thus, operation of the DHCS with dedicated components presents a minimal and acceptable risk.

(2) The probability of RV dilution to 4350 ppm during DHCS processing using the SDS for ion exchange was estimated as 1.1×10^{-6} per year which can be considered negligible. Thus, operation of the DHCS in conjunction with the SDS presents a minimal and acceptable risk.

(3) Dilution of the reactor vessel due to a dilution associated with the FTC/SFP Cleanup System was not considered credible.

(4) Level instrumentation provides adequate detection capability during operation of the DHCS with dedicated components. Either an on-line boronometer or a manual sampling program provides adequate detection capability during DHCS operation in conjunction with the SDS.

E.4.2 Recommendations

(1) The isolation barriers identified in Table E.3 should be placed on a 24 hour checklist to verify proper positioning during operation of the dedicated component DHCS. (Operational difficulties or ALARA concerns may preclude the use of the recommended barriers; in such instances, an equivalent barrier may be used).

(2) When the dedicated component DHCS system is shutdown, the RV must be isolated from the associated DHCS connections. This can be accomplished by continued use of the isolation list provided in Table E.3 during shutdown. If the position of the valves in Table E.3 will not be verified when the DHCS is shutdown, alternative isolation barriers must be placed on the 24 hour checklist in Section 7.3 of operating procedure 4210-OPS-3200.02. An alternative isolation list is provided at the end of Recommendation a.

(3) The isolation barriers identified in Table E.4 should be placed on a 24 hour checklist to verify proper positioning during operation of the DWCS in conjunction with the SDS. (Substitute barriers may be used if operational difficulties or ALARA concerns preclude the use of the recommended barrier).

(4) When the DWCS system is used in conjunction with the SDS system, isolation from flow paths associated with this operational mode must be in place during shutdown. This can be accomplished by continued use of the isolation checklist provided in Table E.4 during shutdown. Alternatively, the alternate shutdown list identified below must be placed in procedure 4210-OPS-3200.02.

Alternative Shutdown List

(Equivalent valves may be used if operational considerations or ALARA concerns preclude use of the recommended valves)

Pathway Isolated	Double Valve Isolation
'A' Filter Train Suction	DWC-V284A, DWC-V4A
'B' Filter Train Suction	DWC-284B, DWC-V4B
'A' Filter Train Discharge	DWC-285A, DWC-16A
'B' Filter Train Discharge	DWC-285B, DWC-16B
Sample Return Line	DWC-V286, CF-V125B
RV Ion Exchange Discharge	DWC-V287, WDL-V109S

(5) During DWCS processing with dedicated DWCS components, level instrumentation should be utilized as the primary method of detecting a boron dilution event. During DWCS operation in conjunction with the SDS, a boron sampling program should be utilized as the primary method of detecting a dilution: either an on-line boronometer or the manual sampling program outlined in Section E.3.2.2 would serve this purpose.

TABLE E.3

BARRIER LIST USING ONLY DEDICATED DWCS SYSTEM

Processing with dedicated DWCS components is accomplished per operating procedure 4215-OPS-3525.01. The valves specified in this table provide isolation of the DWCS flow path. Thus, it is recommended that the valves in this table be placed on a 24 hour checklist for position verification. The checklist may be placed in procedure 4215-OPS-3525.01 or in Section 7.3 of procedure 4210-OPS-3200.02, "Primary Plant Operating Procedure."

CF-V114B	DWC-V062
CF-V128B	DWC-V063
DW-V187	DWC-V065
DWC-V033	DWC-V073
DWC-V034A	DWC-V106
DWC-V034B	DWC-V175
DWC-V039A	DWC-V183
DWC-V039B	DWC-V313
DWC-V041A	DWC-V314
DWC-V041B	DWC-V321
DWC-V042A	DWC-V322
DWC-V042B	DWC-V323
DWC-V051	

TABLE E.4

BARRIER LIST FOR EARLY DEFUELING PROCESSING THROUGH SDS

Early defueling processing is accomplished utilizing SDS in accordance with Operating Procedure 4215-OPS-3525.04. Procedure 4215-OPS-3525.04 is structured such that all valves required for isolation during any maneuver are placed on checklists for periodic verification. Thus, the following valves are recommended to be placed on a checklist in addition to those in Table 4.4-3 of this report. The valves listed here isolate the DWCS filtration loop and the flow path through SDS. (It should be noted that if only the DWCS filtration loop were operated, isolation of the SDS system from the filter loop could be achieved with only the closure of FCC-V002 and the removal of the associated hose. However, it is expected that this will not be a frequent occurrence. Thus, this option was not explicitly presented in this Appendix.)

CA-V133A *	CN-V-SA-_98	SWS-V4	WDL-V190A *
CA-V133B *	CN-V-VA-245	SWS-V6	WDL-V190B *
CA-V135 *	DW-V187	SWS-V7	WDL-V206A *
CA-V154 *	DW-V84 *	WDL-V18A *	WDL-V206B *
CA-P-1 * OFF	DW-V92 *	WDL-V18C *	WDL-V532A *
CA-P-2 * OFF	DW-V223 *	WDL-V28A *	WDL-V532B *
CF-V128B	DWC-V33	WDL-V28C *	WDL-V533 *
CF-V144	DWC-V34A	WDL-V29A *	WDL-V544A *
CN-V-IX-34	DWC-V34B	WDL-V29C *	WDL-V544B *
CN-V-IX-36	DWC-V39A	WDL-V41 *	WDL-V959 *
CN-V-IX-38	DWC-V39B	WDL-V42 *	WDL-V963 *
CN-V-IX-40	DWC-V41A	WDL-V46 *	WDL-V964 *
CN-V-IX-58	DWC-V41B	WDL-V65B *	WDL-V965
CN-V-IX-61	DWC-V42A	WDL-V70A *	WDL-V995
CN-V-IX-102	DWC-V42B	WDL-V70B *	WDL-V1060
CN-V-IX-103	DWC-V63	WDL-V72A *	WDL-V1092 *
CN-V-FL-1	DWC-V73	WDL-V72B *	WDL-V1095
CN-V-FL-6	DWC-V102	WDL-V109A *	WDL-V1153A *
CN-V-PF-62	DWC-V236	WDL-V109B *	WDL-V1153C *
CN-V-PF-68	FCC-V001	WDL-V109C *	WDL-V1170 *
CN-V-PF-69	FCC-V003	WDL-V109D *	WDL-U301 Removed
CN-V-PF-70	(Pumps Disconnected)	WDL-V117 *	WG-V04
CN-V-PF-71	SF-V121A	WDL-V138 *	WG-V05 *
CN-V-PF-72	SF-V121B	WDL-V161A *	WG-V24 *
CN-V-PW-196	SF-V125	WDL-V163B *	WG-V29 *
CN-V-RC-360	SF-V240	WDL-V166A	WG-V30 *
CN-V-RC-363	SDS-V052	WDL-V166B *	WG-V71 *
CN-V-RC-367	SWS-V1 *	WDL-V166C *	WG-V95 **
CN-V-RC-374	SWS-V97 *	WDL-V175 *	
CN-V-SA-258	SWS-V139 *	WDL-V176 *	

* Valve already included in 4210-OPS-3200.02 checklist.

** Valve removed and pipe capped.