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INDIAN POINT 3
LOW PRESSURE INJECTION SYSTEM

A. SUMMARY

A.1 INTRODUCTION

The low pressure injection system (LPIS) is evaluated in the context of a large or medium loss of coolant accident (LOCA). The purpose of the system is to inject water into the core replacing coolant lost from the primary system with water from the refueling water storage tank (RWST). The recirculation phase, which utilizes portions of the system, is analyzed separately.

The analysis is carried out under the following conditions:

- RWST is available.
- The safeguards actuation signal (SIS) is present.
- Success of the system is defined as injection of water into at least two cold legs.

A.2 RESULTS

Tables 1A and 1B summarize the results for the four cases of electric power unavailability considered (combinations of buses 3A and 6A) and lists the WASH-1400 results.

The analysis has revealed the following dominant contributors to LPIS unavailability:

	Mean
With Electric Power Available (Bus 3A and 6A)	2.41×10^{-4}
• Single Element Failures	2.37×10^{-4} (98.3%)
- Check Valve 741	6.91×10^{-5} (28.7%)
- Check Valve 881	6.91×10^{-5} (28.7%)
- MOV 744	3.29×10^{-5} (13.6%)
- MOV 882	3.29×10^{-5} (13.6%)
- Manual Valve 846	3.29×10^{-5} (13.6%)
• Double Failures	5.57×10^{-6} (2.3%)
- Both RHR pumps 31 and 32	3.29×10^{-6} (1.4%)
- Pump maintenance and hardware failure	2.28×10^{-6} (0.9%)

The overall LPIS system unavailability is found to be 2.41×10^{-4} during normal power availability. Under degraded power conditions (loss of one bus), the overall LPIS system unavailability is 2.36×10^{-3} and the dominant contributors are shown below:

	Mean
Degraded Electric Power (Bus 3A or 6A Unavailable)	2.36×10^{-3}
• Pump fails to start on demand	1.36×10^{-3} (57.6%)
• Maintenance	7.36×10^{-4} (32.3%)
• Single failures (hardware)	2.37×10^{-4} (10.0%)

A.3 CONCLUSION

The LPIS unava lability has been calculated assuming different states of electric power In all cases, single failures played a dominant role. With human errc not found a factor in this analysis, hardware failures and maintenance were found to be the largest contributors to system unavailability Particularly, with one bus unavailable, hardware failures dominated.

B. SYSTEM DESCRIPTION

B.1 SYSTEM FUNCTION

For a large LOCA, the LPIS provides initial cooling of the core and replaces coolant lost from the primary system with water from the refueling water storage tank (RWST).

B.2 SYSTEM CONFIGURATION

A block diagram and a simplified P&ID for the system are shown in Figures 1 and 2. Success of at least one of the two RHR pump trains will provide sufficient flow to keep the core covered after a large LOCA given that two of the three intact legs (excluding the broken leg) deliver flow to the core.

B.3 SYSTEM OPERATION

The pumps of this subsystem are activated by the safety injection signal and deliver 3,000 gpm each to the reactor coolant system (RCS) by way of the residual heat removal (RHR) heat exchangers when the primary system pressure is approximately 150 psig. The function of this portion of the safety injection system is to deliver, upon rapid depressurization and loss of coolant, large quantities of water to aid in rapidly recovering the core.

The RHR pumps draw water from the RWST and discharge to the No. 31 and 32 RHR heat exchangers' tube side. The heat exchanger performs no heat transfer function during active injection, but rather serves for the recirculation phase. The heat exchangers' discharge is then directed to the four RCS cold legs by way of the accumulator connection lines.

When a safety injection signal is generated, the following events will occur. If outside power or three diesels are available, both pumps start; if only two diesels are functioning, a minimum of one pump will be started. The pumps will draw water via normally open valve 882 from the RWST and discharge through normally open valve 744. (The control power for valves 744 and 882 is normally deenergized.) When either valve closes, the "Safeguards Valve Off Normal Position" and the DC monitor alarms annunciate. The flow is then to the RHR heat exchangers. Component cooling is supplied to the RHR heat exchangers, but because of the relative low temperature of the coolant from the RWST, no actual cooling is performed by the component cooling at this time. HCVs 638 and 640 are normally open and annunciate the "Safeguards Valve Off Normal Position" alarm if either moves off of the open position.

The heat exchanger outlets join into a header and then branch off to feed the accumulator discharge lines which feed the four cold legs. Flow indication is provided on the lines' feeding loops to give the operator indication of the system status.

B.4 SUPPORT SYSTEMS

The system is started by a signal from the safeguards actuation system (SAS), which starts the RHR pumps. Manual actuation from the control room is also possible. Electric power is necessary for success of the system. Table 2 shows the power supplies to the various components of the LPIS. Pump cooling is not critical due to the relatively short time involved (about 30 minutes) and the low temperature of the water of the RWST.

B.5 TEST REQUIREMENTS

The RHR pumps are started manually from the control room monthly (test 3PT-M18). Table 3 shows the components of the system that are tested along with components tested quarterly (test 3PT-Q22) and during cold shutdown (test 3PT-V9).

The monthly test provides verification that 6 manual valves remain open, 15 motor-operated valves remain in normal positions, and 4 check valves open on demand. The heat exchangers are also shown to pass flow. No valves are stroked during this test and the system remains in its normal configuration; therefore, system operation should not be degraded during the test. All locked open valves, and valves 749 and 882 are physically verified open weekly.

The quarterly test strokes eight MOVs and two air-operated valves while the system remains in normal configuration during the test.

During and at cold shutdown, 8 MOVs are tested to note holding required position, 12 check valves are tested to note opening on demand and reseating correctly.

B.6 MAINTENANCE REQUIREMENTS

Maintenance is performed as required. If a pump is found failed, it is isolated from the system for a period up to 24 hours during which the pump is repaired. If repair is not complete during this period, the reactor is shut down. When one pump train is out of service, the other train is tested daily.

A spare pump and associated spare parts are maintained in inventory to accommodate expeditious exchange or repair when an installed pump is found to be inoperable.

C. LOGIC MODEL

C.1 TOP EVENTS

The LPIS fault tree is developed for the event "Insufficient Flow from LPIS." This event appears in the large and medium LOCA event trees and must be preceded by a successful accumulator system operation which is required to initiate recovery of the core.

C.2 SYSTEM FAULT TREE

Fault tree methodology is used to analyze the LPIS. The top structure of the tree shows explicitly the parts of the system that are disabled during maintenance (or testing, if applicable). Figure 3 shows the first level of the tree. The INHIBIT gates specify the conditions under which the tree is developed further. The fault trees for the transfers X, Y, and Z are shown in Figure 4. Special attention should be paid to the maintenance trees because the configuration of the system changes and the position of valves may change also. The X, Y, and Z are carried through the trees to the train gate level where the train is eliminated for the Y and Z cases.

The fault tree contains only hardware failures. For each component we list the failure mode (e.g., fails open, closed, does not start, etc.) and failures to supply energy or the signals to actuate. The failure causes are not listed. The fault tree is complete in the sense that the minimal cutsets of the tree are equivalent to the top event.

C.3 FAULT TREE CODING

Table 4 is a list of basic events, their failure modes, corresponding codes, and mean values.

C.4 MINIMAL CUTSETS

The minimal cutsets are identified using the blocks from Figure 1. The five valves in single flow lines that exist in the LPIS represent five single-event minimal cutsets. In addition, the SI signal to start can be considered a single-event cutset if operator action is not included.

- Check valve 741 fails to open.
- Motor-operated valve 744 fails closed.
- Check valve 881 fails to open.
- Motor-operated valve 882 fails closed.
- Manual valve 846 fails closed.
- Single pipe failure (see Table 5).

The motor-operated valves are deenergized open such that the "Failing Closed Mode" would be similar to a manual valve failing closed (i.e., the gate drops into the flowpath).

Tables 6 and 7 show the additional single event cutsets for the cases where pump trains 31 or 32 are out of service for maintenance.

The letter identified blocks from Figure 1 represent "blocks" that are groups of lower level components. The members of each letter block are listed below for reference in further analysis.

Block	Elements In The Block
A	Check valve 881, MOV 882, Manual valve 846
A'	MOV 885A, MOV 885B. This double failure would allow water to go into the sump which would cause an earlier start of recirculation, but the water would not be lost.
B	Manual valves 735B, 739B. Check valve 738B, RHR pump 32. The double failures involving excessive leakage back through check valves 886A or 886B and MOV 1802A or 1802B transferring open were found to be of low probability and not included in the major contributors (on the order of 10^{-13}). Likewise check valves 738A or 738B having excessive leakage and the pump not starting on that path were found to be of low probability and not included in the major contributors (on the order of 10^{-8}).
C	Manual valves 735A, 739A. Check valve 738A, RHR Pump 31. The double failures involving excessive leakage back through check valves 886A or 886B and MOV 1802A or 1802B transferring open were found to be of low probability and not included in the major contributors (on the order of 10^{-13}). Likewise check valves 738A or 738B having excessive leakage and the pump not starting on that path were found to be of low probability and not included in the major contributors (on the order of 10^{-8}).
D	MOV 744, Check valve 741. Since the monthly test of the RHR pumps does not use the line containing valves 883 and 1863, they are validated closed monthly and the probability of both opening at the time of a safety injection was considered small.

Block	Elements In The Block
E	Manual valve 742, Heat exchanger 31, MOV 889B, MOV 747, HCV 638, MOV 899B. Flow through MOVs 888A and 888B would not be lost as it would follow a different path into the core. Therefore, these valves were not included as failures. MOVs 889A and 889B are not considered single failures since the flow will split between the spray line and the injection headers on the path which has the 889 valve open. The other path would run nearly normal head if both pumps were running. In addition, if the containment spray pumps are running, they provide 300 psi head which would cause flow into the LPIS path.
F	MOV 745B, MOV 745A, Heat exchanger 32, MOV 889A, MOV 746, HCV 640, MOV 899A. Flow through MOVs 888A and 888B would not be lost as it would follow a different path into the core. Therefore, these valves were not included as failures. MOVs 889A and 889B are not considered single failures since the flow will split between the spray line and the injection headers on the path which has the 889 valve open. The other path would run nearly normal head if both pumps are running. In addition, if the containment spray pumps are running, they provide 300 psi head which would cause flow into the LPIS path.
G	Check valves 897A, 838A
H	Check valves 897B, 838B
I	Check valves 897C, 838C
J	Check valves 897D, 838D

Using these letter blocks, double failures can be determined by the following combinations: (B and C), A', (E and F), and depending on which cold leg has had the large LOCA, combinations of G, H, I, and J as follows:

LOCA Leg	Double Failures
1	HI, IJ, JH
2	GI, IJ, JG
3	GH, HJ, JG
4	GH, HI, IG.

Since the probability of the LOCA occurring in any one of the legs is equal, each of these double failures is equally likely. There are no three-element or higher order failures in this LPIS.

D. QUANTIFICATION

D.1 BOUNDARY CONDITION, ELECTRIC POWER AVAILABLE ON BUSES 3A AND 6A

D.1.1 Hardware Contribution

Each single-event minimal cutset is analyzed using plant-specific data:

- Check valve 741 fails to open on demand. The mean and variance are:

  Mean_{CV1}: 6.91×10^{-5}

  Variance_{CV1}: 1.03×10^{-8}.

- Motor-operated valve 744 fails closed (deenergized open).

  $\text{Mean}_{MOV,C1}$: $9.15 \times 10^{-8}/\text{hr} \times 24\ \text{hr/day} \times \frac{\text{30-day test cycle}}{2}$

  $= 3.29 \times 10^{-5}$

  $\text{Variance}_{MOV,C1}$: $1.01 \times 10^{-14} \times (24 \times 15)^2 = 1.31 \times 10^{-9}$.

- Check valve 881 fails to open on demand.

  Mean_{CV2}: 6.91×10^{-5}

  Variance_{CV2}: 1.03×10^{-8}.

- Motor-operated valve 882 fails closed (deenergized open).

  $\text{Mean}_{MOV,C}$: $9.15 \times 10^{-8}/\text{hr} \times \frac{\text{720-hr test cycle}}{2} = 3.29 \times 10^{-5}$

  $\text{Variance}_{MOV,C}$: $1.01 \times 10^{-14} \times \left(\frac{720}{2}\right)^2 = 1.31 \times 10^{-9}$.

- Manual valve 846 fails closed (locked open).

  $\text{Mean}_{MV,C}$: $9.15 \times 10^{-8}/\text{hr} \times \frac{\text{30-day test cycle}}{2} \times \frac{24\ \text{hrs}}{\text{day}}$

  $= 3.29 \times 10^{-5}$

  $\text{Variance}_{MV,C}$: $1.01 \times 10^{-14} \times \left(\frac{30 \times 24}{2}\right)^2 = 1.31 \times 10^{-9}$.

- Pipe failure. Table 5 shows the pipe sections that constitute single failures of the LPIS.

The total hardware contribution for single failures is the addition of the components A and D using DPD.

$$\text{Mean}_{\text{singles}} = 2\ \text{mean}_{CV} + \text{mean}_{MOV,C1} + \text{mean}_{MOV,C} + \text{mean}_{MV,C}$$

$$= 2 \times 6.91 \times 10^{-5} + 3 \times 3.29 \times 10^{-5}$$

$$= 2.37 \times 10^{-4}$$

$$\text{Variance}_{\text{singles}} = 4.02 \times 10^{-8}.$$

D.1.2 Test And Maintenance Contribution

The monthly test 3PT-M18 starts each pump for 15 to 30 minutes and recirculates flow through the heat exchanger and back to the pump suction. This test leaves all valves in their normal configuration and assures flow through MOVs 744, 745A, and 745B. The high pressure at the MOVs 744 injection heads does not allow flow through MOVs 899A, B, MOVs 746, 747, or HCVs 638 and 640. The only time that flow is assured through these valves is during test RPT-V9, during or at cold shutdown. Therefore, if one of them fails between these tests, detection may not be noted during the quarterly valve tests (3PT-Q22) with a failure such as the gate dropping off the stem. The valve operator would still appear to be normal but the flowpath could be blocked.

There is some chance that the valves stroked during the quarterly test will be left in the wrong position, but none of the single failure valves are involved in this test so the affected valves will be treated in the next section on double failures.

Valve maintenance is not considered during normal operation on any valve that must change position on a safety injection.

D.1.3 Human Error Contribution

The LPIS receives an automatic safety injection signal to the pumps with all valves being set in normal injection flowpath position. No operator interaction is normally required during this phase until the recirculation phase begins.

D.1.4 Single Failure Contribution

Table 8 presents the contribution of single failures to system unavailability.

D.2 QUANTIFICATION OF DOUBLE FAILURES

D.2.1 Hardware Contribuiton

All remaining hardware failure contributions come from two-element cutsets as described in Section C. Each block is examined here to determine the magnitude of the block's contribution to unavailability.

Block B (or C) Pump Train Section

	Subscript	Unavailability	
		Mean	Variance
RHR pump (fails to start)	P	1.36×10^{-3}	1.22×10^{-6}
Check valve (fails to open)	CV	6.91×10^{-5}	1.03×10^{-8}
Manual valves (transfer closed)	MV	3.29×10^{-5}	1.31×10^{-9}

The mean of B (or C) is then

$$Mean_B: \quad mean_P + mean_{CV} + 2\ mean_{MV} = 1.49 \times 10^{-3}$$

$$Variance_B: \quad 1.25 \times 10^{-6}.$$

The pumps alone contribute 1.36×10^{-3} so they are the largest contributor in the train. The double failure BC is then, using DPD:

$$Mean_{BC}: \quad (mean_B)^2_B = \left(1.49 \times 10^{-3}\right)^2 = 3.29 \times 10^{-6}$$

$$Variance_{BC}: \quad 2.68 \times 10^{-11}.$$

Evaluation of the heat exchanger blocks E and F used the following valves.

	Subscript	Unavailability	
		Mean	Variance
Motor valve 899A (B) (transfers closed)	MOV0	3.29×10^{-5}	1.31×10^{-9}
Motor valve 747 (746) (transfers closed)	MOV1	3.29×10^{-5}	1.31×10^{-9}
Motor valve 638 (640) (transfers closed)	MOV2	3.29×10^{-5}	1.31×10^{-9}
Motor valve 889A (B) (transfers open) ($2.00 \times 10^{-8} \times 720/2$)	MOV3	0.72×10^{-5}	3.52×10^{-8}
Heat exchanger 31 (32) (plugged)	HX	ϵ	
Manual valve 742 (train 31) (transfers closed)	MV	3.29×10^{-5}	1.31×10^{-8}
2 MOVs 745A, 745B (train 32) (transfer closed)	MOV4	3.29×10^{-5}	1.31×10^{-8}

The above tabulation summarizes the contributors for both block E and block F. The elements for block E include all the elements except the two MOVs (745A, 745B). Block F includes all the elements except the single manual valve (742). The unavailability of the blocks is computed below and used to compute the system unavailability.

Blocks E and F are slightly different since one has two MOVs instead of one manual valve. Using DPD arithmetic:

Mean_E: $4(3.27 \times 10^{-5}) + .72 \times 10^{-5} = 1.39 \times 10^{-4}$

Variance_E: 1.87×10^{-8}

Mean_F: $5(3.29 \times 10^{-5}) + .72 \times 10^{-5} = 1.72 \times 10^{-4}$

Variance_F: 2.82×10^{-8}.

Then

Mean_{EF}: $1.39 \times 10^{-4} \times 1.72 \times 10^{-4} = 2.37 \times 10^{-8}$

Variance_{EF}: 1.20×10^{-15}.

The remaining two-event cutsets of the check valves in the cold legs are insignificant, as shown here:

$$\text{Mean}^2_{CV}: \left(6.91 \times 10^{-5}\right)^2 = 4.77 \times 10^{-9}.$$

Even with 100 such cutsets, the contribution to system hardware unavailability is still dominated by the single-event cutsets and the two-event cutset of both pumps failing to start.

D.2.2 Test Contribution

Referring to Section D.1.2, testing of the pumps monthly does not degrade the system. The quarterly test of the MOVs in the heat exchanger blocks is performed by closing and then opening each valve before the next one is tested. This procedure minimizes the contribution to unavailability due to a valve being left in the closed position.

D.2.3 Maintenance Contribution

As discussed in Section D.1.2, valve maintenance is not considered here, but RHR pump maintenance is a contributor to system unavailability.

RHR pump 31 shows one instance of being down for maintenance with the reactor not in cold shutdown. The total operating hours (1976 to 1980) corresponding to these instances yield a pump unavailability due to maintenance of

Mean: 7.63×10^{-4}

Variance: 5.10×10^{-8}.

The system fails when B is under maintenance and C also fails; thus, we get:

Mean: $7.63 \times 10^{-4} \times 1.49 \times 10^{-3} = 1.14 \times 10^{-6}$

Variance: 7.36×10^{-12}.

Likewise, when C is under maintenance and B fails, we get the same result. Therefore, the total contribution is

Mean: $2 \times 1.14 \times 10^{-6} = 2.28 \times 10^{-6}$

Variance: 2.94×10^{-11}.

D.2.4 Human Error Contribution

From the discussion of the tests in Section D.1.2, the flow tests after maintenance at refueling or cold shutdown assure that valves are aligned correctly. The monthly tests do not change valve position. The quarterly tests do not contribute to valve mispositioning. After pump maintenance, the pump isolation valves are verified open by a flow test of the repaired pump train. Therefore, no human error is included due to these maintenance procedures.

D.2.5 Other Causes

Most of the observed coupled failures in the industry involved motor-operated or air-operated valves that had to change position on demand. The frequent partial tests and the full annual system test indicate that an unforeseen common cause failure is of low frequency.

D.2.6 Double Failure Contribution

Table 9 summarizes the double failure contributions.

D.3 NO TRIPLE FAILURES

D.4 SYSTEM UNAVAILABILITY

Table 10 shows the results that have been derived for the mean values of the dominant contributors to LPIS unavailability. These contributors are the basis for the uncertainty analysis. The mathematical expression for the unavailability of the system in terms of the unavailabilities of the dominant contributors is:

$$Q_{LPIS} = 2Q_{CV} + 3Q_{MOV1} + Q_{BC} + Q_{maint} + BQ_{BC} + Q_{EF} = 2.41 \times 10^{-4}.$$

Using DPD arithmetic we find for Q_{LPIS}

Mean: 2.41×10^{-4}

Variance: 3.97×10^{-8}

5th Percentile: 5.92×10^{-5}

Median: 1.82×10^{-4}

95th Percentile: 6.14×10^{-4}.

E. QUANTIFICATION: BOUNDARY CONDITION, DEGRADED ELECTRIC POWER

When either Bus 3A or 6A is not available, an RHR train becomes unavailable. This causes the elements in the remaining path to become single-element cutsets. The block B(C) is then added directly to the other single event cutsets to calculate the unavailability with one bus out. Referring to Figure 2, the number of valves of each type must be determined since the data structure causes dependence among valves that use the same generic data base.

Manual (MOVs that do not operate)	= 9 or 10
Check valves	= 3
Pump	= 1

The calculation still shows that the pump and MOV that must change position dominate the other single elements in the flowpath.

If a bus is unavailable and maintenance is being performed, the system would be unavailable. Both buses down make the system unavailable. These results are shown in Table 11.

TABLE 1A

LPIS UNAVAILABLE--ELECTRIC POWER AVAILABLE

Bus Condition	Mean	Variance	5th Percentile	Median	95th Percentile
Buses 3A and 6A Available	2.41×10^{-4}	3.97×10^{-8}	5.92×10^{-5}	1.82×10^{-4}	6.14×10^{-4}
WASH-1400 Comparison	not given	not given	3.10×10^{-4}	4.70×10^{-3}	7.40×10^{-3}

TABLE 1B

LPIS UNAVAILABLE--PARTIAL POWER AVAILABLE

Buses Unavailable

System Unavailibility (Mean)	3A	6A	3A&6A
	2.36×10^{-3}	2.36×10^{-3}	1.0

TABLE 2

LPIS POWER SUPPLIES

Component	Power Supply
RHR Pump 31	Bus Number 3A
RHR Pump 32	Bus Number 6A

TABLE 3

TESTING REQUIREMENTS

Component	Testing/Inspection
RHR Pump 31	Started and stopped monthly, when leaving cold shutdown, and at refueling.
RHR Pump 32	Started and stopped monthly, when leaving cold shutdown, and at refueling.
HCV638, HCV640	Stroked once; quarterly.
MOV744; 882; 745A,B; 746; 747	Verify open; monthly.
MOV745A,B; 889A,B	Stroked once; quarterly.
MOV885A,B; 889A,B	Verify open; monthly.
Manual Valves 735A,B; 739A,B; 846	Verify open; monthly
Check Valves 881, 738A,B; 741	Open on demand; monthly, refueling.
Check Valves 887A-D; 838A-D	Seated correctly; leaving cold shutdown.
Check Valves 887A-D; 838A-D	Open on demand; refueling.

TABLE 4

LIST OF COMPONENTS

Component	Failure Mode	Fault Tree Coding	Mean Failure Rate	H/D	Variance	Reference
Check Valves						
897(A,B,C,D)	Fails to open	BCV897(A,B,C,D)Q	6.91×10^{-5}	D	1.03×10^{-8}	3
838(A,B,C,D)	Fails to open	BCV838(A,B,C,D)Q	6.91×10^{-5}	D	1.03×10^{-8}	3
981	Fails to open	BCV981-Q	6.91×10^{-5}	D	1.03×10^{-8}	3
733(A,B)	Fails to open	BCV733(A,B)Q	6.91×10^{-5}	D	1.03×10^{-8}	3
741	Fails to open	BCV741-Q	6.91×10^{-5}	D	1.03×10^{-8}	3
Manual Valves						
742	Transfers closed	BXV742-C	9.15×10^{-8}	H	1.01×10^{-14}	1
739(A,B)	Transfers closed	BXV739(A,B)C	9.15×10^{-8}	H	1.01×10^{-14}	1
735(A,B)	Transfers closed	BXV735(A,B)C	9.15×10^{-8}	H	1.01×10^{-14}	1
846	Transfers closed	BXV846-C	9.15×10^{-8}	H	1.01×10^{-14}	1
Motor-Operated Valves						
638 (butterfly)	Transfers closed	BMV638-C (butterfly)	9.15×10^{-8}	H	1.01×10^{-14}	1
640 (butterfly)	Transfers closed	BMV640-C (butterfly)	9.15×10^{-8}	H	1.01×10^{-14}	1
745(A,B)	Transfers closed	BMV745(A,B)C	9.15×10^{-8}	H	1.01×10^{-14}	1
744	Transfers closed	BMV744-C	9.15×10^{-8}	H	1.01×10^{-14}	1
882	Transfers closed	BMV882-C	9.15×10^{-8}	H	1.01×10^{-14}	1
885(A,B)	Transfers open	BMV885(A,B)B	2.00×10^{-8}	H	1.89×10^{-13}	2
746	Transfers closed	BMV746-C	9.15×10^{-8}	H	1.01×10^{-14}	1
747	Transfers closed	BMV747-C	9.15×10^{-8}	H	1.01×10^{-14}	1
889(A,B)	Transfers open	BMV889(A,B)B	2.00×10^{-8}	H	1.89×10^{-13}	2

TABLE 4 (continued)

LIST OF COMPONENTS

Component	Failure Mode	Fault Tree Coding	Mean Failure Rate	H/D	Variance	Reference
Heat Exchangers						
31	Plugged	BHEHE31L	ϵ			25, 26
32	Plugged	BHEHE32L	ϵ			25, 26
Pumps (RHR)						
31	Failure to start on demand	BPMPM31S	1.35×10^{-3}	D	1.22×10^{-6}	11
32	Failure to start on demand	BPMPM32S	1.36×10^{-3}	D	1.22×10^{-6}	11
Pump Motors						
31	Loss of function	BMOPM31S	combined with pump failure			
32	Loss of function	BMOPM32S	combined with pump failure			

ϵ - very small with respect to other components

TABLE 5

SYSTEM EFFECTS OF PIPE FAILURE

	Pipe Section Nuclear Header	Diameter (in.)	System Failure	Potential for Other Systems Impact	Initiating Event	Comments
1.	Line Number 155 - Supply to RHR pumps from RWST	12	Yes	Yes, loss of RWST	No	Can be isolated manually (valve 846)
2.	Line Number 57 - Supply RHR pumps from Containment sump (after MOV 8958)	14	Yes	Loss of pump suction (and RWST)	No	See item 1 above
3.	Pump Suction and Discharge Piping (2 pumps)	14/8	Yes	Loss of RWST	No	Individual pump can be isolated manually
4.	Line Number 9, Pump Discharge to RHR Heat Exchangers	[illegible]	Yes	Loss of RWST	No	Can be isolated
5.	Outlet RHR Heat Exchangers	8	Yes	Loss of RWST	No	
6.	Individual Loop Injection Lines (after flow restricting orifice) (8)	6	No	Yes, possible loss of associated accumulator	No	See accumulator piping table

TABLE 6

ADDITIONAL SINGLE-EVENT MINIMAL
CUTSETS WITH PUMP TRAIN 31 DISABLED
DUE TO MAINTENANCE

BPMPM32S:	RHR Pump 32 Mechanical
BMOPM32S:	RHR Pump 32 Motor
BXV739BC:	Manual Valve 739B
BXV735BC:	Manual Valve 735B
BCV738BQ:	Check Valve 738B

TABLE 7

ADDITIONAL SINGLE-EVENT MINIMAL
CUTSETS WITH PUMP TRAIN 32 DISABLED
DUE TO MAINTENANCE

BPMPM31S:	RHR Pump 31 Mechanical
BMOPM31S:	RHR Pump 31 Motor
BXV739AC:	Manual Valve 739A
BXV735AC:	Manual Valve 735A
BCV738AQ:	Check Valve 738A

TABLE 8

CAUSE TABLE FOR SINGLE FAILURES - BUSES 3A AND 6A AVAILABLE

Cause	Mean Unavailability	Effects			
		Components	System	Other Systems	Initiating Event
Hardware failure	6.91×10^{-5}	CV741 fails to open	fails	not affected	no effect
Hardware failure	6.91×10^{-5}	CV891 fails to open	fails	not affected	no effect
Hardware failure	3.29×10^{-5}	MOV744 closes (deenergized open)	fails	not affected	no effect
Hardware failure	3.29×10^{-5}	MOV892 closes (deenergized open)	fails	not affected	no effect
Hardware failure	3.29×10^{-5}	Manual valve 845 closes (locked open)	fails	Safety Injection	no effect
Total Hardware	2.37×10^{-4}				
Testing and Maintenance	0	none	no effect	no effect	no effect
Human Error	0	none	no effect	no effect	no effect
TOTAL	2.37×10^{-4}				

Dominant Contributor = Hardware failure

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TABLE 9

CAUSE TABLE FOR DOUBLE FAILURES

Cause	Mean Frequency	Effects			
		Components	System	Other Systems	Initiating Event
Coincident hardware failures	3.29×10^{-6}	Mainly RHR pumps	fails	no effect	no effect
Maintenance and hardware failures	2.28×10^{-6}	RHR pump maintenance	fails	no effect	no effect
Human error and hardware failures	0	no effect	no effect	no effect	no effect
TOTAL	5.57×10^{-6}				

Dominant Contributor = Nearly Equivalent Contributions

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TABLE 10

DOMINANT CONTRIBUTOR CAUSE TABLE FOR LPIS BUSES 3A AND 6A AVAILABLE

Dominant Cause	Failure Mode	Mean Unavailability
SINGLE FAILURES		
Hardware Failures	Valves stop flow	2.37×10^{-4}
DOUBLE FAILURES		
Coincident Hardware Failures		3.29×10^{-6}
Maintenance	Pump unavailable	2.28×10^{-6}
TOTAL		2.41×10^{-4}

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TABLE 11

DOMINANT--CAUSE TABLE FOR LPIS
(One Bus Out)

Dominant Cause	Failure Mode	Mean Unavailability
Hardware Failure	Pump fails to start	1.36×10^{-3}
Maintenance	On pump train 31 or 32	7.63×10^{-4}
Hardware Failure	Single nonoperating valves	2.37×10^{-4}
TOTAL		2.36×10^{-3}

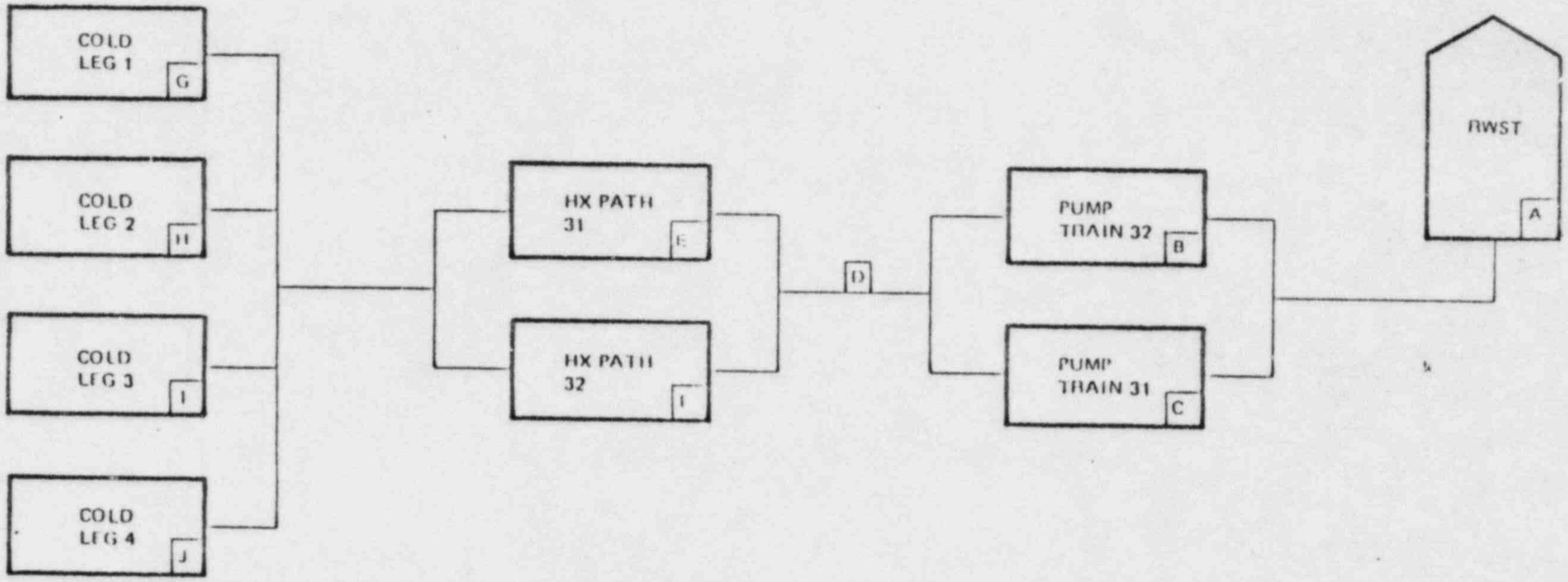

Figure 1. Low Pressure Injection System Reliability Block Diagram

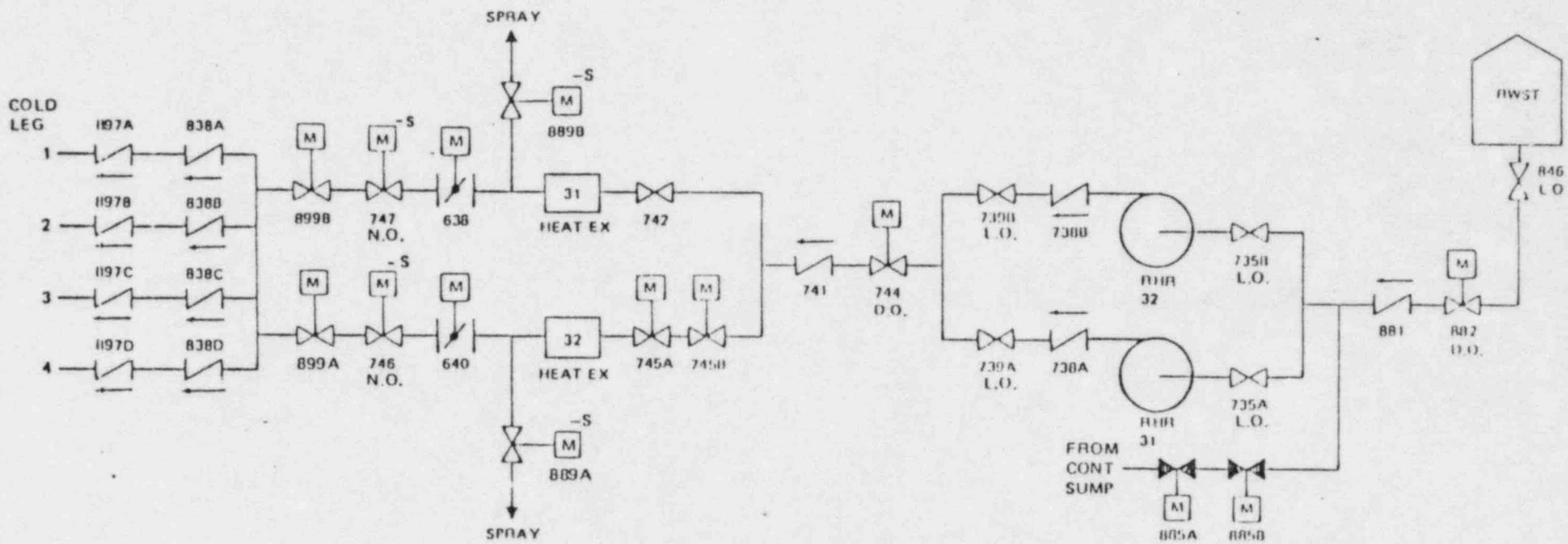

Figure 2. Low Pressure Injection System Simplified P&ID

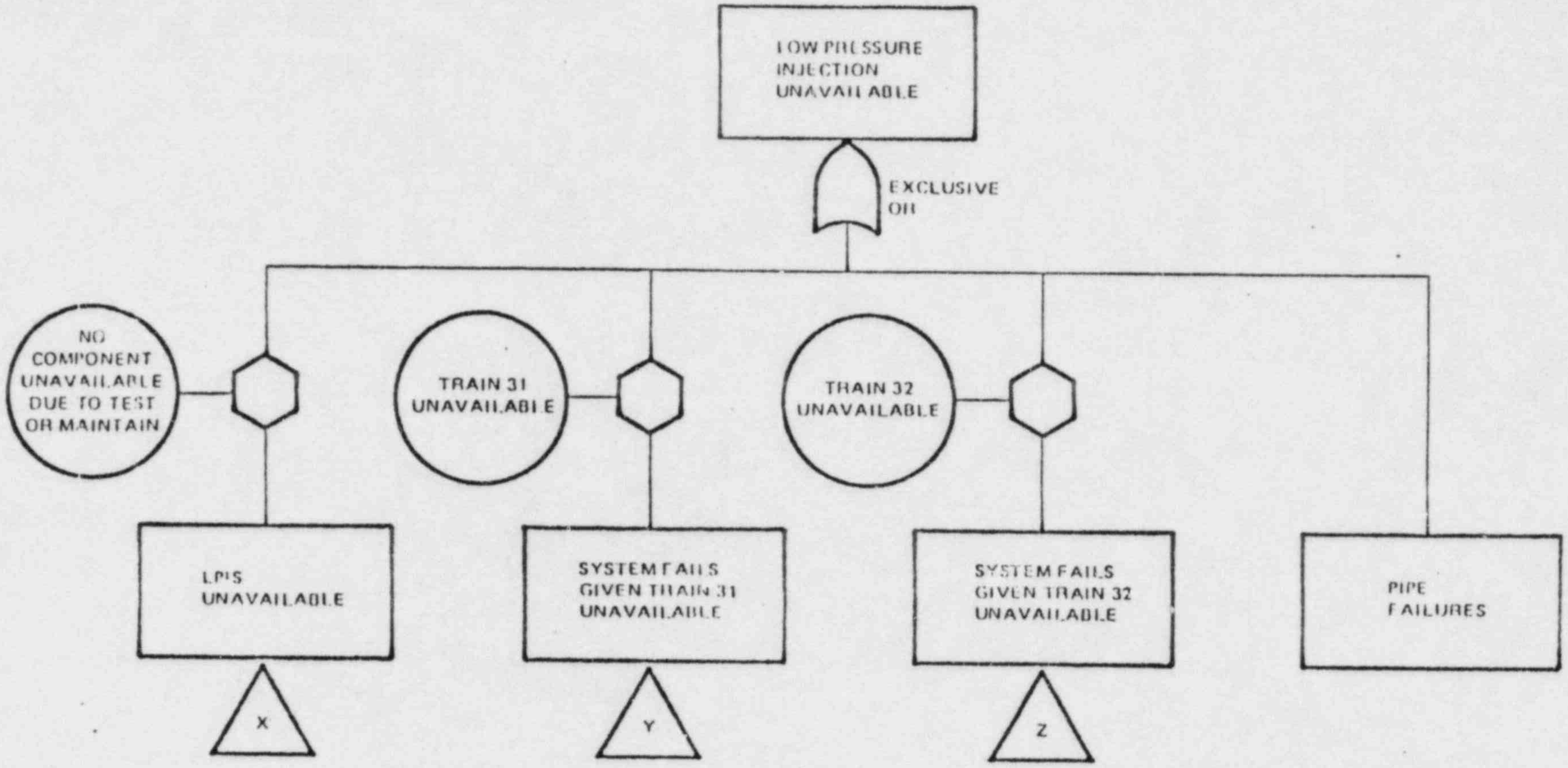

Figure 3. Top Structure of the Fault Tree

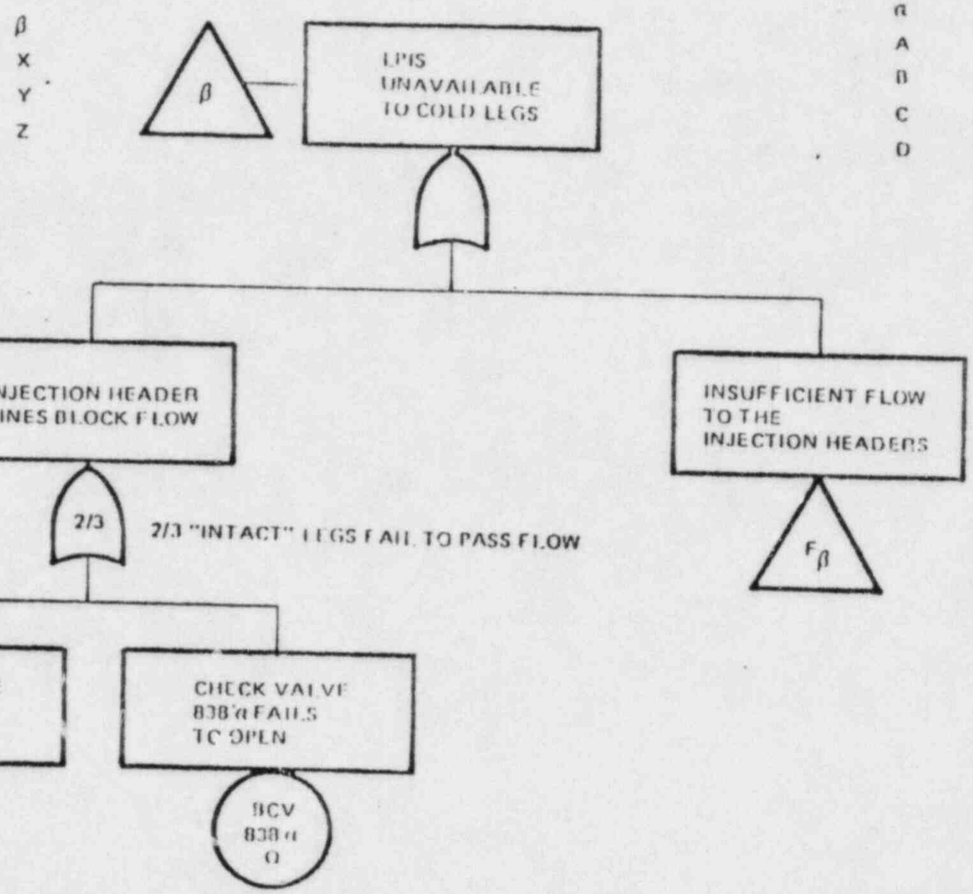

Figure 4. Low Pressure Injection Fault Tree
(Sheet 1 of 8)

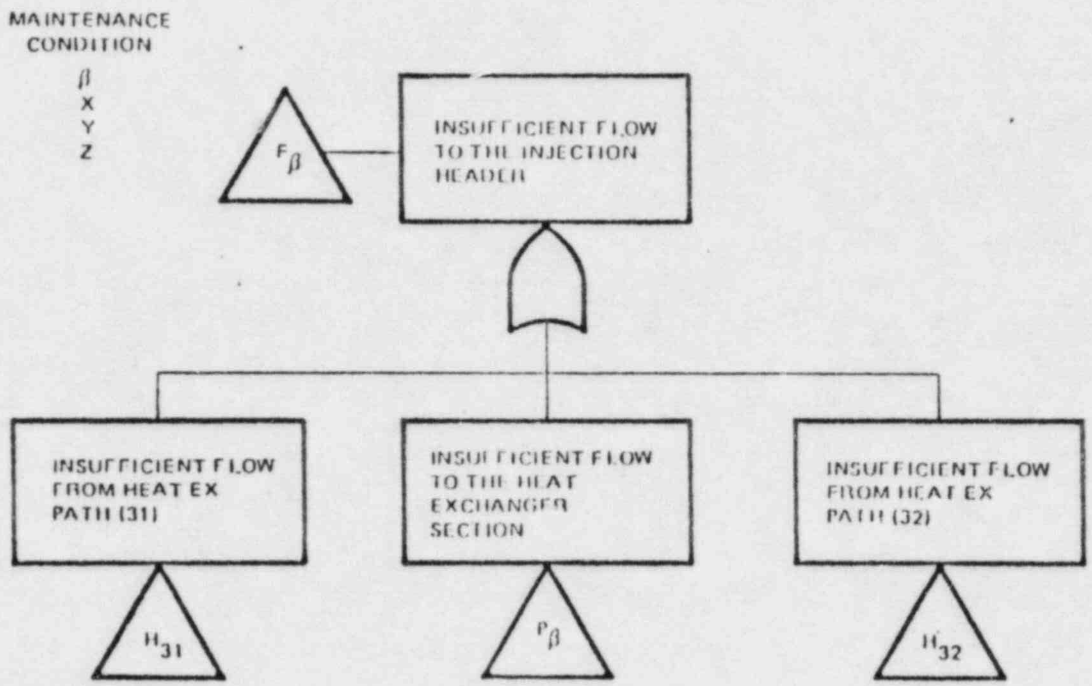

Figure 4. (Sheet 2 of 8)

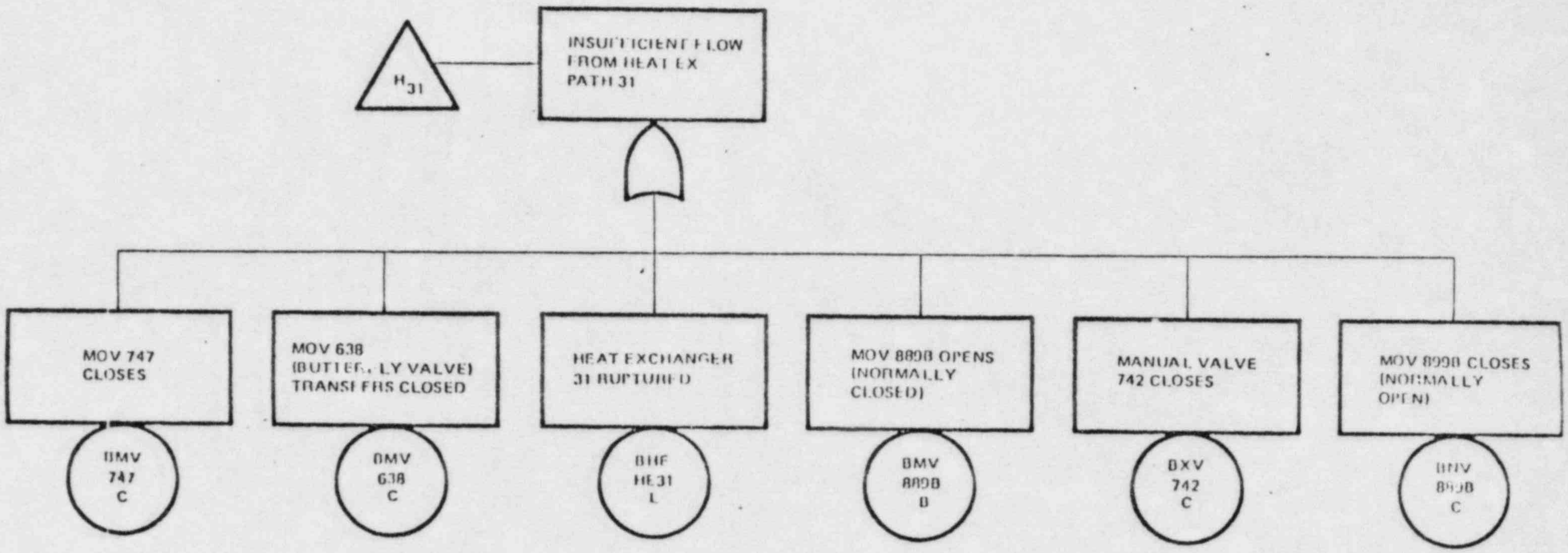

Figure 4. (Sheet 3 of 8)

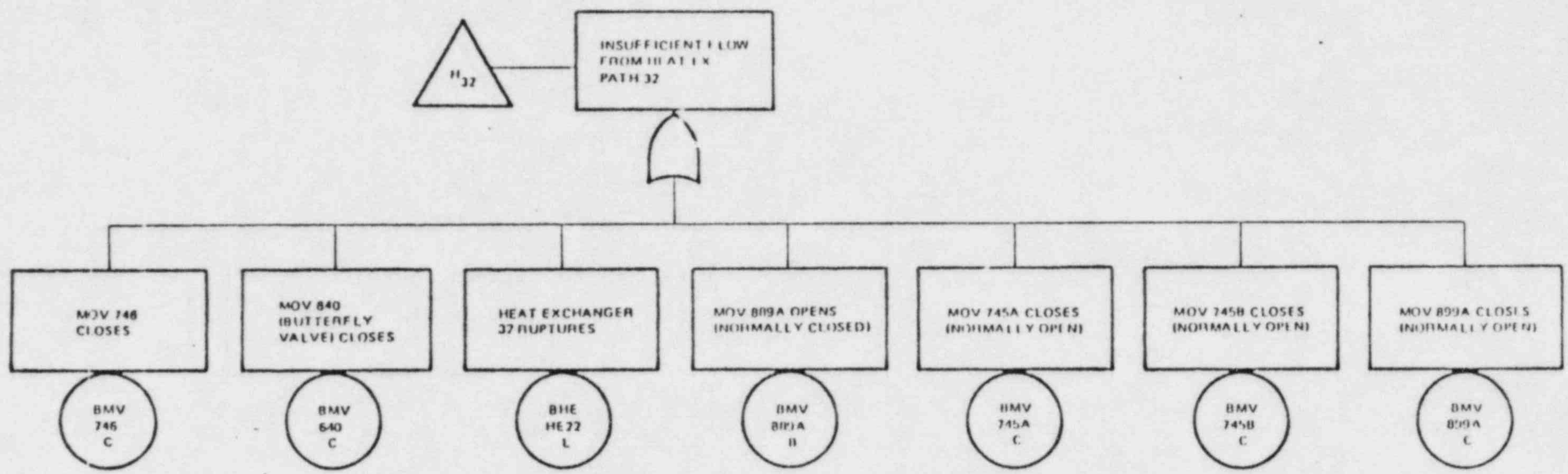

Figure 4. (Sheet 4 of 8)

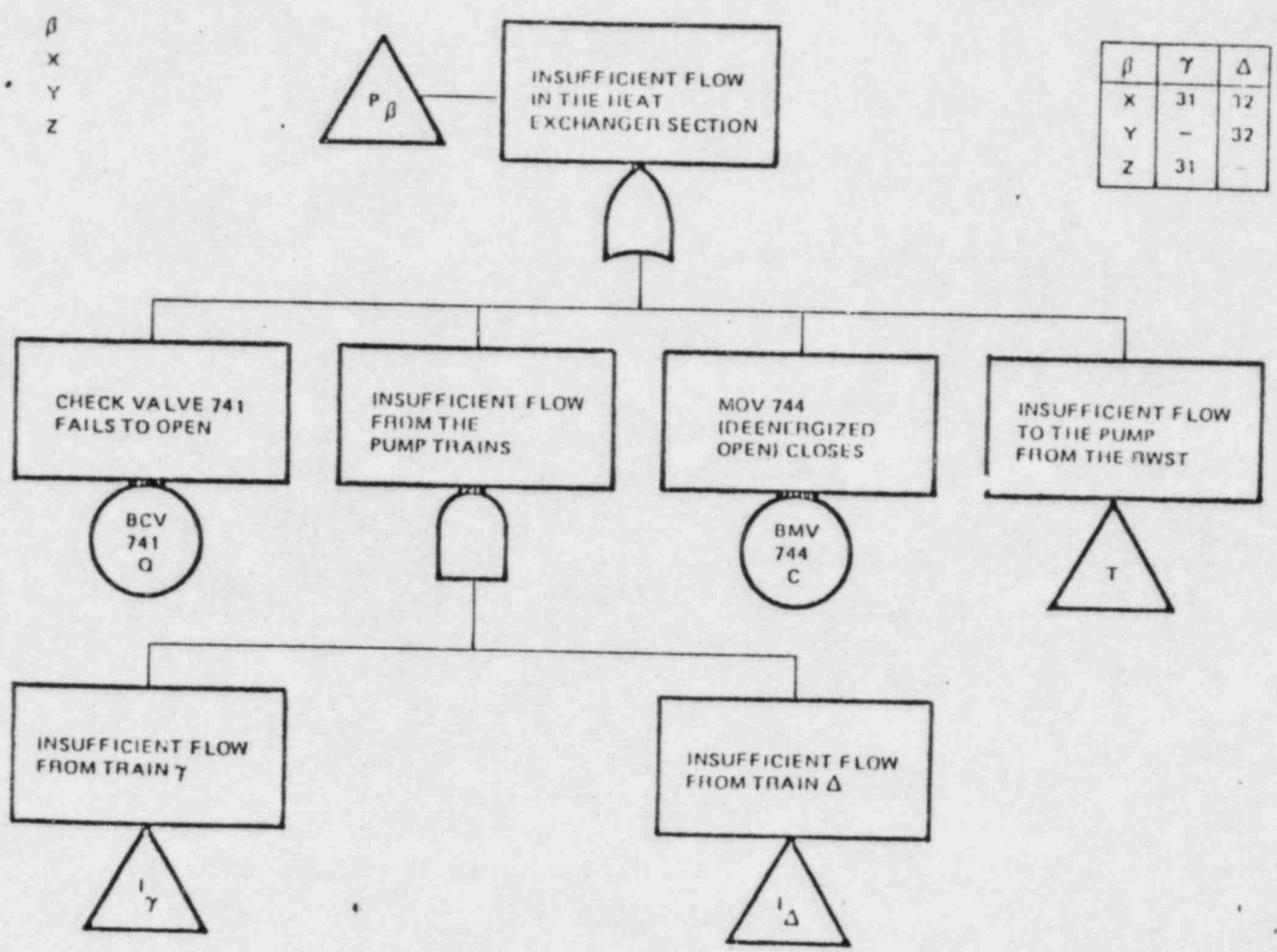

Figure 4. (Sheet 5 of 8)

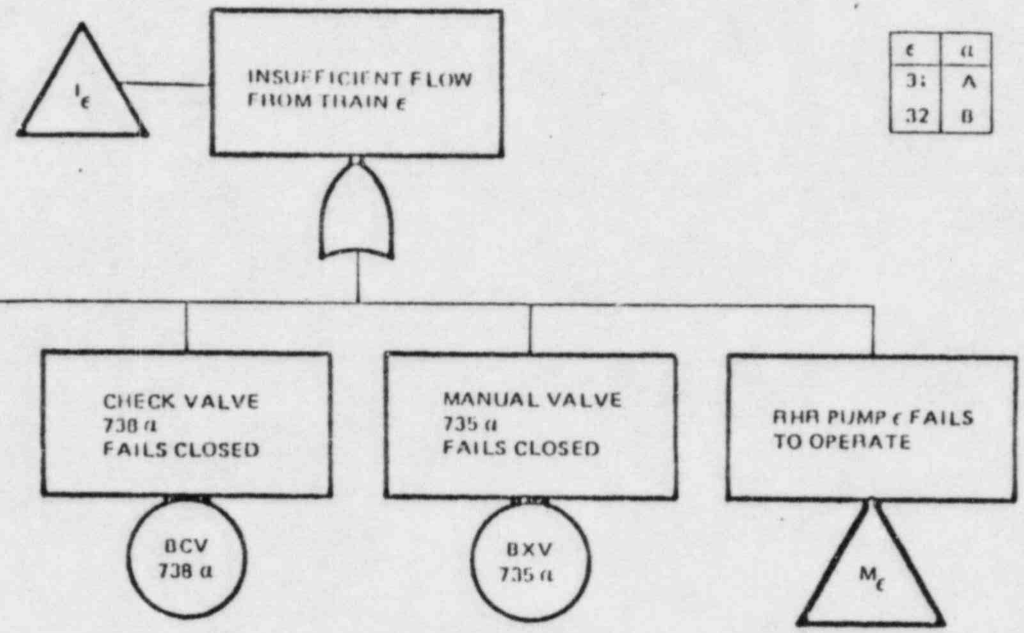

Figure 4. (Sheet 6 of 8)

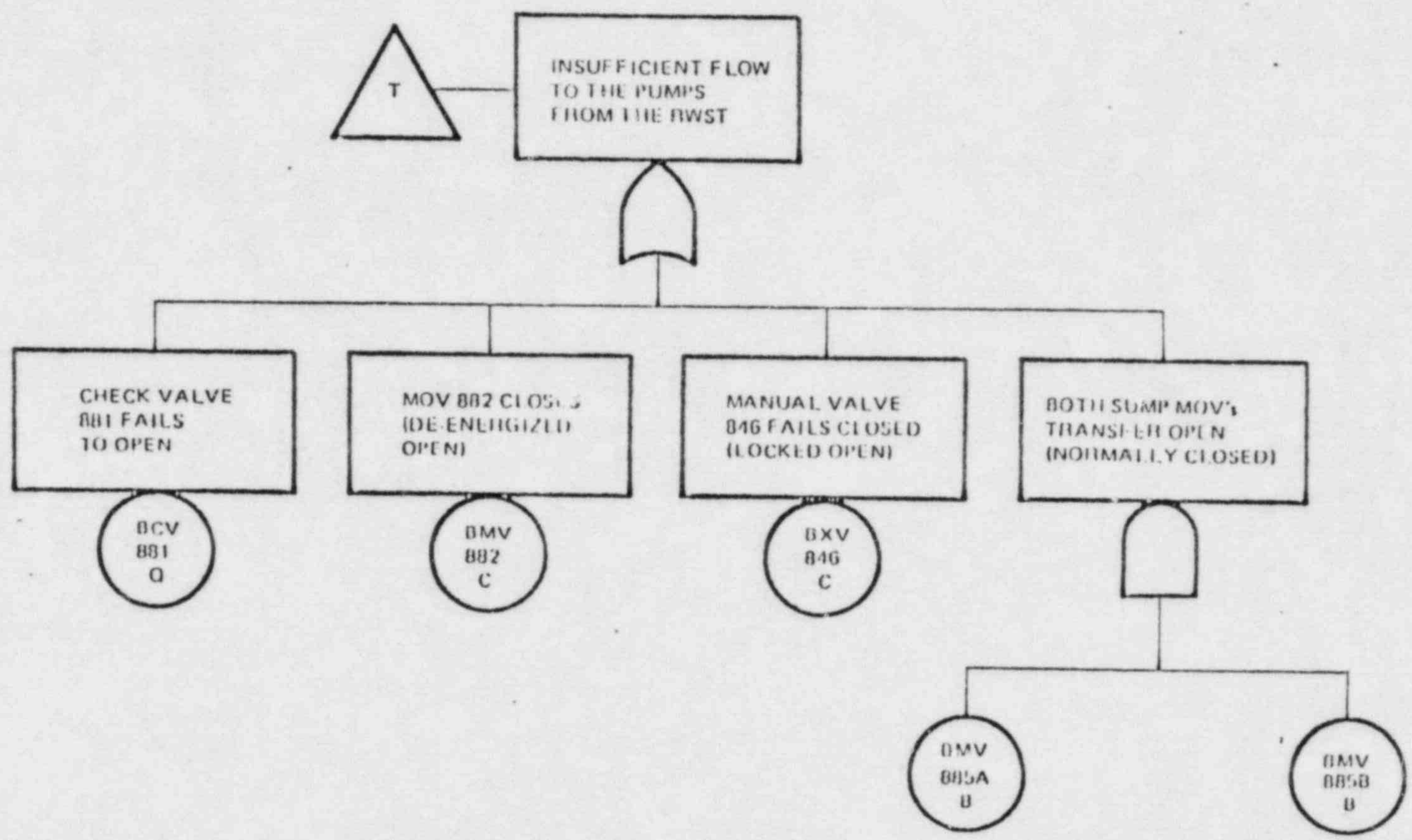

Figure 4. (Sheet 7 of 8)

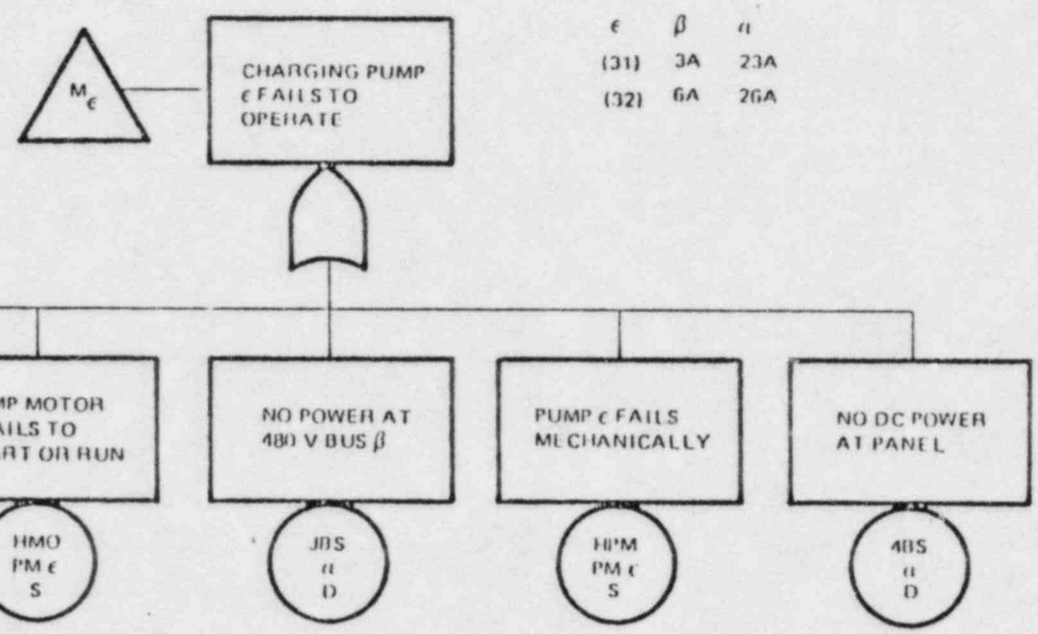

Figure 4. (Sheet 8 of 8)