INDIAN POINT UNIT 3
CONTAINMENT SPRAY SYSTEM

DRAFT

A. SUMMARY

A.1 INTRODUCTION

The containment spray system is evaluated for the post LOCA injection phase, wherein borated water from the RWST is pumped to the containment spray headers by the containment spray pumps. Later, during the recirculation phase, spray is provided by the recirculation pumps or the residual heat removal (RHR) pumps.

This analysis has been performed to determine the frequency with which the containment spray and sodium hydroxide (NaOH) addition systems would be expected to fail when required to respond following a LOCA. These frequencies will be used in the event trees.

Sodium hydroxide addition is treated as a separate system since it would only be useful in case of a primary coolant release to containment. It appears as a separate event in the event trees.

The analysis of the containment spray system is carried out under the following conditions:

- RWST is available
- The safeguards actuation signal is present.

An additional condition for the NaOH addition system is the success of the containment spray system as a previous event in the event trees.

A.2 RESULTS

Table 1 summarizes the results for the cases of electric power availability considered (buses 5A and 6A) and lists the WASH-1400 results as a comparison.

The analysis has revealed the following dominant contributors:

Containment Spray	Mean
• Electric power to buses 5A and 6A	3.0×10^{-5}
- Random Failures	1.3×10^{-5} (43.3%)
- Human Error	1.4×10^{-5} (46.7%)
• No electric power to one bus (5A or 6A)	4.0×10^{-3}
- Random Failures	3.1×10^{-3} (77.5%)
- Maintenance	7.3×10^{-4} (18.3%)
- Human Error	2.0×10^{-4} (05.0%)

NaOH Addition System

	Mean
• Electric power to buses 5A and 6A	9.6×10^{-4}
- Random Failures	7.6×10^{-4} (79.2%)
- Human Error	2.0×10^{-4} (20.8%)
• No electric power to one bus (5A or 6A)	1.3×10^{-2}
- Random Failures	1.1×10^{-3} (84.6%)
- Human Error	2.0×10^{-4} (15.4%)

A.3 CONCLUSION

Both systems have single failure points but these are generally associated with passive components, i.e., the containment spray suction header and the spray additive tank in the NaOH system. The tank outlet valve in the NaOH system is also a single failure point but is normally locked in the open position. Failures of this valve are caused by structural or human errors and have been considered in the analysis.

In the containment spray system, random hardware failures due to the spray pumps are the dominant contributors to system unavailability. The loss of one bus increases the unavailability.

In the NaOH addition system, failure of the spray additive tank and the outlet valve dominate the random failures, while human errors associated with the manual valves which are required to change position during every monthly test also contribute significantly to system unavailability.

B. SYSTEM DESCRIPTION

B.1 SYSTEM FUNCTIONS

The primary functions of this system are:

- To reduce the containment pressure following a loss-of-coolant accident or a steam line break accident inside containment.
- To remove iodine (by NaOH addition) released to the containment atmosphere in the event of a breach in the fuel cladding following a loss-of-coolant accident.

A secondary function of the containment spray system is to provide dousing water to the charcoal filter banks of the containment recirculation fan cooling units (this function is analyzed in a separate section on the containment fan cooling system).

B.2 SYSTEM SUCCESS CRITERIA

B.2.1 Containment Spray

During the injection phase, either of the two spray trains delivering borated water at 2,600 gpm through its set of 221 spray nozzles is sufficient to maintain containment pressure below the design pressure following a LOCA when the reactor core's residual heat is released to containment as steam.

Success paths for containment spray during the injection phase are illustrated in the simplified block diagram, Figure 1. This diagram shows that the borated water supply from the RWST and failure of the suction header line No. 181 are the only two single failure points in the system. The two pump trains in parallel illustrate that either one is sufficient for system success. The normally closed MOV in each spray train must open and the pump must start and run for a maximum of 2 hours with minimum safeguards. Otherwise, all valves are normally in their correct positions for system operation.

B.2.2 Sodium Hydroxide Addition

During the injection phase and continuing 30 minutes into the recirculation phase, at least one of the sodium hydroxide addition trains must introduce approximately 25 gpm of the NaOH solution from the spray additive tank into an operating containment spray train.

This success criterion is illustrated by the simplified block diagram of Figure 2. Only valves that must change position are shown.

There are three single failure points: 1) supply of the NaOH solution from the spray additive tank, 2) valve 1841 which must remain open (normally locked open), and 3) valve 873B not remaining closed (normally locked closed).

B.3 SYSTEM CONFIGURATION

The containment spray and sodium hydroxide addition systems are illustrated by the flow diagram, Figure 3.

B.3.1 General Description

For the injection phase, the containment spray system consists of the following primary components:

- Containment Spray Pumps, 31 and 32
- Motor-Operated Discharge Valves, 866A and 866B
- Discharge Header Containment Isolation Valves, 869A and 869B
- Pump Suction Valves, 865A and 865B
- Discharge Check Valves, 867A and 867B
- Two Sets of Spray Nozzles (221 each set)
- Suction Header Line No. 181
- Discharge Lines.

The following associated valves and lines are necessary for system tests:

- Spray Test Line
- Spray Test Valves 878A and 878B
- Air Test Valves 868A and 868B.

The sodium hydroxide addition portion of the system operates during the injection phase and for approximately 30 minutes into the recirculation phase (LOCA only). This part of the system consists of the following primary components.

- Spray Additive Tank
- Air-Operated Tank Valves, 876A and 876B
- Manual Valves, 1839A and 1839B
- Manual Tank Isolation Valve 1841
- Check Valves, 1838A and 1838B
- Eductors Nos. 31 and 32
- Lines 188, 579, 187, 578
- Nitrogen Supply Valve 872B.

The following valve is used for periodic flushing of the eductors with borated water from the RWST and for the monthly pump tests:

- Manual Valve 873B (from suction header No. 181)

Sample and instrumentation lines and valves 3" diameter are noted in Figure 3 but are not included in the analysis because their failure will not effect system operation.

Lines and valves shown in Figure 3 for charcoal filter dousing are discussed in the section on containment fan coolers and filtration.

The RWST is evaluated as a separate interfacing system because it serves several systems.

The spray pumps, valve, and spray additive tank are located in the primary auxiliary building. Spray nozzles and their headers are located inside the containment building.

B.3.1.1 Major System Components

The major components of the system are described in the following paragraphs.

B.3.1.2 - Containment Spray Pumps

The spray pumps are of the horizontal, single stage, centrifugal type driven by electric motors and are each capable of delivering 2,600 gpm at 300 psig. The pumps are not fitted with flow or pressure instrumentation. The pumps have mechanical seals which do not require external cooling.

Each pump has a flow rate equal to 100% of the heat removal capability necessary to maintain containment pressure below the design pressure. Therefore, each pump has a flow rate sufficient to maintain containment integrity following a LOCA.

The two containment spray pumps are supplied with 480 volt power as follows (from individual breakers):

- Pump No. 31 Bus No. 5A
- Pump No. 32 Bus No. 6A.

Each pump breaker control circuit is identical and only the circuit of No. 31 pump will be discussed. Each breaker's control switch is located on the safeguards panel; status light indications are above each switch. There are two switches; one for pump No. 31 to control breaker 52/CS1 and one for pump No. 32 to control breaker 52/CS2. The switch has the following four positions (spring return to auto): (1) Pull-Out - The pump is disabled from starting by any automatic start signal. With the switch in this position the "Safeguards Equipment Locked Open" alarm will be annunciated on the safeguards panel in the CCR. (2) Stop - Pump will be stopped if it is running by energizing the trip coil. (3) Auto - Pump will be started by the containment spray initiation signal. (4) Start - Pump will be started.

When the pump is running it can be tripped by:

- Putting the switch to either the Stop or Pull-Out position.
- Undervoltage at the 480 volt bus No. 5A.
- By the closing of the recirculation phase switch RS-1 (pump No. 32 only).
- The magnetic overload breaker, from overcurrent.

B.3.1.3 Motor-Operated Pump Discharge Valve

There is one 8-inch motor-operated discharge valve in each of the two flow trains. These are MOVs 866A and 866B (see Figure 3). These are the only valves which are required to change position for the system to operate. Valve A is powered from MCC-36A and valve B from MCC-36B.

B.3.1.4 Air-Operated NaOH Addition Valves

The two air-operated valves in the discharge line from the spray additive tank are normally closed. These valves are in parallel so if either one opens, the NaOH solution can be obtained. These valves fail open upon loss of air. Air is provided from the instrument air system.

B.3.1.5 Spray Additive Tank

The spray additive tank is made of carbon steel and is lined with stainless steel to protect the tank from the highly corrosive caustic contained within. The tank contains at least a 30% concentration by weight of sodium hydroxide (NaOH). The NaOH is effective in removing elemental (inorganic) iodine by a trapping process (fixes iodine into a liquid phase). By removing the iodine from the containment atmosphere, the offsite thyroid dose is reduced. The NaOH will also increase the pH of the fluid in the sumps.

The level in the tank is monitored at the safeguards panel in the central control room (CCR) by level transmitter (LT) 931. This device signals level controller (LC) 931 to provide a low level alarm ("NaOH Tank Low-Level") at 80% level. The alarm is also on the safeguards panel. Tank level is also locally monitored by LI-932. Technical specifications require that the tank contain at least 4,000 gallons of a 30% NaOH solution by weight. This corresponds to a level of 75% of full scale. The level in the additive tank will be maintained above 80% (4,400 gallons) to preclude actuation of the low level alarm during normal plant operations.

Flow from the tank is measured by flow transmitter (FT) 930 which signals flow indicator (FI) 930 mounted on the safeguards panel. When flow is established with both pumps FI-930 flow is about 50 gpm. The tank is protected from overpressure by relief valve 1815 set at 275 psig with a capacity of 20 gpm. Valve 873A is provided for tank draining should repairs be necessary (not shown in Figure 3).

To prevent decomposition of the NaOH it is essential to maintain an inert atmosphere in the tank during long term storage. For this purpose a nitrogen supply is provided to the tank through manual valve 872B and line 578. A pressure on the order of 1/2 to 2 psig will be maintained in the tank during storage. The pressure is monitored locally on PI-930 and relieved when necessary through manual valve 871. This may be required during seasonal temperature changes. Two vacuum breakers are installed on the tank to admit air when NaOH is drawn from the tank.

B.3.1.6 Spray Nozzles

The stainless steel spray nozzles are of the ramp bottom design and are not subject to clogging by particles less than 1/4 inch in maximum dimension. The nozzles provide droplets of 1,000 micron diameter when a differential pressure of 40 psid exists across the nozzle. They are located in the containment building and are connected to four 360° ring headers of radii 8'2" (228.5' elevation), 25'4" (223.5' elevation), 42'3" (218.5' elevation) and 59'6" (213.5' elevation). There are two sets of 221 nozzles each (442 nozzles) distributed on the four headers. This nozzle and header arrangement results in maximum coverage with either branch of the system operating alone.

B.3.1.7 Liquid Jet Eductor

The means of adding NaOH to the spray water is provided by a liquid jet eductor. This is a device which uses the kinetic energy of a pressurized liquid to entrain another liquid, mix the two, and discharge the mixture against a counter pressure. The pressurized liquid is the spray pump discharge which is used to entrain the NaOH solution and discharge the mixture into the suction of the spray pumps. There is one eductor for each spray pump. They are located in the primary auxiliary building.

B.4 SYSTEM OPERATION

B.4.1 Normal System Arrangement

The system is, by nature, inactive and as such is arranged so as not to interfere with normal plant operation. The pumps are idle and are open to the RWST by locked open suction valves 865A and 865B. The motor operated discharge valves 866A and 866B are closed. The discharge header containment isolation valves (869A and 869B) are locked open. The spray additive tank is filled and is isolated by closed air operated valves 876A and 876B. All instrument valves are opened. Drain and test connection valves are closed and the pipe ends are capped. The spray additive tank N_2 supply and vent valves are closed. In-line tank discharge valve 1841 is locked opened and eductor valves 1839A and 1839B are locked open. Test valves 878A and 878B, 1806A and 1806B are locked closed. Test valve 1813 is closed. Air test valves 868A and 868B are locked closed and their ends capped.

B.4.2 System Actuation

Following a safety injection signal the containment spray system is brought into service by either of the following signals:

- High-High Containment Pressure - This signal occurs at approximately 50% of the containment design pressure (setpoint is 23 psig).

- Manual Initiation - Two buttons are <u>simultaneously</u> actuated on the safeguards panel.

If a spray signal is initiated by either of the above, the following will occur:

1. The spray pump discharge valves 866A and 866B are supplied with an open signal.

2. Both spray pumps will be signaled to start.

3. Two minutes after the spray signal is initiated the additive tank discharge valves 876A and 876B will be supplied with an open signal provided that the NaOH cancel button has not been pressed.

B.4.3 Automatic System Response

When the spray system is activated as described above both spray pumps will draw water from the RWST via line no. 181. The pumps discharge to the spray headers. The spray isolation motor-operated valves are provided with control switches on the safeguards panel and are normally closed. Position indicating lights are provided for each valve on the safeguards panel.

Unless cancelled by the operator a portion of the pump discharge is directed through the liquid jet eductor which draws the NaOH solution from the spray additive tank and injects the fluid into the spray flow.

A 2-minute time delay is utilized so that the operator can determine whether a primary of coolant leak or a steam line break has occurred, and if necessary, cancel the addition of NaOH (see Section B.4.4, Manual Operator Action).

It would take approximately 70 to 80 minutes to discharge the total NaOH solution in the spray additive tank using both pumps. For the first 15 to 22 minutes following the maximum loss-of-coolant accident, both spray pumps may be operating. After the injection phase has been completed, one spray pump will continue to operate for approximately 30 minutes to empty the RWST and complete the addition of NaOH. FI-930 will indicate flow from the additive tank. Containment pressure indicators (PI) 948A, 948B, 948C, and 949A, 949B, and 949C, are located in CCR on the safeguards panel. The system will be taken out of service after recirculation flow has been established by the eight-switch sequence (see the recirculation system description) and the RWST no longer contains enough coolant to continue running spray pump no. 31 (or no. 32 if no. 31 is inoperative).

B.4.4 Manual Operator Action

If the operator determines that the accident is a steam break, he has two minutes to press the "NaOH Cancel" button on the safeguards panel. This action will prevent valves 876A and 876B from opening and thus the addition of NaOH will be prevented. The "NaOH Cancel" button is provided to reduce the chances of accidental NaOH injection and also to avoid NaOH injection when the type of accident will not result in

fission product release to the containment atmosphere. This "Cancel" decision may be defeated at any later time by opening both valves by using their control switches on the safeguards panel. Each valve is provided with a control switch and position indicating lights on the safeguards panel.

B.4.5 Charcoal Filter Dousing

The ten motor-operated spray valves, 880A through 880K (no "I") are normally closed and upon being opened each will annunciate the "Safeguards Valves Off Normal Position" alarm. Each valve has a control switch and indicator lights located on the safety injection supervisory panel. (For further details see containment fan cooling, Section B.3.)

B.5 ALARMS

Alarms are generated to warn the operator that an unsatisfactory condition exists, and appropriate corrective action is required. Only those alarms directly concerned with the containment spray system are discussed. All the following alarms are annunciated on the two safeguards panels.

1. Safeguards Valve Off Normal Position - common alarm, generated when any engineered safeguards system valve leaves the position called for during normal plant operations. Only valves directly used in the spray system are listed:

Valve No.	Normal Position	Alarms When	Valve Name
880A through 880K	Closed	Valve leaves full closed	Charcoal filter dousing units.
889A 889B	Closed	Valve leaves full closed	Outlet of RHR heat exchangers to inlet of Spray Header.
1613	Closed	Valve open	Spray test line to RWST.

2. Spray Additive Tank Low-Level - alarm generated when the level in the additive tank decreases to 80%.

3. Safeguards Equipment Locked Open - common alarm, generated when control switch for either of the spray pumps is placed in the Pull-Out position.

4. High-High Containment Pressure - common alarm, actuated when 1/6 pressure detectors indicate 23 psig within containment.

5. 480V Switchgear Motor Trip - common alarm, annunciated when either pump trips due to overload.

B.6 INTERFACES WITH OTHER SYSTEMS

Following a LOCA the containment spray system* including NaOH addition depends upon the following systems:

1. The Refueling Water Storage Tank - to store and provide borated water for the functions of the system.

2. Electrical Power - pump and valve operation (see Table 2 for list of buses and MCCs).

3. Safeguards Actuation System (for the system start signals).

B.7 SYSTEM TEST AND MAINTENANCE

At regular intervals portions of the system are inspected and tested for proper functioning. At other times, items of equipment are rendered inoperative because of maintenance actions. In the case of testing, the system can usually be quickly returned to operational status. In the case of maintenance this may not be possible; the times allowed before shutdown are specified as operating limits. Both conditions can effect system availability as discussed below.

B.7.1 System/Component Tests

The containment spray system is a principal plant safeguard that is normally on standby during reactor operation. Complete system tests cannot be performed when the reactor is operating because a safety injection signal causes reactor trip, main feedwater isolation and containment isolation, and a containment spray system test requires the system to be temporarily disabled. The method of assuring operability is by combined systems tests performed during refueling shutdowns, with more frequent component tests, which can be performed during reactor operation.

The refueling test demonstrates proper automatic operation of the containment spray system. With the pumps blocked, the components receive the safeguards actuation signal in the proper sequence. The test demonstrates the operation of the valves, pump circuit breakers, and automatic circuitry.

*This system is redundant to the containment fan coolers for containment heat removal and pressure reduction. When necessary, the containment spray system provides dousing water for the fan cooler charcoal filters.

The pumps are started manually from the control room on a monthly basis. Only one pump is run at a time, followed by return of that flowpath to the valve lineup required for containment spray before another pump is tested. A pump must run for at least 15 minutes for a successful test. Motor-operated valves are stroked monthly from the control room, as part of the pump operability tests.

During reactor operation, the instrumentation is generally checked on each shift and the initiating circuits tested monthly. The testing is discussed in the safeguards actuation system description.

The sodium hydroxide addition system is partially tested whenever the associated spray pump is tested, i.e., monthly. Because of the corrosiveness of the sodium hydroxide, flow from the spray additive tank is not tested. The eductor, however, is tested by opening the locked closed valve 673B to the RWST header. This permits flushing of the eductor, proving that it functions properly. Spray nozzles are checked with air every 5 years by means of air or infrared techniques. Concentration of NaOH solution in the spray additive tank is checked monthly.

Table 3 summarizes the test/inspection requirements.

3.7.2 Maintenance Time Limits

According to unit technical specifications, one containment spray pump may be out of service for a period not to exceed 24 hours, provided three of the five fan cooler units are operable and the remaining containment spray pump is demonstrated to be operable.

Any valve required for the functioning of the system during and following accident conditions may be inoperable provide it is restored to an operable status within 24 hours and all valves in the system that provide the duplicate function are demonstrated to be operable.

One of the sodium hydroxide trains can be out of service for up to 7 days providing the other trains and its containment spray pump are operable.

Any maintenance of the spray additive tank requires reactor shutdown.

C. SYSTEM LOGIC MODELS

C.1 TOP UNDESIRED EVENTS

Two different fault tree models have been constructed to evaluate the frequency of:

1. Insufficient borated water sprayed into containment (containment spray during injection).

2. Insufficient solution injected into containment (sodium hydroxide addition).

The two different fault trees correspond to the event tree events of containment spray (CS) and sodium hydroxide addition (NA), respectively.

C.2 SYSTEM FAULT TREE MODELS

The fault tree for the containment spray (CS) event (item 1 above) is shown in Figure 4. INHIBIT gates below the top event OR gate condition subsequent gates depending on test or maintenance states of the system. The tree is also conditional upon success of the following other systems:

- RWST Borated Water Supply (evaluated elsewhere as a separate system)
- Electrical Power to Supply Buses and MCCs
- Automatic Start Signal.

The fault tree for the sodium hydroxide additions (NA) event (item 2 above) is shown in Figure 5. The system depends upon a particular spray pump circuit associated with its eductor, therefore, the spray pumps are shown here in addition to Figure 4. (The failure frequencies for the spray pump circuit are those derived from analysis of the CS fault tree analysis. This introduces some pessimism into the overall event tree sequences but the compromise is necessary because of the way in which CS and NA are considered as two separate systems in the event tree.)

C.3 BASIC EVENT CODES

Tables 4 and 5 list the basic event codes appearing in the two fault trees. Several "house" events appear in the trees showing dependency on the support systems list above. These have been coded as though they were basic events but are not listed in the tables.

Also shown in Tables 4 and 5 are the applicable failure modes and their plant-specific failure rates with reference to the list of components.

C.4 MINIMAL CUTSETS

Minimal cutsets for both fault trees have been identified using the computer code RAS. These combinations are listed in Tables 6 and 7. The dominant cutsets are identified through quantifications in

Section D. Single failures are identified by these tables and are also illustrated in Figures 1 and 2.

C.4.1 Containment Spray

For the fault tree shown in Figure 4 and considering only hardware failures, there is one single event cutset (single failure point). This is the passive component, line 161, from the RWST to the two spray pumps.

- CPPC161G: Suction line from RWST.

The failure mode is plugging of the line--a very low probability event. Rupture of this line would also cause failure of the system; however, because of the large volume of water that would be released it would be immediately detected and the reactor shut down. For this reason the rupture failure mode was not listed.

There are 81 double event cutsets and these are listed in Table 6. Only single and double cutsets are evaluated.

C.4.2 Sodium Hydroxide Addition

For the fault tree shown in Figure 5 and considering only random hardware failure as in Section C.4.1 above, there are four single event cutsets in the sodium hydroxide addition system. These are:

- CTKNAOHG: Plugging of (or failure to obtain solution from) the spray additive tank.
- [illegible]: Mechanical failure closed of tank valve 1841 (a locked open valve).
- [illegible]: Locked closed test valve 873B left open (human error).
- SASCAOWK: No automatic open signal to AOVs 876A and 876B.

The demand failure frequencies of these single failure points are given in Section D.

There are 17 double event cutsets. Both single and double cutsets are listed in Table 7. These are all of the possible random hardware failure cutsets for the fault tree logic model.

D. QUANTIFICATION

D.1 CONTAINMENT SPRAY

D.1.1 System States

Whenever the reactor is not shut down, this system will be in one of the following three states:

1. Neither train out for test or maintenance
2. One or the other train out for maintenance
3. One or the other train out for test.

Based upon plant-specific data, a containment spray pump is unavailable due to testing for an average of 45 15 minutes each 30 days/month (the tolerance noted is an estimate).

Train Unavailable Due to Test: Mean: 1.0×10^{-3}

Variance: 5.9×10^{-8}.

During the period 1976 to 1980, two maintenance events have been performed on the containment spray pumps. The total cumulative pump hours is 99,600 and the out-of-service time is 20 hours (out-of-service time cannot exceed 24 hours because of operating limits).

Train Unavailable Due to Maintenance: Mean: 7.3×10^{-4}

Variance: 5.3×10^{-8}.

These state values are the conditional events for the INHIBIT gate shown in the fault tree Figure 4 sheet 1.

D.1.2 Input Condition

Two input conditions have been considered:

- Both 480 VAC buses available
- Bus 5A or Bus 6A failed.

The above conditions are evaluated as ON/OFF events. Failure rate data used in subsequent quantifications are summarized in Table 4.

D.1.3 Both 480 VAC Buses Available

Random Hardware Failures

For Trains A or B, the following is the quantification of mean random hardware failures (reference Table 4 for data).

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Locked Open Valve 866 mechanical closing and considering monthly inspections:

$$\text{Mean } \alpha_{\lambda V_1} = 9.1 \times 10^{-8} \left(\frac{720}{2}\right) = 3.3 \times 10^{-5}$$

Variance = 1.3×10^{-9}.

Spray Pump and Motor 31 (or 32) the failure to start and failure to run for an average of 120 minutes is:

Mean $\alpha_p = 1.4 \times 10^{-3}$

Variance = 1.2×10^{-6}.

MOV 866 fails to open:

Mean $\alpha_{MV} = 1.5 \times 10^{-3}$

Variance = 2.6×10^{-6}.

Check Valve 867 stuck closed:

Mean $\alpha_{CV} = 6.9 \times 10^{-5}$

Variance = 1.0×10^{-8}.

Locked Open Containment Manual Valve 869 closing mechanical (same as valve 866 above):

Mean $\alpha_{\lambda V_2} = 3.3 \times 10^{-5}$

Variance = 1.3×10^{-9}.

Spray Nozzles (221) Plugging sufficient to fail the system: the spray nozzles and spray headers are maintained in a dry condition and are inspected every 5 years. Because of the environment in which these nozzles exist, large scale corrosion, which could be sufficient to plug the spray nozzles, will not occur. For this reason, the frequency of plugging of the nozzles is assigned a negligibly small frequency.

The one single-event cutset of suction pipe 181 plugging based on 1 week detection time is very small and does not contribute significantly to system failure.

Failure of One Train

Then, summing the above means:

Mean: 3.1×10^{-3}, Train A (or B)

Variance: 3.6×10^{-6}.

Total Random Failures

For the state condition of neither train out for test or maintenance, both trains failing is:

$$\text{Mean } CS_R = \text{pump train } 2 = 1.3 \times 10^{-5}$$

One Train Out For Maintenance

For the state conditions of Train A or B out for maintenance (state availability) and random failure of the other train:

$$\text{Mean } CS_M = 2(3.1 \times 10^{-3})(7.3 \times 10^{-4}) = 4.5 \times 10^{-6}.$$

One Train Out For Test

For the state conditions of Train A or B out for test (state availability) and the failure to reopen valve 869A or 869B, we have:

$$\text{Mean } CS_T = 2(3.1 \times 10^{-3})(1.0 \times 10^{-3})(9.0 \times 10^{-3})^{*} = 5.6 \times 10^{-8}.$$

Human Error

Each train is tested monthly. This test requires the closing of the manual containment isolation valve, 869A or 869B, for the pump train under test. The human error for this event is made up of the error of omission, failing to reopen the valve, and the probability of not discovering the error of omission. From the chapter, Human Error Rates, the following human error rates for these two errors are used:

Error	Mean	Variance
1. Failure to restore valve to proper position.	9.0×10^{-3}	1.8×10^{-4}
2. Failure to discover error #1.	2.2×10^{-2}	1.9×10^{-3}

The following expression defines the contribution of this human error to system failure:

$$Q_{\text{Human error}} = P_{(\text{both})}P_{(\text{nondiscovery})} + 2P_{(\text{one})}P_{(\text{nondiscovery})}P_{(\text{pump train})}.$$

*The value 9.0×10^{-3} is used for event CXV869A(orB)Q because it is judged that, following a LOCA which occurs when a train flow test is being performed, the operator may not think to open the containment isolation valve.

$P_{(both)}$ is the frequency of both valves being closed due to operator error. With low dependence between the actions, $P_{(both)}$

$$P_{(both)} = P_{(one)} \left[\frac{1-19[P_{(one)}]}{20}\right]$$

$P_{(nondiscovery)}$ is the probability of not discovering the error of omission.

$P_{(one)}$ is the frequency for a single valve being closed due to operator error.

$P_{(pump\ train)}$ is the frequency of failure of a single pump train due to random failures.

The human error contribution is:

Mean, $CS_H = 1.4 \times 10^{-5}$

Variance $= 1.3 \times 10^{-9}$.

Common Cause

Common cause failures of the same type component in different trains could occur but the probability in a standby system that is tested monthly and can be maintained during reactor operation is judged to be very small. Additionally, common external causes such as fire or flooding are evaluated elsewhere in this study and incorporated in the event mitigating sequences. For these reasons no common cause contribution has been assigned to the system.

Total Unavailability - Electric Power Available

Total containment spray system unavailability when electric power is available (normal and emergency) is:

Mean, $CS_{sys} = CS_R + CS_M + CS_T + CS_H$

$= 3.0 \times 10^{-5}$

Variance $= 1.1 \times 10^{-9}$.

Table 8 lists the dominant causes of unavailability and the effects.

Next, the condition of loss of either bus 5A or 6A is analyzed.

D.1.4 Bus 5A (Or 6A) Failed

Failure of one main bus 5A or 6A will disable one train. The other train will be unaffected. The following expression defines the frequency of system failure given loss of power to a single 460V bus:

$$Q_{system} = P(\text{pump train}) + P(\text{maintenance}) + P(\text{test})$$

$$[P(\text{both})\ P(\text{nondiscovery}) + P(\text{one})P(\text{nondiscovery})].$$

The frequency of system failure, given a loss of a single 480V bus is now:

Mean, CS system: 4.0×10^{-3}

Variance: 3.1×10^{-6}.

Table 9 lists the major causes of system failure and system unavailability given bus 5A or 6A unavailable.

D.1.5 Pipe Failures

Pipe failures in the containment spray system have been evaluated quantitatively in Table 10. Plugging of lines would be detected monthly; rupture would be readily detected because of the large amount of water that would be released, even if the system was not operating. Plugging of these large-diameter pipes is considered to be very remote.

There is a slight possibility of line rupture during system operation. Using our value of 8.6×10^{-10} occurrences/hour per section for rupture, the four sections in this system result in an overall failure 3.4×10^{-9}/hour. Allowing for a two-hour system run time, the unavailability would be 6.8×10^{-9} and would not change the system unavailability values calculated above.

D.2 SODIUM HYDROXIDE ADDITION

D.2.1 System States

This system has two states:

1. Both containment spray trains operative
2. One or the other containment spray train inoperative.

D.2.2 Random Hardware Failures

There are three single failures which will fail the system. They are:

- No NaOH from tank
- Valve 1841 not open
- Valve 873B not closed.

In addition, if neither AOV 876A or B open, the system will fail.

Failure to obtain NaOH solution from the spray additive tank is expected with a frequency of: Mean = 2.0×10^{-6}/hr. The causes of failure include vacuum breaker not open, no solution in tank, plugging of the outlet, tank rupture, etc. The tank is inspected monthly so the mean out-of-service time is 365 hours. The unavailability is:

Mean α_{TK} = $(2.0 \times 10^{-6})(365) = 7.3 \times 10^{-4}$

Variance = 7.9×10^{-8}.

Manual valve 1841 at the tank outlet can fail mechanically to the closed position which is expected to occur with the unavailability:

Mean α_{V_1} = 3.3×10^{-5}

Variance = 1.3×10^{-9}.

Manual valve 873 from the RWST for eductor flushing will fail the system if it is not closed following the monthly system test. This is a human error which will be considered later.

Failure of both air-operated valves from the spray additive tank to open will fail the system. These are fail-open valves but could mechanically fail to open with a frequency of:

Mean: 4.95×10^{-4}

Variance: 4.03×10^{-7}.

Failure of both valves is:

Mean α_{V_2} = 6.3×10^{-7}

Variance = 1.6×10^{-11}.

The sum of the single random failure contribution to sodium hydroxide system failure is:

Mean: 7.6×10^{-4}

Variance: 7.8×10^{-8}.

An eductor train consists of a manual valve, check valve, and eductor. These serial components are summed as follows:

Component Failure Unavailability Contribution	Mean	Variance
Manual Valve 1839, not open	3.3×10^{-5}	1.3×10^{-9}
Check Valve 1838, stuck shut	6.9×10^{-5}	1.0×10^{-8}
Eductor plugged	2.4×10^{-4}	3.3×10^{-7}
Total Eductor Train #31 or 32	3.4×10^{-4}	2.7×10^{-7}

When both containment spray trains are operating, the unavailability of both eductor trains is:

$$\text{Mean } \alpha_E = 3.9 \times 10^{-7}$$

$$\text{Variance} = 1.0 \times 10^{-11}.$$

When only one containment spray train is operating:

$$\text{Mean } \alpha_{E_1} = 3.4 \times 10^{-4}$$

$$\text{Variance} = 2.7 \times 10^{-7}.$$

Test

When the containment spray system is tested, the eductors are also tested; therefore, the unavailability for test of this system has been accounted for in the containment spray unavailability.

Maintenance

Any maintenance that is required to be performed on this system requires that the plant be shut down.

Human Error

Failure to reclose valve 8732 from the RWST following an eductor test will render the NaOH system ineffective. This type of failure is composed of two types of human errors: 1) failure to reposition a valve after completing a test (due perhaps to a change in shift) and 2) failure of a second operator to discover the mistake.

Using the error rates shown in Section D.1, the human error contribution to the system unavailability is:

$$\text{Mean } NA_H = 2.0 \times 10^{-4}$$

$$\text{Variance} = 2.4 \times 10^{-7}.$$

Common Cause

Both eductor trains could fail due to plugging of the eductors by sediment from the spray additive tank. Utilizing a beta factor of 1.0×10^{-2} (1/100 years) and the value for NaOH eductor train unavailability given that containment spray is available, common cause failures of system will occur with the following frequency assuming that the probability of sediment is 1.0×10^{-4}:

$$\text{Mean, } NA_C = (3.0 \times 10^{-4})(1.0 \times 10^{-2})(1 - 3.1 \times 10^{-3})(1.0 \times 10^{4})$$

$$= 3.0 \times 10^{-10}$$

<u>Pipe Failures</u>

Pipe failures in the sodium hydroxide system have been evaluated qualitatively in Table 11. There are three sections, one from the spray additive tank, failure of which fails the system, and a spray flow line through each eductor, the failure of which will fail that train. As discussed in D.1.f, the resulting unavailabilities do not alter the system values calculated previously.

<u>Total Unavailability</u>

The total NaOH addition unavailability for the case "Both 480V Buses Available" is:

$$\text{Mean, } NA_{sys} = 9.6 \times 10^{-4}$$

$$\text{Variance} = 2.8 \times 10^{-7}.$$

This result is dominated by the passive single failures of the system.

With power available at only one 480V bus, only one spray pump train is available. Under this condition, the unavailability of the NaOH system is:

$$\text{Mean, } NA_{sys} = 1.3 \times 10^{-3}$$

$$\text{Variance} = 6.7 \times 10^{-6}.$$

This result is dominated by random failures in the spray additive tank, the tank outlet valves, and the eductor train.

Tables 12 and 13 summarize the causes of sodium hydroxide addition system failure.

D.3 STATISTICAL SUMMARY

The results of the systems' quantification have been summarized in Table 1. Median and percentile values were calculated by computer program DPD using component mean and variances and system reliability equations.

TABLE 1

SUMMARY OF RESULTS

CONTAINMENT SPRAY

Condition	Mean	Variance	5th Percentile	Median	95th Percentile
Electric power to buses 5A and 6A.	3.0×10^{-5}	1.1×10^{-9}	6.5×10^{-6}	1.5×10^{-4}	6.1×10^{-3}
No electric power to one bus (5A or 6A).	4.0×10^{-3}	3.1×10^{-6}	1.9×10^{-3}	3.3×10^{-3}	6.5×10^{-3}
WASH-1400	Not given	Not given	1.0×10^{-3}	2.4×10^{-3}	7.8×10^{-3}

SODIUM HYDROXIDE ADDITION

Condition	Mean	Variance	5th Percentile	Median	95th Percentile
Electric power to buses 5A and 6A.	9.6×10^{-4}	2.8×10^{-7}	4.7×10^{-4}	8.3×10^{-4}	1.5×10^{-3}
No electric power to one bus (5A or 6A).	1.3×10^{-3}	6.7×10^{-6}	2.4×10^{-4}	1.1×10^{-3}	4.8×10^{-3}
WASH-1400	Not given	Not given	3.6×10^{-3}	5.9×10^{-3}	1.1×10^{-2}

TABLE 2

ELECTRICAL INTERFACES

Component	Power Supply
Containment Spray Pump 31	480 VAC Bus 5A and Breaker 52/CS1
Containment Spray Pump 32	480 VAC Bus 6A and Breaker 52/CS2
Discharge Stop Valves:	
MOV866A	MCC 36A
MOV866B	MCC 36B

TABLE 3

TESTING AND INSPECTION

Component	Test/Inspection	Frequency	Reference
Spray Pumps 31 and 32	Start and run for 15 minutes minimum	Monthly	Appendix A to License DPR-64 Technical Specification and Basis.
Discharge Stop Valves MOV866A and B	Verify opened and closed	Monthly as part of pump test and quarterly	Appendix A to License DPR-64 Technical Specification and Basis.
Containment Isolation Valves	Verify closed and opened	Monthly	Appendix A to License DPR-64 Technical Specification and Basis.
Eductors	Verify not plugged	Monthly and quarterly	Plant Procedures
Locked Valves (all)	Verify locked in proper position	Weekly	Appendix A to License DPR-64 Technical Specification and Basis.
Spray Additive Tank Level	Verify 75% full	Quarterly	Plant Procedures
NaOH Concentration in Spray Additive Tank	Verify 30% minimum by weight	Monthly	Appendix A to License DPR-64 Technical Specification and Basis.
Spray Nozzles	Flow check	Every 5 years	Appendix A to License DPR-64 Technical Speci-

TABLE 4

CONTAINMENT SPRAY SYSTEM COMPONENT DATA

Component and F. T. Code	Failure Mode	Normal State	Failure Rate Mean/Variance [Demand (D) or Hourly (H)]	Data Source Table B.2-2 (item #)
Motor-Operated Valve				
CMV 866AQ	Failure to open	Closed	1.5×10^{-3}/ 2.6×10^{-6} [D]	6
CMV 866BQ	Failure to open	Closed		
CMV 866CQ	Failure to open	Closed		
CMV 866DQ	Failure to open	Closed		
Manually Operated Valve				
CXV 865AQ	Fails closed	Locked open	9.1×10^{-8}/ 1.0×10^{-14} [H]	1
CXV 865BQ	Fails closed	Locked open		
CXV 869AQ	Fails closed	Locked open		
CXV 869BQ	Fails closed	Locked open		
CXV 869AC	Left closed	Locked open	Human Error	see text
CXV 869BC	Left closed	Locked open		
Check Valve				
CCV 867AQ	Failure to open	Open	6.9×10^{-5}/ 1.0×10^{-8} [D]	3
CCV 867BQ	Failure to open	Open		
Containment Spray Pump and Motor				
CPMCS21N	Does not start or stop before 2 hrs.	Not running	1.4×10^{-3}/ 1.2×10^{-6} [D]	11
CPMCS22N	Does not start or stop before 2 hrs.	Not running	1.8×10^{-5}/ 6.4×10^{-8} [H]	19
Spray Nozzle Sets				
CNZ221AG	Plugging 50%	Passive	ϵ	(Estimated on the basis of engineering judgment.)
CNZ221BG	Plugging 50%	Passive		

TABLE 5

SODIUM HYDROXIDE ADDITION SYSTEM COMPONENT DATA

Component and F. T. Code	Failure Mode	Normal State	Failure Rate Mean/Variance	Data Source Table B.2-2 (item #)
Air-Operated Valves				
CAV 876AQ	Failure to open	Closed	5.00×10^{-4}	
CAV 876BQ	Failure to open	Closed	4.03×10^{-7}	8
			[D]	
Manual Valves				
CXV 873BX	Left open	Locked closed	Human Error	see text
CXV 1841Q	Fails closed	Locked open	9.10×10^{-8}	
CXV 839AQ	Fails closed	Locked open	1.00×10^{-14}	1
CXV 839BQ	Fails closed	Locked open	[H]	
Check Valves				
CCV 838AQ	Failure to open	Open	6.90×10^{-5}	
CCV 838BQ	Failure to open	Open	1.00×10^{-8}	3
			[D]	
Eductor				
CET0021G	Plugged	Passive	2.40×10^{-4}	(Estimated based
CET0022G	Plugged	Passive	3.30×10^{-7}	on engineering
			[D]	judgment.)
Spray Additive Tank				
CTKNAOHG	Failure to supply NaOH solution to system	Full	2.00×10^{-6}	(Estimated based
			6.10×10^{-13}	on engineering
			[H]	judgment.)

TABLE 6

CONTAINMENT SPRAY (CS) SYSTEM--INJECTION PHASE INDIAN POINT 3

CUT SETS WITH 1 BASIC EVENTS.

3)   1) CCS000DX   2) CPP1SING   3) CPS000DX

CUT SETS WITH 2 BASIC EVENTS.

7)	1)	CMV8G6BG	CMV8G6AJ	2)	CMV8G6BU	CCB15DX	3)	CMV8G6BU	CMOCS31T	4)	CMV8G6BU	CPMCS31P
11)	5)	CMV8G6BU	CXV8G5AU	6)	CMV8G6BU	CCV8G7AU	7)	CMV8G6BU	CXV8G7AQ	8)	CMV8G6BU	CSM221AG
15)	9)	CSM221AG	CCB12AX	10)	CSM221AG	CMOCS32T	11)	CSM221AG	CPMCS32P	12)	CSM221AG	CXV8G5AU
19)	13)	CSM221AG	CCV8G7AU	14)	CSM221AG	CXV8G9AU	15)	CSM221AG	CSM221BG	16)	CXV8G9AU	CCB12AX
23)	17)	CXV8G9AU	CMOCS32T	18)	CXV8G9AU	CPMCS32P	19)	CXV8G9AU	CXV8G5BG	20)	CXV8G9AU	CCV8G7AU
27)	21)	CXV8G9AU	CXV8G9BU	22)	CXV8G9AU	CSM221BG	23)	CCV8G7AU	CCB12AX	24)	CCV8G7AU	CMOCS32T
31)	25)	CCV8G7AU	CPMCS32P	26)	CCV8G7AU	CXV8G5AU	27)	CCV8G7AU	CCV8G7BU	28)	CCV8G7AU	CXV8G9BU
35)	29)	CCV8G7AU	CSM221BG	30)	CXV8G5AJ	CCB12AX	31)	CXV8G5AU	CMOCS32T	32)	CXV8G5AU	CPMCS32P
39)	33)	CXV8G5AU	CXV8G5BU	34)	CXV8G5AG	CCV8G7BQ	35)	CXV8G5AU	CXV8G9BU	36)	CXV8G5AG	CSM221BG
43)	37)	CCB15DX	CCB12AX	38)	CMOCS31T	CCB12AX	39)	CPMCS31P	CCB12AX	40)	CCB15DX	CMOCS32T
47)	41)	CMOCS31T	CMOCS32T	42)	CPMCS31P	CMOCS32T	43)	CCB15DX	CPMCS32P	44)	CMOCS31T	CPMCS32P
51)	45)	CPMCS31P	CPMCS32P	46)	CCB15DX	CXV8G5BU	47)	CMOCS31T	CXV8G5BU	48)	CPMCS31P	CXV8G5BU
55)	49)	CCB15DX	CCV8G7BU	50)	CMOCS31T	CCV8G7BU	51)	CPMCS31P	CCV8G7BU	52)	CCB15DX	CXV8G9BU
59)	53)	CMOCS31T	CXV8G9BU	54)	CPMCS31P	CXV8G9BU	55)	CCB15DX	CSM221BG	56)	CMOCS31T	CSM221BG
63)	57)	CPMCS31P	CSM221BG	58)	CMV8G6AU	CCB12AX	59)	CMV8G6AU	CMOCS32T	60)	CMV8G6AU	CPMCS32P
67)	61)	CMV8G6AU	CXV8G5BU	62)	CMV8G6AU	CCV8G7BU	63)	CMV8G6AU	CXV8G9BU	64)	CMV8G6AU	CSM221BG
71)	65)	CSM221AG	JBS16AK	66)	CXV8G9AU	JBS16AK	67)	CCV8G7AU	JBS16AK	68)	CXV8G5AU	JBS16AK
75)	69)	CCB15DX	JBS16AK	70)	CMOCS31T	JBS16AK	71)	CPMCS31P	JBS16AK	72)	CMV8G6AU	JBS16AK
79)	73)	CMV8G6BU	JBS16AK	74)	JBS16AK	CCB12AX	75)	JBS16AK	CMOCS32T	76)	JBS16AK	CPMCS32P
83)	77)	JBS16AK	CXV8G5BU	78)	JBS16AK	CCV8G7BU	79)	JBS16AK	CXV8G9BU	80)	JBS16AK	CSM221BG
84)	81)	JBS16AK	JBS16BK									

TABLE 7

SODIUM HYDROXIDE ADDITION (NA) INDIAN POINT 3 WITHOUT TEST AND MAINTENANCE

CUT SETS WITH 1 BASIC EVENTS.

4)	1) CTKNA0HG	2) CAV1B5IQ	3) CAVB73HX	4) SASCAUVK

CUT SETS WITH 2 BASIC EVENTS.

8)	1) CAVB70AU CAVB70BU	2) CETOO22G CETOO21G	3) CAVB190U CETOO21G	4) CCVB180U CETOO21G
12)	5) CPPLINBL CETOO21G	6) CETOO22G CAVB19AU	7) CAVB190U CAVB19AU	8) CCVB180U CAVB19AU
16)	9) CPPLINBL CAVB19AU	10) CETOO22G CCVB18AU	11) CAVB190U CCVB18AU	12) CCVB180U CCVB18AU
20)	13) CPPLINBL CCVB18AU	14) CETOO22G CPPLINAL	15) CAVB190U CPPLINAL	16) CCVB180U CPPLINAL
21)	17) CPPLINBL CPPLINAL			

TABLE 8

CONTAINMENT SPRAY SYSTEM UNAVAILABILITY [(5A) ∧ (6A)]

Cause	Mean Unavailability	Effects: Components	Effects: System	Effects: Other Systems
Total Random Failures	1.3×10^{-5}	Pumps and valves		
Maintenance	4.5×10^{-6}	Pumps and valves		
Testing	5.6×10^{-8}	Each train		
Human Error	1.4×10^{-5}	Manual Valves	fails	
Common Cause	small contribution	Combinations of same type components	fails	
TOTAL	3.0×10^{-5}			

Dominant contributors are random failures and human error.

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TABLE 9

CONTAINMENT SPRAY SYSTEM UNAVAILABILITY $[(\bar{5A}) \wedge (6A)]$ or $[(5A) \wedge (\bar{6A})]$

Cause	Mean Unavailability	Effects: Components	Effects: System	Effects: Other Systems
Random Failures	3.1×10^{-3}	Pumps and valves		
Maintenance	7.3×10^{-4}	Pumps and valves		
Testing	9.0×10^{-6}	Each train		
Human Error	2.0×10^{-4}	Manual Valves	fails	
Common Cause	small contribution	Combinations of same type components	fails	
TOTAL	4.0×10^{-3}			

Dominant contributor to system unavailability is random pump failure in the train with electrical power.

TABLE 10

EFFECTS OF CONTAINMENT SPRAY PIPE FAILURE

Pipe Section	Diameter (inches)	Failure Mode	Failure Effect
Line #181 from RWST to pump suction header and header to pumps.	12 or 10	Rupture	Loss of RWST water--would be detected and unit shut down.
		Plugging	Water unavailable to system causes system failure--detected at monthly pump test.
Lines from pumps discharge to spray headers.	8	Rupture	No water to spray header--loss of train readily detected and isolatable.
		Plugging	No water to spray header--loss of train--detected at monthly test.

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TABLE 11

EFFECTS OF SODIUM HYDROXIDE ADDITION SYSTEM PIPE FAILURES

Pipe Section	Diameter (inches)	Failure Mode	Failure Effect
Line from Spray Additive Tank	3	Rupture or Plugging	Loss of system
Lines and spray pump flow through eductors	3	Rupture or Plugging	Loss of eductor drain

TABLE 17

SODIUM HYDROXIDE ADDITION SYSTEM UNAVAILABILITY [(5A ∧ (6A)]

Cause	Mean Unavailability	Effects		
		Components	System	Other Systems
Total Random Failure	7.6×10^{-4}	Eductor or valves	Fails	None
Testing	Covered by Containment Spray	-	-	-
Maintenance	None	-	-	-
Human Error	2.0×10^{-4}	Manual valve	Fails	None
Common Cause	3.0×10^{-10}	Eductors plug	Fails	None
Other				
TOTAL	9.6×10^{-4}			

TABLE 13

SODIUM HYDROXIDE ADDITION SYSTEM UNAVAILABILITY $[(\overline{5A} \wedge (6A)]$ OR $[(5A \wedge (\overline{6A})]$

Cause	Mean Unavailability	Effects		
		Components	System	Other Systems
Total Random Failure	1.1×10^{-3}	Eductor or Valves	Fails	None
Testing	Covered by Containment Spray	-	-	-
Maintenance	None	-	-	-
Human Error	2.0×10^{-4}	Manual valve	Fails	None
Common Cause	3.0×10^{-10}	Eductors plug	Fails	None
Other	None identified			
TOTAL	1.3×10^{-3}			

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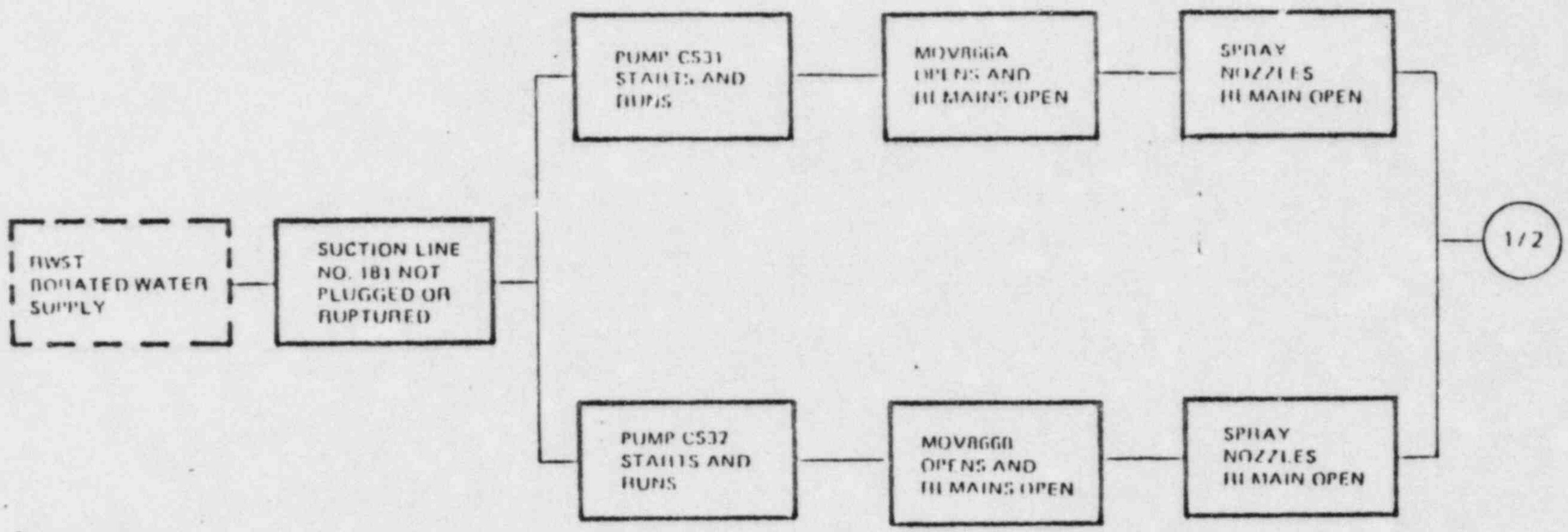


Figure 1. Reliability Block Diagram of Containment Spray System

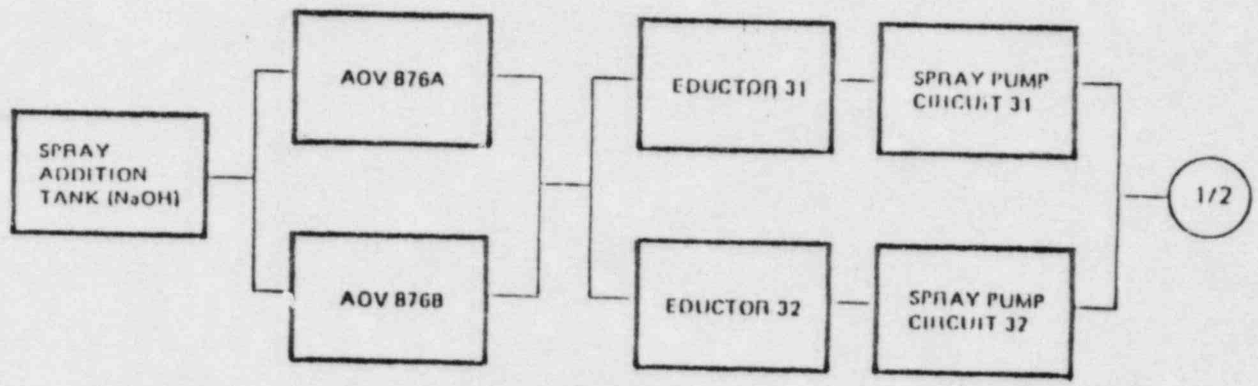


Figure 2. Reliability Block Diagram of NaOH Addition System

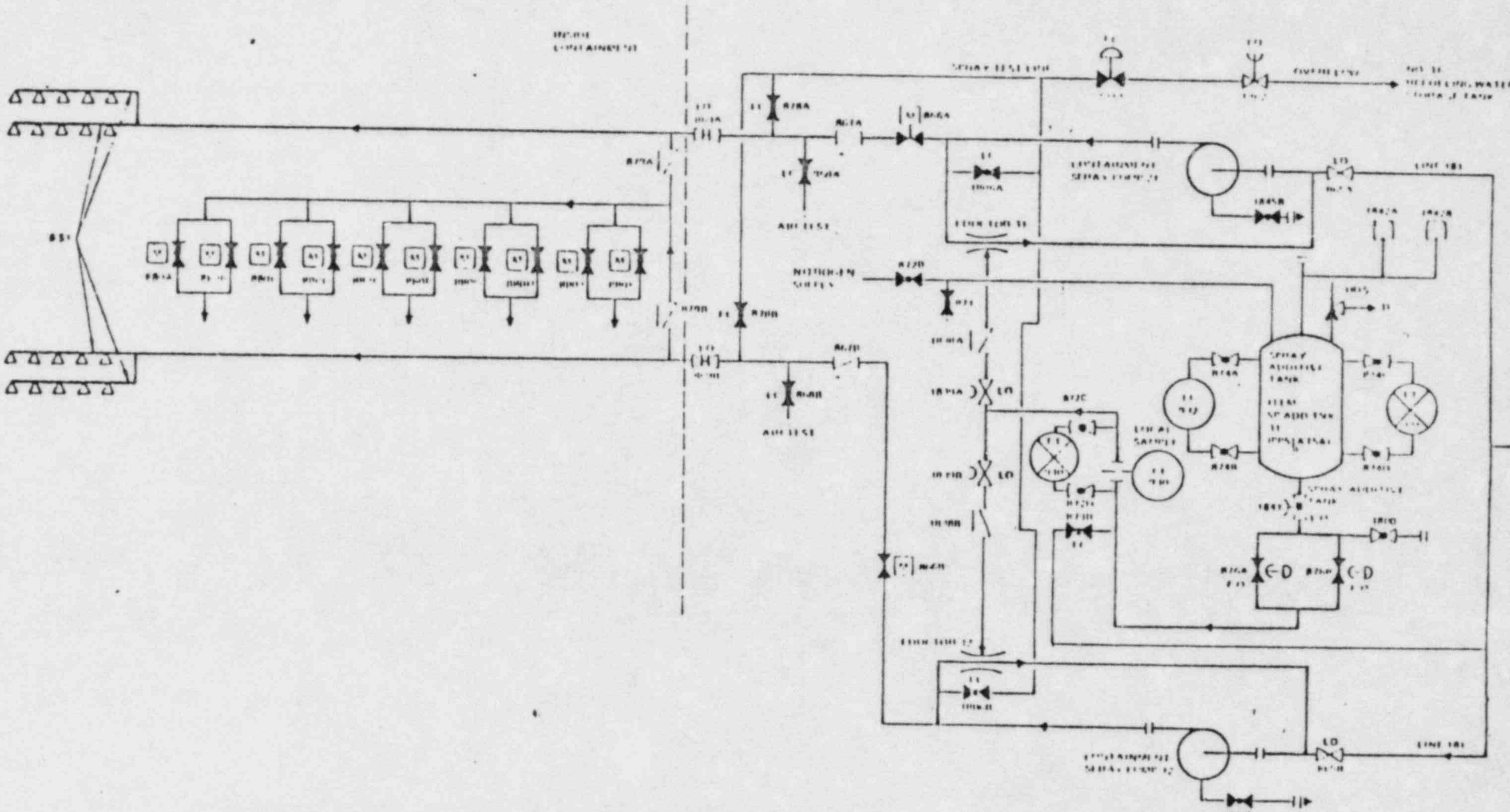


Figure 3. System P&ID Schematic

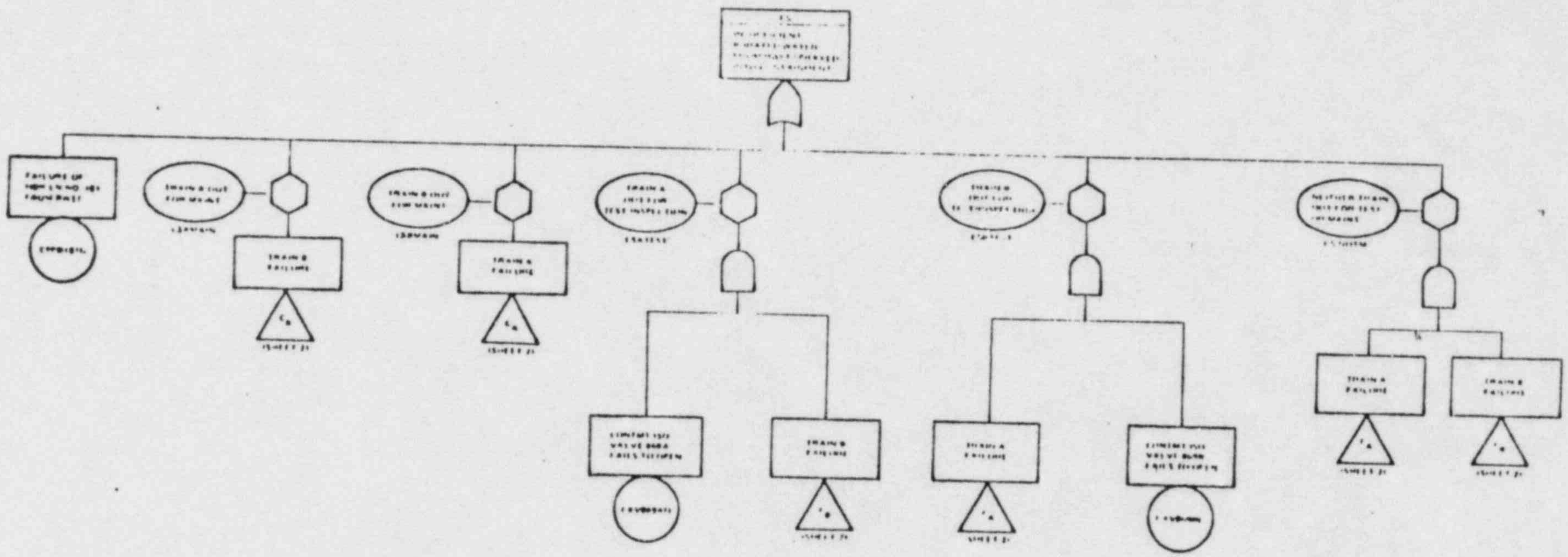


Figure 4. Fault Tree of Containment Spray System
(Sheet 1 of 4)

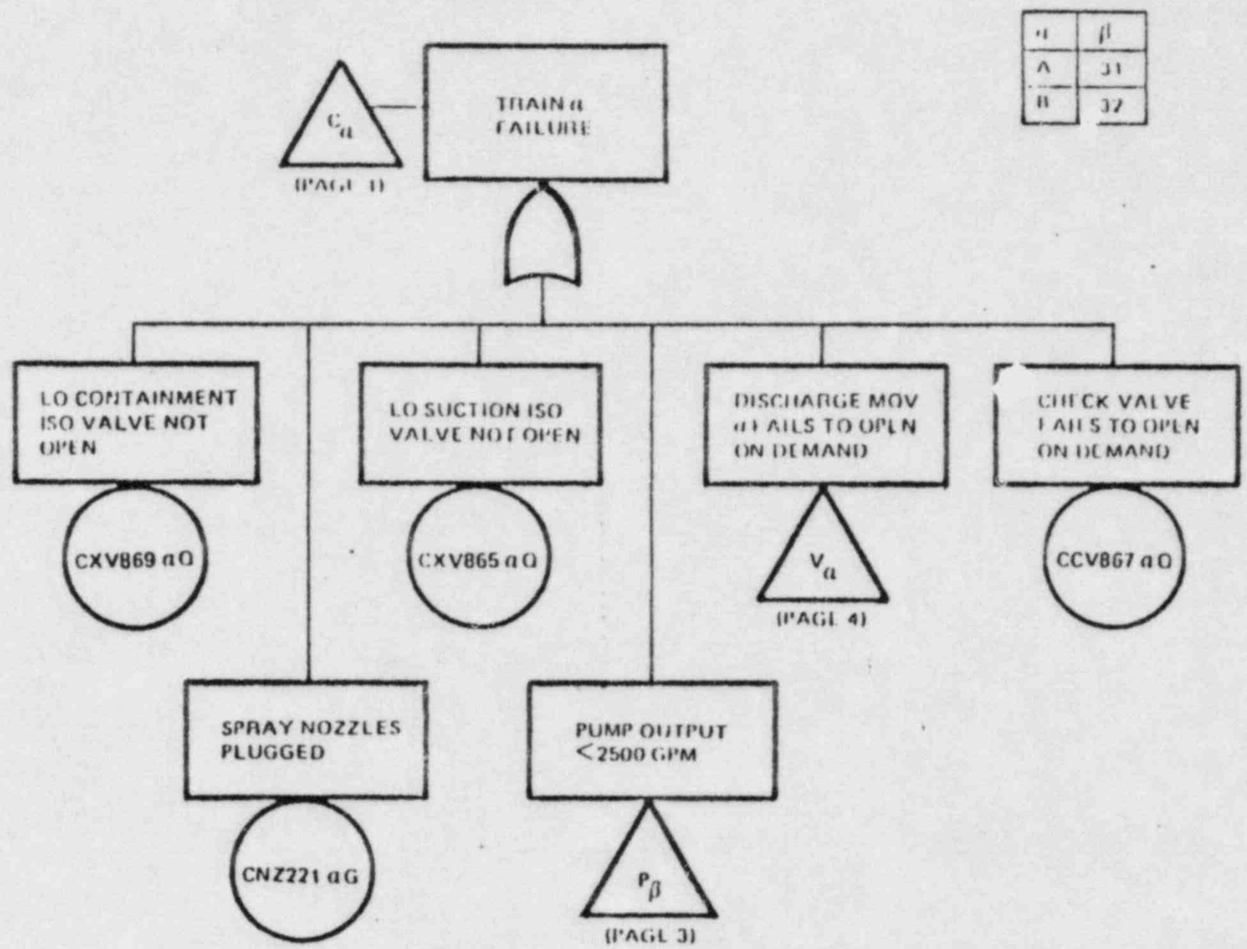


Figure 4. (Sheet 2 of 4)

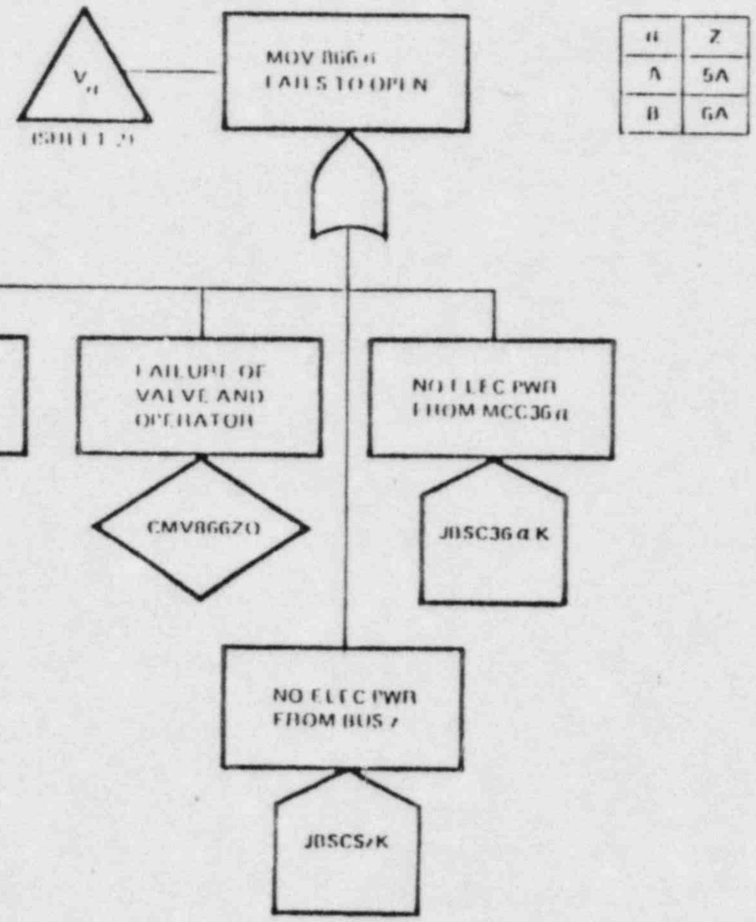


Figure 4. (Sheet 3 of 4)

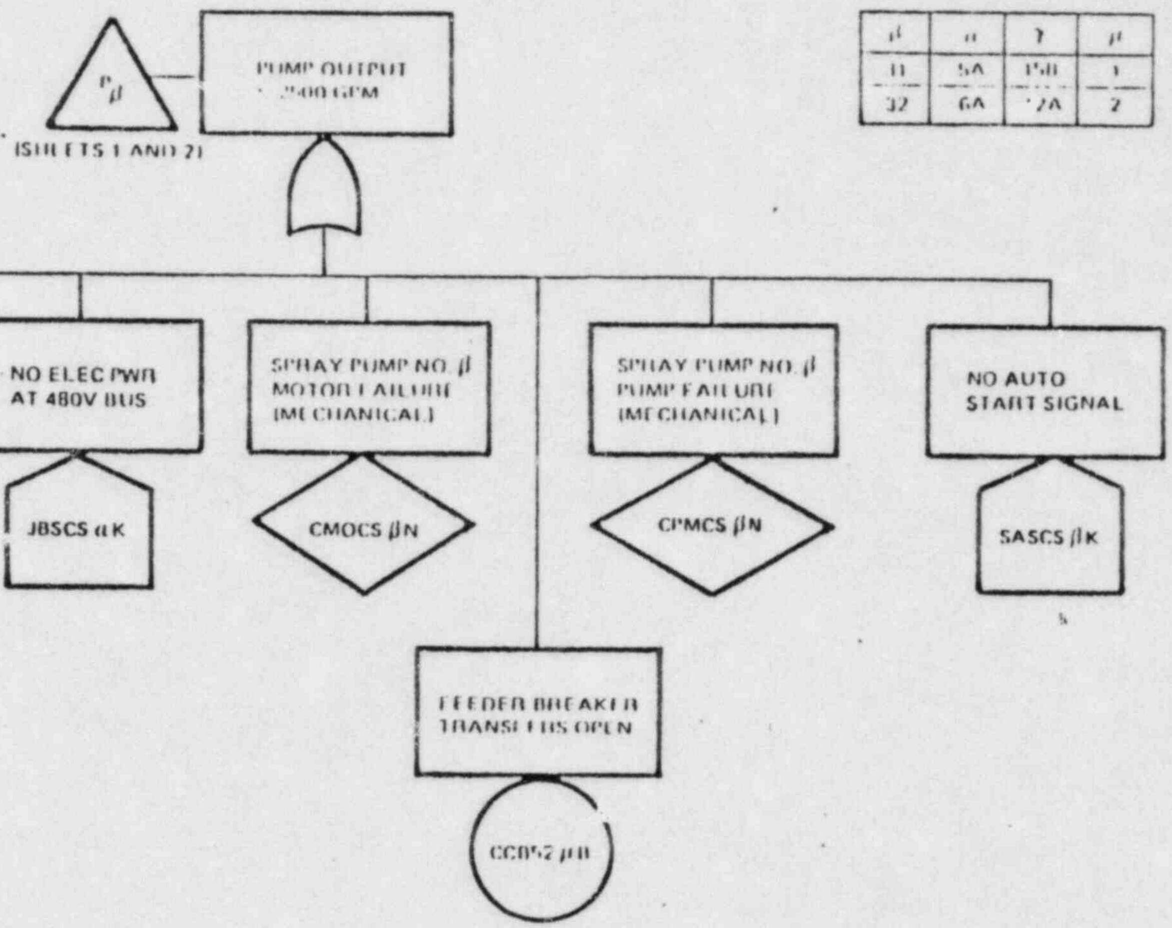


Figure 4. (Sheet 4 of 4)

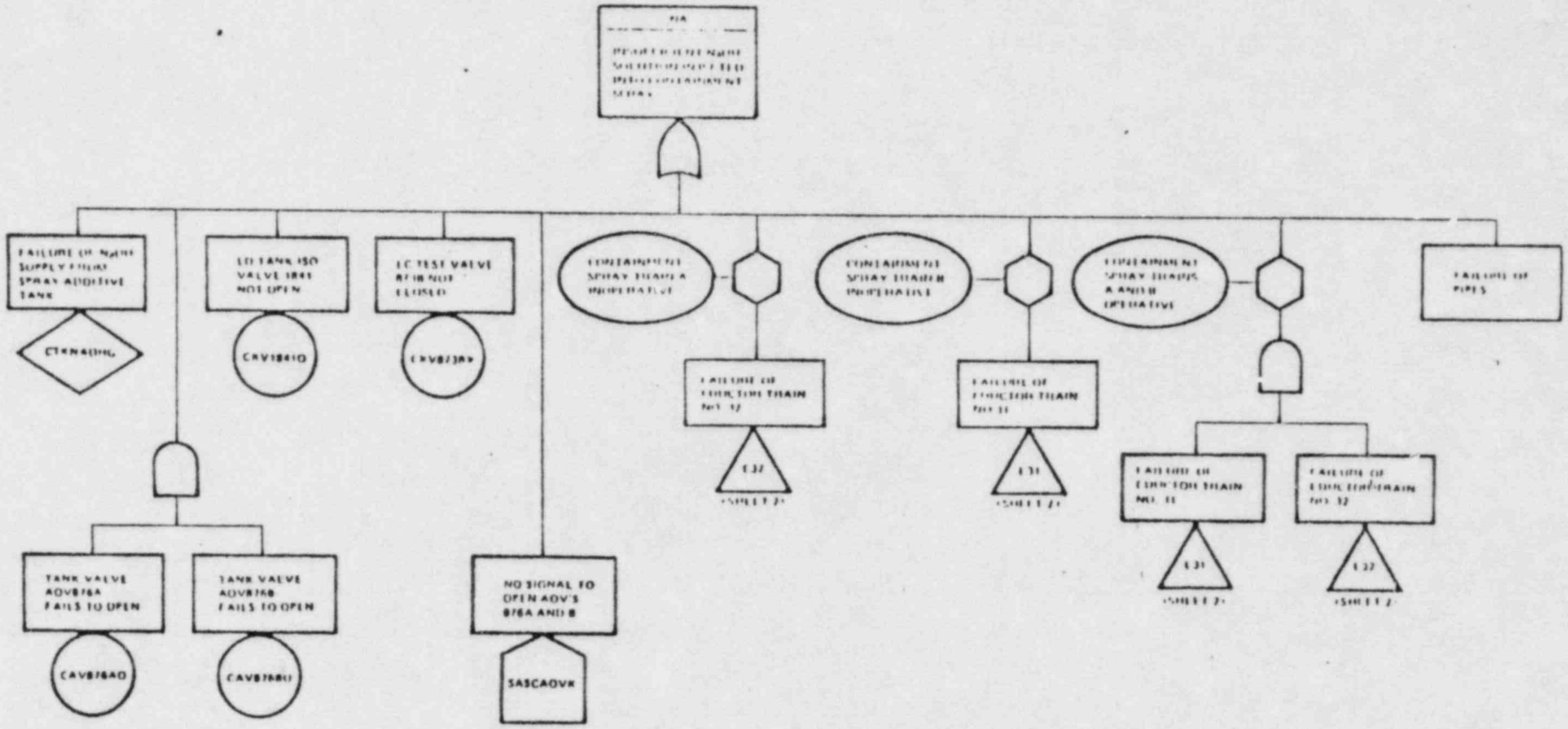
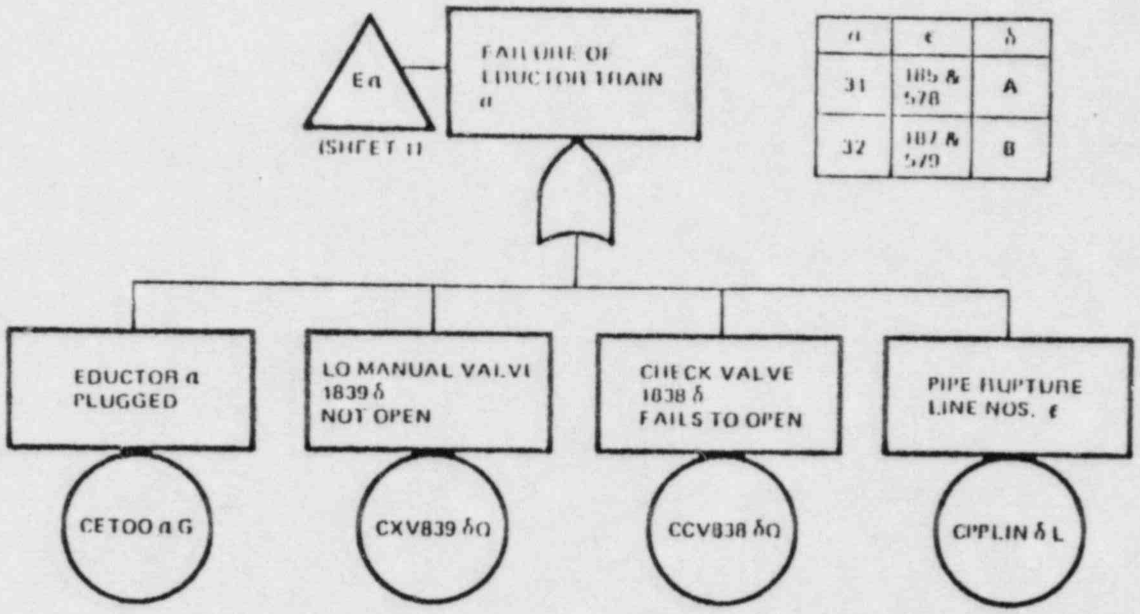


Figure 5. Fault Tree of NaOH Addition System
(Sheet 1 of 2)



α	ε	δ
31	185 & 578	A
32	187 & 579	B

Figure 5. (Sheet 2 of 2)