INEEL

IDAHO NATIONAL ENGINEERING & ENVIRONMENTAL LABORATORY

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NOTE/MESSAGE

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#14

The PRA model is based on the sled-mounted systems that are used at many current decommissioned plants. Information about existing decommissioned plants was gathered by decommissioning project managers (NRC Staff) during visits to four sites covering all four major nuclear steam supply system vendors (General Electric, Westinghouse, Babcock & Wilcox, and Combustion Engineering). The information collected by the staff was provided to the INEEL analysts.

System Description

Figure 1 is a simplified drawing of the system. The spent fuel pool cooling system (SFPC) is located in the SFP area and consists of motor-driven pumps, a heat exchanger, an ultimate heat sink, a makeup tank, filtration system and isolation valves. Suction is taken via one of the two pumps on the primary side from the spent fuel pool and is passed through the heat exchanger and returned back to the pool. One of the two pumps on the secondary side rejects the heat to the ultimate heat sink. A small amount of water from the suction line is diverted to the filtration process and is returned back into discharge line. A regular makeup system supplements the small losses due to evaporation. In the case of prolonged loss of SFPC system or loss of inventory events, the inventory in the pool can be made up using firewater system. There are two firewater pumps, one motor-driven (electric) and one diesel-driven, which provide firewater throughout the plant. A firewater hose station is provided in the SFP area. The firewater pumps are located in a separate structure.

General Assumptions

This analysis is based on the assumptions that the SFP and its support systems (including instrumentation and power sources) are similar to that found during staff visits to four decommissioned plants. The transfer of the last fuel from the reactor to the SFP is assumed to have occurred one year previously. This case is referred as the best case scenario throughout this document. The following general assumptions are made for this case:

- The SFP has instrumentation/indication/alarms in the control room to alert the operator of potential problems in the SFP. These may include level indications, temperature indications, and/or radiation monitors.

- The certified fuel handlers are former reactor operators who are knowledgeable of the facility, the maintenance procedures, and the surrounding community. It is assumed that these operators (through procedures and training) are aware of the available backup sources that can be used to replenish the SFP inventory (i.e., the fire protection pumps, or offsite sources such as from fire engines). Arrangements have been made in advance with fire stations including what is required from the fire department including equipment and tasks.

- The site has two operable firewater pumps, one diesel-driven and one electrically driven from offsite power.

- The makeup capability (with respect to volumetric flow) is assumed as follows:

Make-up pump:	20 - 30 gpm
Firewater pump:	100 - 200 gpm
Fire engine:	100 - 250 gpm [depending on hose size: 1-½" (100 gpm) or 2-½" (250 gpm)]

  It is therefore assumed that, for the larger loss of coolant inventory accidents, makeup through the makeup pumps is not feasible unless the source of inventory loss can be isolated.

- The operators perform walkdowns of the SFP area once per shift (8- to 12-hour shifts). A different crew member is assumed for the next shift. It is also assumed that the SFP water is clear and pool level is observable via a measuring stick in the pool that can alert operators to level changes.

- Requirements for fire detection and suppression may be reduced (when compared to those for an operating plant) and it is assumed that automatic detection and suppression capability may not be present.

- Overhead cranes have stops to help prevent heavy loads from being moved over the spent fuel pool.

- All equipment, including external sources (fire department), are available and in good working order.
- A complete set of procedures is available to operators that is function-oriented and allows early start of actions to restore cooling.

A sensitivity analysis was performed. For this case it was assumed that the SFP and its support systems are configured in a manner that is only slightly better than the minimum allowed by current NRC regulations. We believe that no prudent utility would configure its SFP system in this way, however, the assumptions in the "minimal state" are not precluded by current NRC regulations. This case is used to help provide safety insight to determine if there may be a need for additional regulation in this area. The following general assumptions are made for the sensitivity case:

- The control room has level and/or temperature indicators; however, these are not required to be maintained in an operable state. The radiation monitors and associated alarms in the control room are only required to be operable when fuel is being moved. In the PRA model, the control room instrumentation is assumed unavailable 10% of the time.
- The certified fuel handlers are individuals who meet the minimum training requirements. Plant staffing is assumed to be the minimum required. It is also assumed that the operators would walkdown the pool area less frequently.
- There is limited makeup capability (with respect to volumetric flow). Since there is no requirement that fire protection equipment to be maintained operable, no credit is taken for the diesel-driven firewater pump's ability to provide inventory makeup or fire suppression.
- Overhead cranes have stops to help prevent heavy loads from being moved over the spent fuel pool. Cranes are operated by non-nuclear trained operators.

In addition to the above assumptions, the following assumptions are applicable to both scenarios:

- The emergency diesel generators and support systems such as residual heat removal and service water (that could provide SFP cooling or makeup prior to the plant being decommissioned) have been removed from service.
- The SFP cooling system, its support systems, and the electric driven fire protection pump are fed off the same electrical bus.
- Procedures exist to mitigate small leaks from the SFP or for loss of SFP cooling system. However, it is assumed that these procedures are not sufficiently detailed to provide a timeframe as to when actions have to be completed. It is also assumed that there are no automatic actuations and that all pumps or valves have to be manually operated and aligned.
- The only significant technical specification applicable to SFPs is the requirement for radiation monitors to be operable when fuel is being moved. There are no T.S. requirements for the cooling pumps, makeup pumps, firewater pumps, or any of the support systems.
- In the estimation of tornado risk, it was assumed that an F4 or F5 tornado would be required if significant damage were to be possible to a PWR or BWR spent fuel pool. If a tornado of this magnitude is present at the plant site, it is assumed that the SFP integrity would be lost, leading to fuel uncovery. An F2 to F5 tornado could result in possible significant damage to the SFP support system. This is modeled as a loss of offsite power event (from severe weather).
- Shipping cask handling is the dominant heavy load operation. Spent fuel casks will be the only heavy loads moved over the spent fuel pool with sufficient mass to significantly damage the pool. It is assumed that crane operators will follow safe load path procedures when moving heavy loads near the spent fuel pool.
- Generic industry data was used for initiating event frequencies for the loss of offsite power, the loss of pool cooling, and the loss of coolant inventory.

- The effects of criticality were not considered in the risk evaluation. Its potential for impact on risk is considered to be very low.
- A seismic event is not addressed in this analysis as NRC is going to evaluate seismic risk using a 'check list' approach.

1.1. Loss of Cooling Event Tree

This event tree models generic loss of cooling events (i.e., those not related to other causes such as fire or loss of power, which are modeled in later sections). Figures 2 and 3 show the Loss of Cooling event timeline diagram and an event tree sequence progression.

1.1.1. Initiating Event LOC – Loss of Cooling

1.1.1.1. Event Description and Timing

This initiating event includes conditions arising from loss of coolant system flow due to the failure of pumps or valves, from piping failures, from an ineffective heat sink (e.g., loss of heat exchangers), or from a local loss of power (e.g., failure of electrical connections).

1.1.1.2. Relevant Assumptions

- If no action is taken to restore SFPC system, water level would reach to 3 ft above the top of fuel (defined endstate for this analysis) in 128 hrs.

1.1.1.3. Quantification

This initiator is represented by basic event IE-LOC. An initiation frequency of 3.0E-3/yr is taken from NUREG-1275, "Operating Experience Feedback Report – Assessment of Spent Fuel Cooling" (Ref 1). This represents loss of cooling events in which temperatures rose more than 20°F, and which resulted from failures of pumps, valves, piping, or from loss of heat sink (heat exchangers), or from local losses of power (e.g., electrical connections).

1.1.2. Top Event CRA – Control Room Alarms

1.1.2.1. Event Description and Timing

This event represents that control room instrumentation fails to alarm given that SFP cooling has been lost, or that the operator fails to respond to that alarm. The proper conditions for an alarm are assumed to exist within the first 8 to 12 hours of the loss of cooling (i.e., one shift). Failure could be due to operator error (failure to respond), failure of the signal channel, or loss of indication due to electrical faults. Success for this event is defined as the operator recognizing the alarm and understanding the need to investigate its cause. This event is quantified by fault tree GCRA112 and includes hardware and human failures.

1.1.2.2. Relevant Assumption

- Within 8 to 12 hours of the loss of cooling, one or more alarms or indications will reflect an out-of-tolerance condition to the operators in the control room (there may be level indication available locally or remotely, but any change in level is not likely to be significant until later in the sequence of events)

Best Case

- The SFP has at least one SFP water temperature monitor, with either direct indication or a trouble light in the control room (there could also be indications or alarms associated with pump flow and pressure)
- Regular maintenance is performed on the instrumentation
- Operator has received formal training and there are procedures to guide him

Sensitivity Case

- Operator has not received formal training and there are no procedures to guide him
- No test and maintenance is performed on existing instrumentation

1.1.2.3. Quantification

Human Error Probabilities

One operator failure is modeled under this top event (basic event HEP-DIAG-ALARM). The operator may fail to respond to an indication in the control room and diagnose a loss of cooling event. Such a signal would likely be the first indication of trouble, so the operator would not be under any heightened state of alertness. On the other hand, it is not likely that any other signals or alarms for any other conditions would be present to distract the operator. The source for this error rate is THERP (Table 20-23) or the operator failing to diagnose based on a single control room alarm. The sensitivity case uses the upper bound estimate taking into consideration the lack of training, diagnostic procedures, and rigorous conduct of operations.

Non-HEP Probabilities

Best Case
The value used for failure of the alarm channel (event SPC-LVL-LOF, 1.0E-5) was taken from NUREG-1740 (Ref 2). The value used for local electrical faults leading to alarm channel failure (event SPC-LVL-LOP, 2.0E-3) was estimated based on information in NUREG-1275, Volume 12 (Ref 1).

Sensitivity Case
The value for failure of the alarm channel (event SPC-LVL-LOF, 1.0E-1) is used due to lack of maintenance (see sensitivity analysis assumptions). The sensitivity case also uses 2.0E-2 as the value for local electrical faults leading to alarm channel failure (event SPC-LVL-LOP).

1.1.2.4. Summary of Basic Events

Basic Event	Best Case	Sensitivity Case
HEP-DIAG-ALARM	3.0E-4	3.0E-3
SPC-LVL-LOF	1.0E-5	1.0E-1
SPC-LVL-LOP	2.0E-3	2.0E-2

1.1.3. Top Event IND – Other Indications of Loss of Cooling

1.1.3.1. Event Description and Timing

This top event models that the operators fail to recognize the loss of cooling during walkdowns over multiple shifts. Indications available to the operator during a walkdown include high area temperature and humidity, low water level from boil-off, and local alarms. After the loss cooling event begins, the operator has more than 10 shifts (about 128 hours) to discover the loss of SFP cooling. Success for this event is defined as the operator recognizing the abnormal condition and understanding the need to investigate its cause. This event is modeled by fault tree GFFT130.

1.1.3.2. Relevant Assumptions

- The loss of cooling may not be noticeable during the first two shifts but conditions are assumed to be sufficient to trigger high temperature alarms locally and in control room
- SFP environment is expected to be hot and humid

Best Case
- Operators perform walkdowns once per shift (every 8 to 12 hours) and document walkdowns in a log
- Regular test and maintenance is performed on instrumentation
- After bulk boiling begins, level changes in the SFP will be indicated on a large, graduated level indicator in the pool
- Operator has received formal training and there are procedures to guide him

Sensitivity Case
- Walkdowns are not performed once per shift (every 8 to 12 hours) and are not required to be logged

- No test and maintenance is performed on instrumentation
- Operator has not received formal training and there are no procedures to guide him

1.1.3.3. Quantification

Human Error Probabilities

This top event includes two HEPs, depending on whether the control room alarms have failed, or the operator has failed to respond to the alarms. If the operator failed to respond to control room alarms, then event HEP-WLKDWN-DEPEN models his failure to recognize the loss of cooling during walkdowns, taking into account the dependence on event HEP-DIAG-ALARM. If the alarms failed, then event HEP-WLKDWN-LSFPC models his failure to recognize the loss of cooling during walkdowns, with no dependence on previous HEPs. These failure rates were developed using THERP, and are based upon three individual failures: failure to carry out an inspection, missing a step in a written procedure, and misreading a measuring device. For the best case we also assumed multiple opportunities for recovery. For the sensitivity case we assumed complete dependence among the shifts, and therefore, no opportunity for recovery was considered.

Note that this fault tree model includes additional events to account for dependency properly. Event HEP-WLKDWN-DEPEN is ANDed with the failure of the operator to recognize control room alarms (event HEP-DIAG-ALARM, described in Section 1.1.2.3). Also, event HEP-WLKDWN-LSFPC is ANDed with Gate GCRA112-EQP, which represents the failure of control room alarm equipment.

1.1.3.4. Summary of Basic Events

Basic Event	Best Case	Sensitivity Case
HEP-WLKDWN-LSFPC	1.0E-5	5.0E-3
HEP-WLKDWN-DEPEN	5.0E-2	5.0E-2

1.1.4. Top Event OCS – Operator Recovery of Cooling System

1.1.4.1. Event Description and Timing

Once the operators recognize loss of spent fuel pool cooling, they will likely focus their attention on repair of the SFP cooling system. It is only after bulk boiling begins and the water level drops below the cooling system suction that the operator will inject water from other makeup systems (e.g., firewater). Therefore, the time available to recover the SFP cooling system could be as long as 43 hours (see top event OFD, Section 1.1.5.1). However, we have assumed that the operator has only until bulk boiling begins (33 hours) to restore the SFP cooling system. This assumption is based on concerns about volume reduction due to cooling and whether the makeup system capacity is sufficient to overcome that volume reduction.

If the loss of cooling was detected via the control room alarms, the operator has the full 33 hours in which to repair the system. Assuming that it takes at least 16 hours before parts and technical help arrive, then the operator has 17 hours (33 hours less 16 hours) to repair the pump. Failure to repair SFPC system event is modeled as HEP-COOL-REP-E. This case is modeled by fault tree GLCR121.

If discovered during walkdowns, we've assumed he has only 9 hours available (33 hours less 24 hours before loss of cooling was noticed). Since it is assumed that it takes at least 16 hours before technical help and parts arrive, it is not possible that SFPC system can be repaired in time before the bulk boiling would begin. Failure to repair SFPC system event is modeled as HEP-COOL-REP-L. This case is modeled by fault tree GLCR161.

1.1.4.2. Relevant Assumptions

- The operator will avoid using raw water (e.g., water not chemically controlled) if possible
- The operator cannot use the SFPC system once the level drops below the suction of the cooling system and the pool begins boiling
- The boil-off rate is assumed to be higher than the SFP makeup system capacity
- Time to bulk boiling is 33 hours from the time cooling is lost

- The boil-off rate is 0.2 ft/hr
- If the loss of cooling was detected through shift walkdowns, then we assume 24 hours has passed before discovery
- It takes two shifts (16 hours) to contact maintenance personnel, make a diagnosis, and get new parts
- Mean time to repair the SFP cooling system is 10 hours
- Repair crew is different than the onsite operators

Best case

- Operator has received formal training and there are procedures to guide him

Sensitivity Case

- Operator has not received formal training and there are no procedures to guide him

1.1.4.3. Quantification

<u>Human Error Probabilities</u>

The probability of failure to repair SFPC system is represented by the exponential repair model:

$$e^{-\lambda t}$$

where

λ mean repair rate (inverse of mean time to repair)

t available time

In the case when discovery was from the control room, probability of failure to repair SFPC system event, HEP-COOL-REP-E, would be 0.18 based on 17 hours available to repair.

In the case the discovery was due to operator walkdown (HEP-COOL-REP-L), it is assumed that there is not enough time available to repair and restart the SFP makeup system in time to prevent bulk boiling, and has been assigned a value of 1.0.

1.1.4.4. Summary of Basic Events

Basic Event	Best Case	Sensitivity Case
HEP-COOL-REP-E	1.8E-1	1.8E-1
HEP-COOL-REP-L	1.0	1.0

1.1.5. Top Event OFD – Operator Recovery Using Onsite Sources

1.1.5.1. Event Description and Timing

At this point in the event tree, if the operator made the correct diagnosis of loss of SFPC system, the operator tried to restore the SFP cooling system but failed. After 43 hours, the level of the pool has dropped below the suction of the SFP cooling system (see below), so that repair of that system will not have any effect until pool level is restored. The operator now has 85 hours to provide makeup using firewater to the pool to prevent fuel uncovery (128 hours less 43 hours). This event represents failure of the operator to recognize the need to start the firewater system, and to actually start a firewater pump and provide makeup to the SFP. He has both electric- and diesel-driven firewater pumps available to perform this function. Furthermore, given failure of both pumps, the operator has time to attempt to repair one of the pumps. This event has been modeled by the fault trees GLCR123 and GLCR163 for discovery via control room alarm or walkdown, respectively.

We assume that the operator will not use alternate systems (e.g., firewater) until after bulk boiling begins and the level drops to below the suction of the cooling system. It is assumed that the suction of the cooling system is 2 ft below the nominal pool level. Therefore, if bulk boiling begins at 33 hours, and the boil-off rate is 0.2 ft/hr, then the total time available is as follows:

$$\text{Time to Bulk Boiling} + \text{Time for Boil-off} = 33\text{ hrs} + \frac{2\text{ ft}}{0.2\text{ ft/hr}} = 43\text{ hrs}$$

Refilling time is estimated to be more than 2 ft/hr for a 250-gpm capacity pump (1 ft/hr for a 100-gpm capacity pump). There is a possibility that the operator may wait until the SFP cooling system is available before he starts a firewater pump.

1.1.5.2. Relevant Assumptions

- The operator has 85 hours to provide makeup
- The operator will avoid using raw water (e.g., water not chemically controlled) if possible
- The operator must use raw water to refill the pool once the level drops to below the suction of the cooling system and the pool begins boiling
- The boil-off rate is assumed to be higher than the SFP makeup system capacity
- The suction of the cooling system is 2 ft below the nominal pool level
- The operator must travel to the firewater pumps to start them locally
- It takes two shifts (16 hours) to contact maintenance personnel, make a diagnosis, and get new parts
- There is a means of fixing a fire hose in place, so that the operator is not required to stand in a hot, humid, and possibly radiologically hazardous area for the period of time required to refill the SFP
- Onsite operator initiates the FW system
- Repair crew is different than onsite operators
- Repair crew failed to restore SFPC system
- Mean time to repair the FW pump is 10 hours

Best case
- Operator has received formal training and there are procedures to guide him
- Firewater pumps are maintained on a regular schedule

Sensitivity Case
- Operator has not received formal training and there are no procedures to guide him
- The diesel-driven firewater pump is not available
- No test and maintenance is performed on the electric firewater pump on a regular schedule

1.1.5.3. Quantification

<u>Human Error Probabilities</u>

The repair crew was unable to fix the SFPC system within the first 43 hours. The fault trees used to quantify this top event comprises the following three operator actions:

HEP-RECG-FWSTART represents the operator's failure to recognize the need to initiate the firewater system. This event was quantified using the SPAR HRA technique. The assumptions for the best case included expansive time (> 24 hours), a high level of stress, diagnostic type procedures, good ergonomic interface, and good quality of work process. For the sensitivity case we assumed expansive time, high stress, low training, and no procedures. This diagnosis task provides the diagnosis for the subsequent actions taken to re-establish cooling to the pool.

HEP-FW-START represents failure to start the electric or diesel firewater pump within 85 hours after the onset of bulk boiling, given that the decision to start a firewater pump was made. No difficult valve alignment is required, but the operator may have to position a hose in the pool area. This event HEP-FW-START was quantified using SPAR HRA technique. For the best case we assumed expansive time (> 50 times the required time), high stress, highly complex task because of the multiple steps, its non-routine nature, quality procedures available, as well as good ergonomics including equipment and tools matched to procedure, and finally a crew who had executed these tasks before, conversant with the procedures and one another. For the sensitivity case we again assumed expansive time, a highly complex task for the same reasons, no training, and no procedures.

HEP-FW-REP-DEPEN represents the failure of the repair crew to repair a FW pump. Note that the repair crew had failed to restore the SFPC system. Therefore, dependency was model in the failure to repair FW system. We assume that the operator will focus his recovery efforts on only one pump. Assuming that it takes another two shifts (16 hours) before technical help and parts arrive, then the operator has 69 hours (85 hours less 16 hours) to repair the

pump. Assuming a 10-hour mean time to repair, the probability of failure to repair the pump would be Exp [-(1/10) × 69] = 1.0E-3. For HEP-FW-REP-DEPEN a low level of dependence was applied modifying the failure rate of 1.0E-3 to 5.0E-2 using the THERP formulation for low dependence.

Non-HEP Probabilities

Basic event FP-2PUMPS-FTF represents the failure of both firewater pumps.

Best Case
The pump may be required to run 8 to 10 hours at the most (250 gpm capacity), given that the water inventory drops by 20 ft (i.e., 3 ft from the top of the fuel). A failure probability of 3.7E-3 for failure to start and run for the electric pump and 0.18 for the diesel driven pump are used from INEL-96/0334 (Ref 3). These individual pump failures result in a value of 6.7E-4 for event FP-2PUMPS-FTF.

Sensitivity Case
Because of lack of maintenance, a value of 0.05 for failure to start and run was assigned to the electric firewater pump. No credit was given for the diesel-driven pump.

1.1.5.4. Summary of Basic Events

Basic Event	Best Case	Sensitivity Case
HEP-RECG-FWSTART	2.0E-5	1.0E-1
HEP-FW-START	1.0E-5	1.5E-1
HEP-FW-REP-DEPEN	5.0E-2	5.0E-2
FP-2PUMPS-FTF	6.7E-4	5.0E-2

1.1.6. Top Event OFB – Operator Recovery Using Offsite Sources

1.1.6.1. Event Description and Timing

Given the failure of recovery actions using onsite sources, this event accounts for recovery of coolant makeup using offsite sources. Adequate time is available for this action, provided that the operator recognizes that recovery of cooling using onsite sources will not be successful, and that offsite sources are the only viable alternatives. This top event is quantified using fault tree GFFT111-LOC. This top event is represented by a basic event HEP-INV-OFFSITE.

1.1.6.2. Relevant Assumptions

- The operator has 85 hours to provide makeup and inventory cooling

Best Case
- Procedure explicitly states that if the water level drops below a certain level (e.g., 15 ft below normal level) operator must initiate recovery using offsite sources
- Operator has received formal training and there are procedures to guide him
- Offsite resources are familiar with the facility and participate at regular intervals in emergency exercises

Sensitivity Case
- There is no procedures or training explicitly guiding operator when to initiate recovery using offsite sources
- Operator has not received formal training and there are no procedures to guide him
- Offsite resources are not familiar with the facility and have not participated in emergency exercises

1.1.6.3. Quantification

Human Error Probabilities

The operator must recognize that extreme measures must be taken to provide makeup to the SFP, and he has had ample time up to this point to attempt recovery of both the SFP cooling system and both firewater pumps. This top

event includes operator actions for both the diagnosis of the need to provide inventory from offsite, and the action itself. This task was quantified using the SPAR HRA technique. For the best case for the diagnosis portion of the task we assumed expansive time, a high level of stress, a moderate complexity as this requires recognizing the need to move to the final line of defense, and a highly trained staff, with diagnostic procedures. For the action portion we assumed expansive time, extreme stress (it's the last opportunity for success), high complexity because of the involvement of offsite personnel, highly trained staff with good procedures, good ergonomics (equipment is available to make offsite support straightforward) and good work processes. For the sensitivity case for the diagnosis portion of the task we assumed expansive time, high stress, a moderately complex task requiring recognition of the need to use the last resource, no training, and no procedures. For the action portion we assumed expansive time, extreme stress (it's the last opportunity for success), high complexity because of the involvement of offsite personnel, no training, and no procedures. For both cases, we applied a low level of dependence to account for the effects of prior tasks.

Note that this fault tree model includes additional events to account for dependency properly. Event HEP-INV-OFFSITE is ORed with the failure of the operator to recognize the need to start the firewater system (event HEP-RECG-FWSTART, described in Section 1.1.5.3). In essence, if the operator fails to recognize the need for firewater, we assume he will fail to recognize the need for other offsite sources of makeup.

1.1.6.4. Summary of Basic Events

Basic Event	Best Case	Sensitivity Case
HEP-INV-OFFSITE	5.0E-2	3.2E-1

1.1.7. Summary

Table 1 presents a summary of basic events

Table 1 Basic Event Summary for the Loss of Cooling Event Tree

Basic Event Name	Description	Best Case	Sensitivity Case
HEP-DIAG-ALARM	Operator fails to respond to a signal indication in the control room	3.0E-4	3.0E-3
HEP-WLKDWN-LSFPC	Operator fails to observe the loss of cooling in walkdowns (independent case)	1.0E-5	5.0E-3
HEP-WLKDWN-DEPEN	Operator fails to observe the loss of cooling in walkdowns (dependent case)	5.0E-2	5.0E-2
HEP-COOL-REP-E	Repair crew fails to repair SFPC system	1.8E-1	1.8E-1
HEP-COOL-REP-L	Repair crew fails to repair SFPC system	1.0	1.0
HEP-RECG-FWSTART	Operator fails to diagnoses need to start the firewater system	2.0E-5	1.0E-1
HEP-FW-START	Operator fails to start firewater pump and provide aligrment	1.0E-5	1.5E-1
HEP-FW-REP-DEPEN	Repair crew fails to repair firewater system	5.0E-2	5.0E-2
HEP-INV-OFFSITE	Operator fails to provide alternate sources of cooling from offsite	5.0E-2	3.2E-1
FP-2PUMPS-FTF	Failure of firewater pump system	6.7E-4	5.0E-2
SPC-LVL-LOF	Failure of control room alarm channel	1.0E-5	1.0E-1
SPC-LVL-LOP	Electrical faults leading to alarm channel failure	2.0E-3	2.0E-2

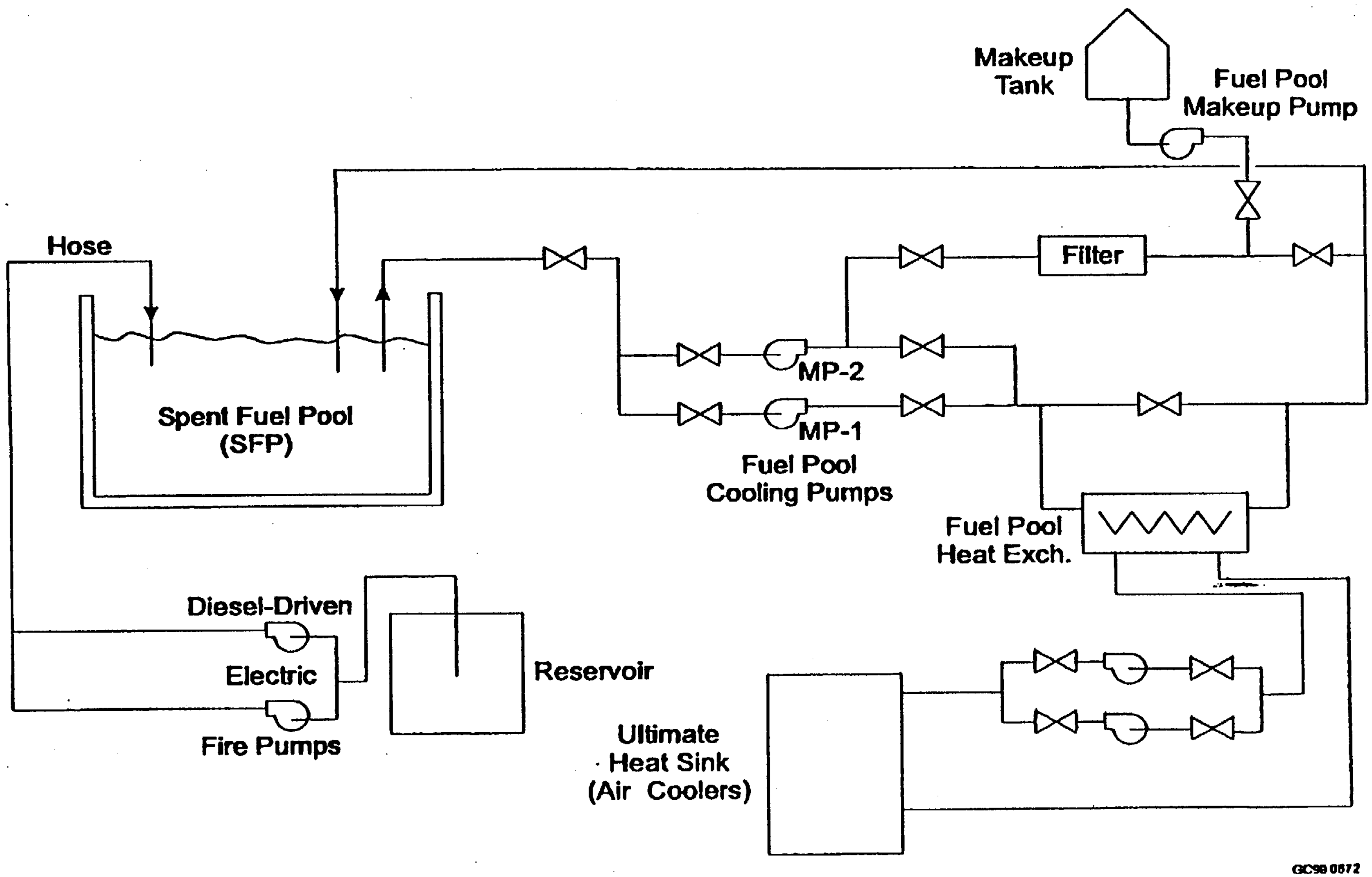
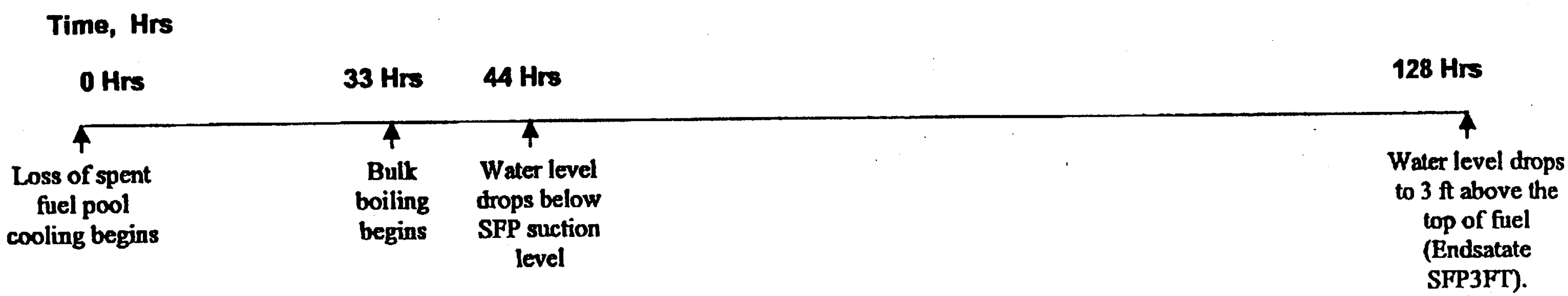
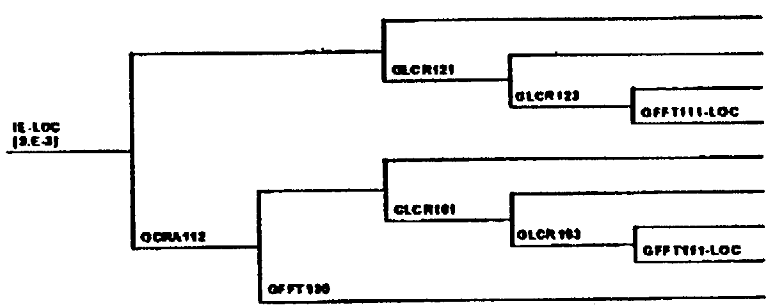


Figure 1 Simplified Diagram of Spent Fuel Pool Cooling and Inventory Makeup Systems

Figure 2 Loss of Cooling Event Timeline



LOSS OF COOLING	CONTROL ROOM ALARMS	OTHER INDICATIONS OF LOSS OF COOLING	OPERATOR RECOVERY OF COOLING SYSTEM	OPERATOR INITIATES MAKEUP USING FIRE PUMPS	RECOVERY USING OFF SITE SOURCES
IE-LOC	CRA	IND	OCS	OFD	OFB



#	SEQUENCE-NAMES	END-STATE-NAMES	FREQUENCY
1	IE-LOC	OK	
2	IE-LOCOCS	OK	
3	IE-LOCOCSOFD	OK	
4	IE-LOCOCSOFDOFB	SFP3FT	1.197E-006
5	IE-LOCCRA	OK	
6	IE-LOCCRAOCS	OK	
7	IE-LOCCRAOCSOFD	OK	
8	IE-LOCCRAOCSOFDOFB	SFP3FT	1.837E-010
9	IE-LOCCRAIND	SFP3FT	4.906E-008

Figure 3 Loss of Cooling Event Tree

References

1 NUREG-1275, "Operating Experience Feedback Report – Assessment of Spent Fuel Cooling," Volume 12, U.S. Nuclear Regulatory Commission, February 1997

2 NUREG/CR-1740, "Data Summaries of Licensee Event Reports of Selected Instrumentation and Control Components at U.S. Commercial Nuclear Power Plants from January 1, 1976 to December 31, 1978," U.S. Nuclear Regulatory Commission, May 1981

3 INEL-96/0334, "Loss of Spent Fuel Pool Cooling PRA: Model and Results," Idaho National Engineering and Environmental Laboratory, September 1996

BEST CASE ANALYSIS

SEQUENCE CUT SETS (QUANTIFICATION) REPORT

IE-LOC Sequence : 4 Mincut Upper Bound : 1.197E-008

Cut No.	% Total	% Cut Set	Prob/ Freq.	CURRENT CUT SETS
1	90.2	90.2	1.1E-008	HEP-COOL-REP-E, HEP-RECG-FWSTART
2	97.8	7.6	9.1E-010	FP-2PUMPS-FTF, HEP-COOL-REP-E, HEP-FW-REP-DEPEN, HEP-INV-OFFSITE
3	100.0	2.3	2.7E-010	HEP-COOL-REP-E, HEP-FW-START, HEP-INV-OFFSITE

IE-LOC Sequence : 8 Mincut Upper Bound : 1.537E-010

Cut No.	% Total	% Cut Set	Prob/ Freq.	CURRENT CUT SETS
1	78.1	78.1	1.2E-010	HEP-COOL-REP-L, HEP-RECG-FWSTART, SPC-LVL-LOP
2	89.8	11.7	1.8E-011	HEP-COOL-REP-L, HEP-DIAG-ALARM, HEP-RECG-FWSTART
3	96.3	6.5	1.0E-011	FP-2PUMPS-FTF, HEP-COOL-REP-L, HEP-FW-REP-DEPEN, HEP-INV-OFFSITE, SPC-LVL-LOP
4	98.3	2.0	3.0E-012	HEP-COOL-REP-L, HEP-FW-START, HEP-INV-OFFSITE, SPC-LVL-LOP
5	99.3	1.0	1.5E-012	FP-2PUMPS-FTF, HEP-COOL-REP-L, HEP-DIAG-ALARM, HEP-FW-REP-DEPEN, HEP-INV-OFFSITE
6	99.7	0.4	6.0E-013	HEP-COOL-REP-L, HEP-RECG-FWSTART, SPC-LVL-LOP
7	99.9	0.3	4.5E-013	HEP-COOL-REP-L, HEP-DIAG-ALARM, HEP-FW-START, HEP-INV-OFFSITE
8	100.0	0.0	5.0E-014	FP-2PUMPS-FTF, HEP-COOL-REP-L, HEP-FW-REP-DEPEN, HEP-INV-OFFSITE, SPC-LVL-LOP
9	100.0	0.0	1.5E-014	HEP-COOL-REP-L, HEP-FW-START, HEP-INV-OFFSITE, SPC-LVL-LOP

IE-LOC Sequence : 9 Mincut Upper Bound : 4.506E-008

Cut No.	% Total	% Cut Set	Prob/ Freq.	CURRENT CUT SETS
1	99.9	99.9	4.5E-008	HEP-DIAG-ALARM, HEP-WLKDWN-DEPEN
2	100.0	0.1	6.0E-011	HEP-WLKDWN-LSFPC, SPC-LVL-LOP
3	100.0	0.0	3.0E-013	HEP-WLKDWN-LSFPC, SPC-LVL-LOP

SENSITIVITY CASE ANALYSIS

SEQUENCE CUT SETS (QUANTIFICATION) REPORT

IE-LOC Sequence : 4 Mincut Upper Bound : 7.987E-005

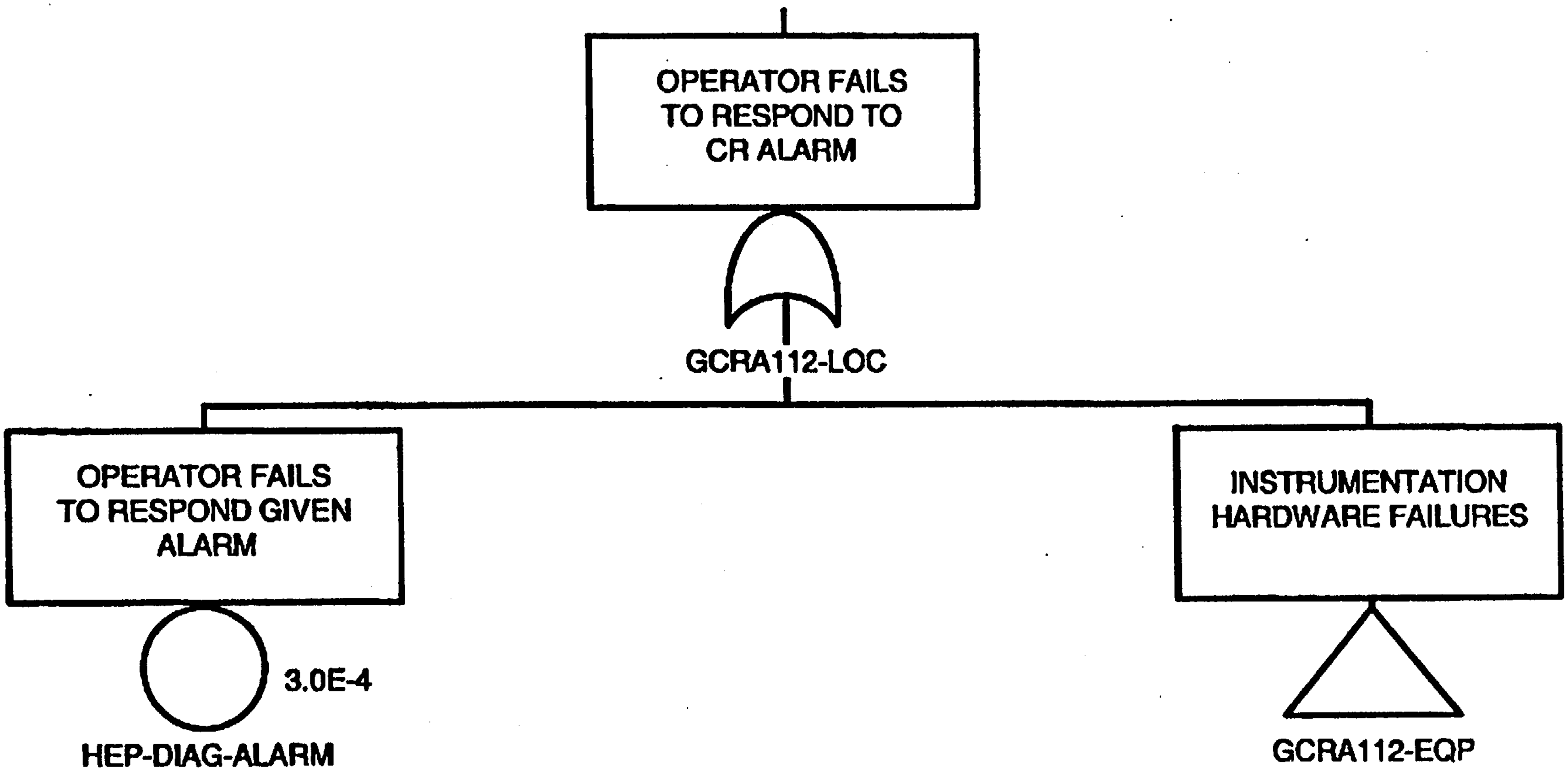
Cut No.	% Total	% Cut Set	Prob/ Freq.	CURRENT CUT SETS
1	67.6	67.6	5.4E-005	HEP-COOL-REP-E, HEP-RECG-FWSTART
2	100.0	32.5	2.6E-005	HEP-COOL-REP-E, HEP-FW-START, HEP-INV-OFFSITE
3	100.0	0.5	4.3E-007	FP-2PUMPS-FTF, HEP-COOL-REP-E, HEP-FW-REP-DEPEN, HEP-INV-OFFSITE

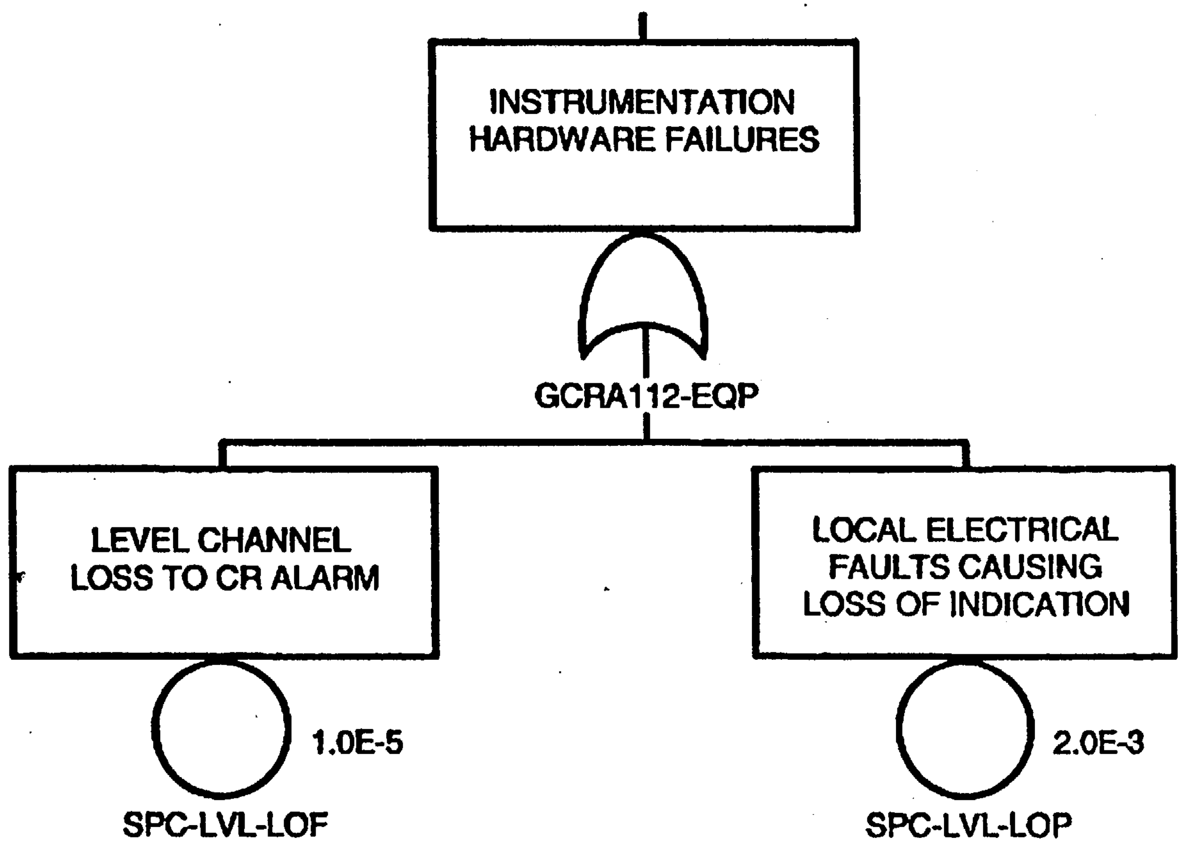
IE-LOC Sequence : 8 Mincut Upper Bound : 5.460E-005

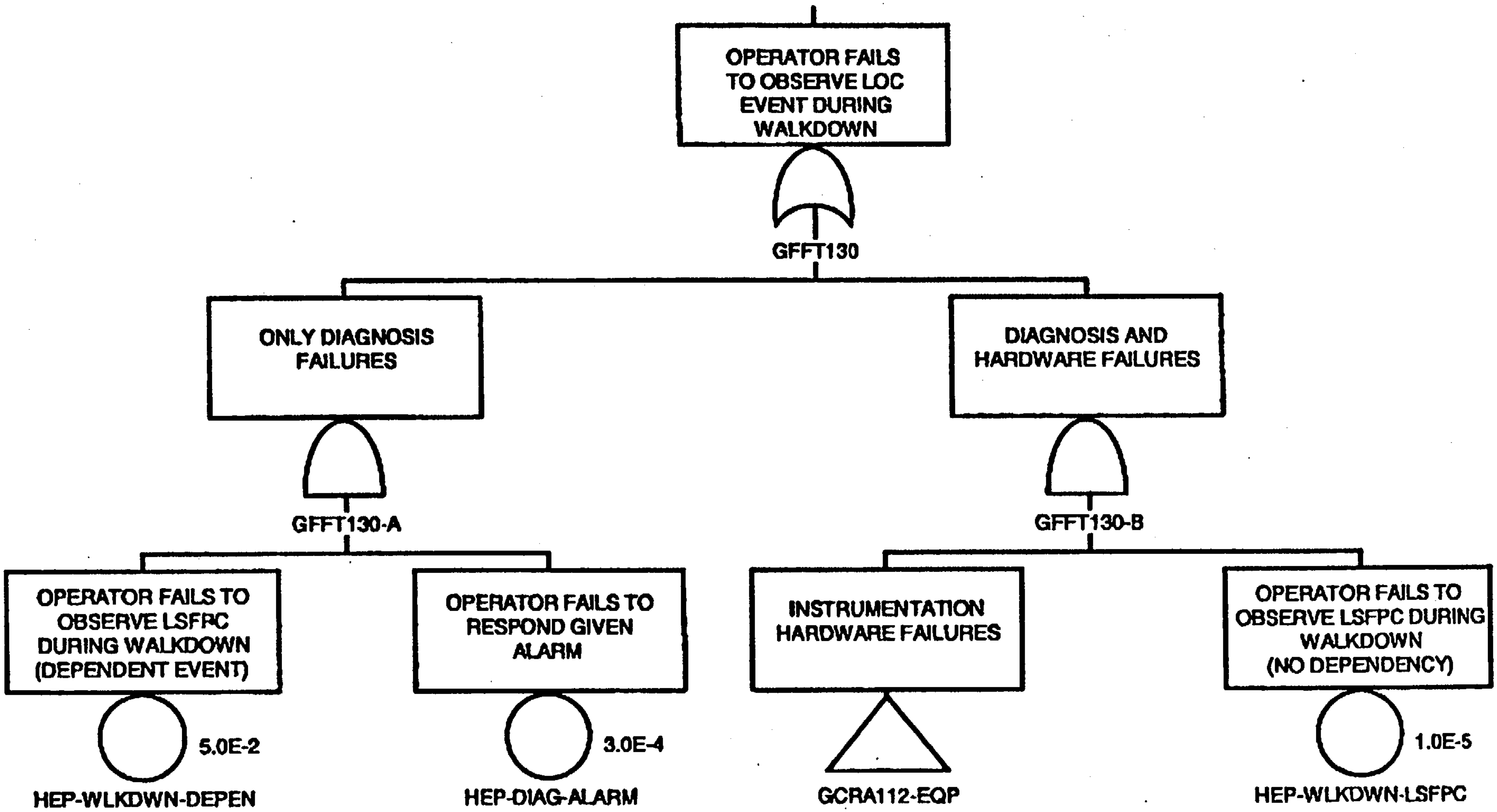
Cut No.	% Total	% Cut Set	Prob/ Freq.	CURRENT CUT SETS
1	55.0	55.0	3.0E-005	HEP-COOL-REP-L, HEP-RECG-FWSTART, SPC-LVL-LOP
2	81.3	26.4	1.4E-005	HEP-COOL-REP-L, HEP-FW-START, HEP-INV-OFFSITE, SPC-LVL-LOF
3	92.3	11.0	6.0E-006	HEP-COOL-REP-L, HEP-RECG-FWSTART, SPC-LVL-LOP
4	97.6	5.3	2.9E-006	HEP-COOL-REP-L, HEP-FW-START, HEP-INV-OFFSITE, SPC-LVL-LOP
5	99.2	1.7	9.0E-007	HEP-COOL-REP-L, HEP-DIAG-ALARM, HEP-RECG-FWSTART
6	100.0	0.8	4.3E-007	HEP-COOL-REP-L, HEP-DIAG-ALARM, HEP-FW-START, HEP-INV-OFFSITE
7	100.0	0.4	2.4E-007	FP-2PUMPS-FTF, HEP-COOL-REP-L, HEP-FW-REP-DEPEN, HEP-INV-OFFSITE, SPC-LVL-LOF
8	100.0	0.1	4.8E-008	FP-2PUMPS-FTF, HEP-COOL-REP-L, HEP-FW-REP-DEPEN, HEP-INV-OFFSITE, SPC-LVL-LOP
9	100.0	0.0	7.2E-009	FP-2PUMPS-FTF, HEP-COOL-REP-L, HEP-DIAG-ALARM, HEP-FW-REP-DEPEN, HEP-INV-OFFSITE

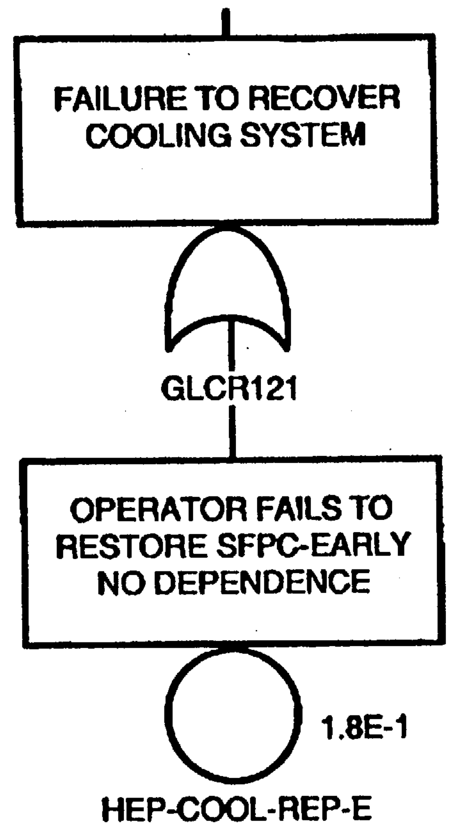
IE-LOC Sequence : 9 Mincut Upper Bound : 2.250E-006

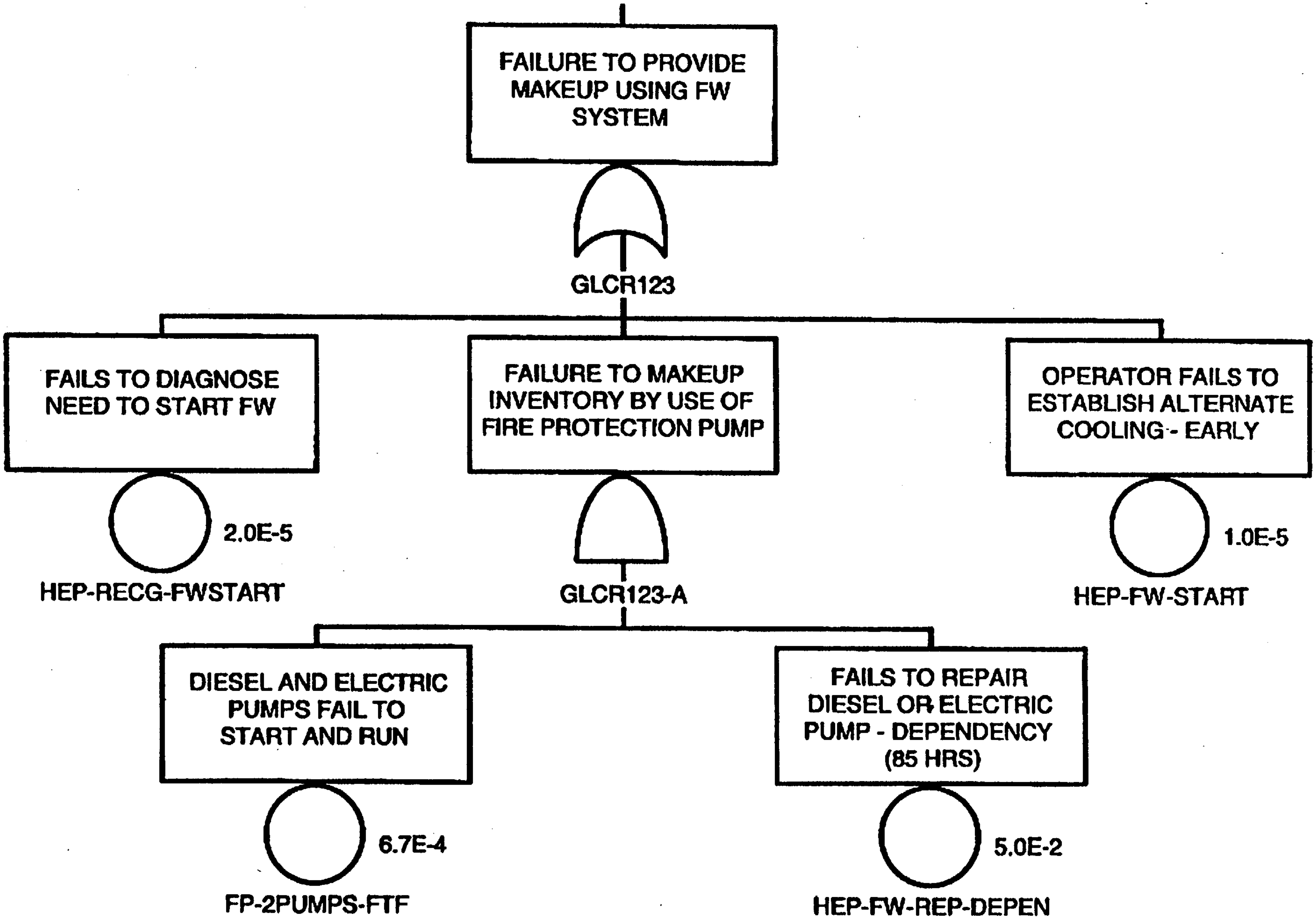
Cut No.	% Total	% Cut Set	Prob/ Freq.	CURRENT CUT SETS
1	66.7	66.7	1.5E-006	HEP-WLKDWN-LSFPC, SPC-LVL-LOF
2	86.7	20.0	4.5E-007	HEP-DIAG-ALARM, HEP-WLKDWN-DEPEN
3	100.0	13.3	3.0E-007	HEP-WLKDWN-LSFPC, SPC-LVL-LOP

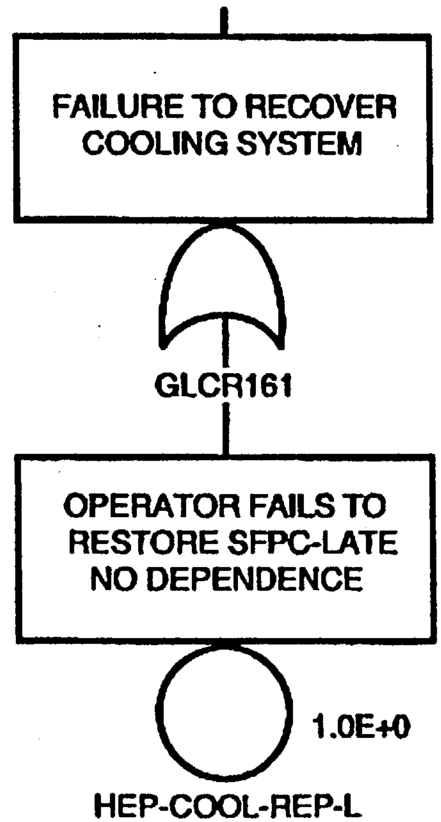

OPERATOR FAILS TO RESPOND TO CR ALARM
GCRA112-LOC
OPERATOR FAILS TO RESPOND GIVEN ALARM
3.0E-4
HEP-DIAG-ALARM
INSTRUMENTATION HARDWARE FAILURES
GCRA112-EQP

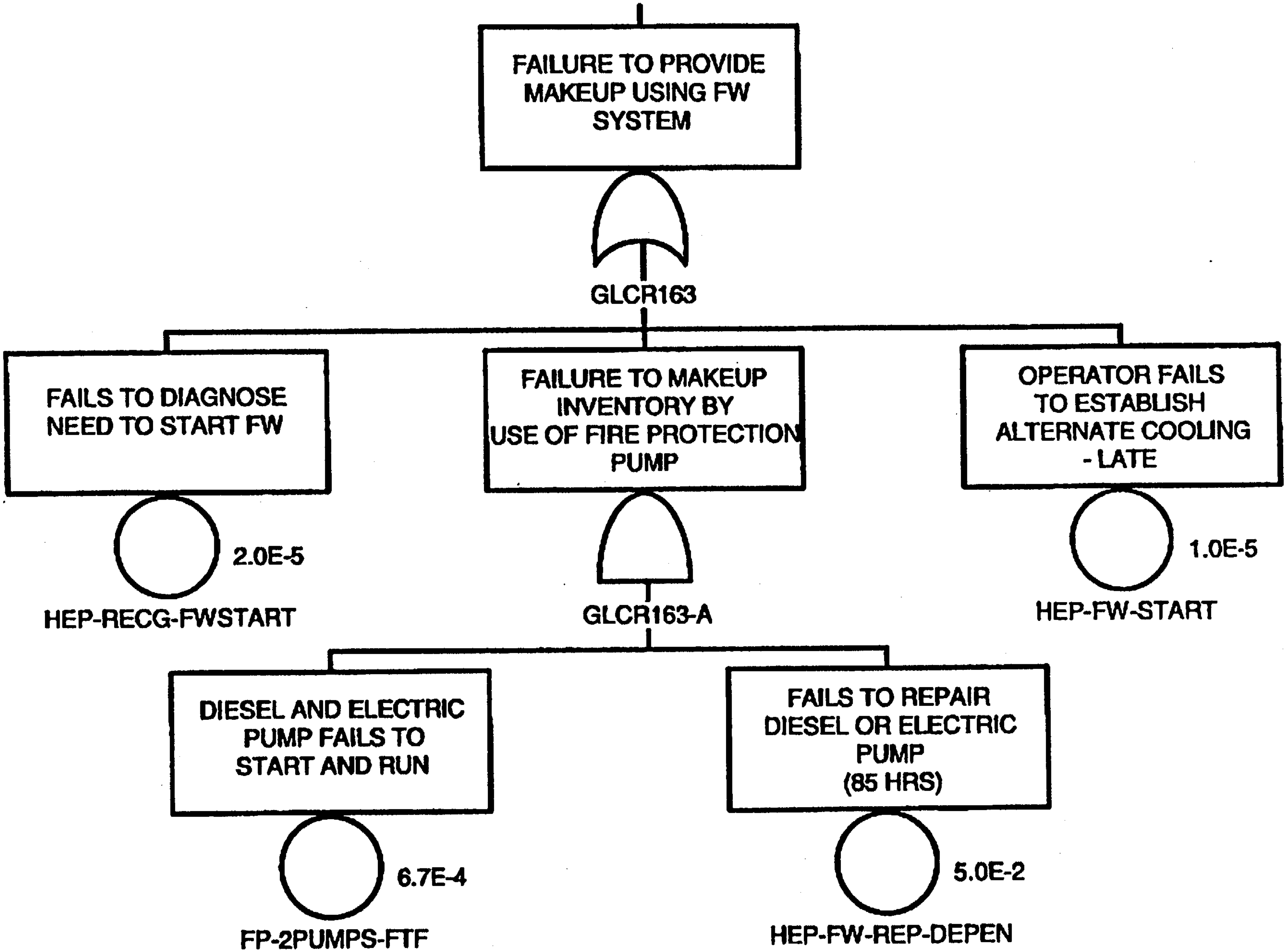

INSTRUMENTATION HARDWARE FAILURES
GCRA112-EQP
LEVEL CHANNEL LOSS TO CR ALARM
1.0E-5
SPC-LVL-LOF
LOCAL ELECTRICAL FAULTS CAUSING LOSS OF INDICATION
2.0E-3
SPC-LVL-LOP

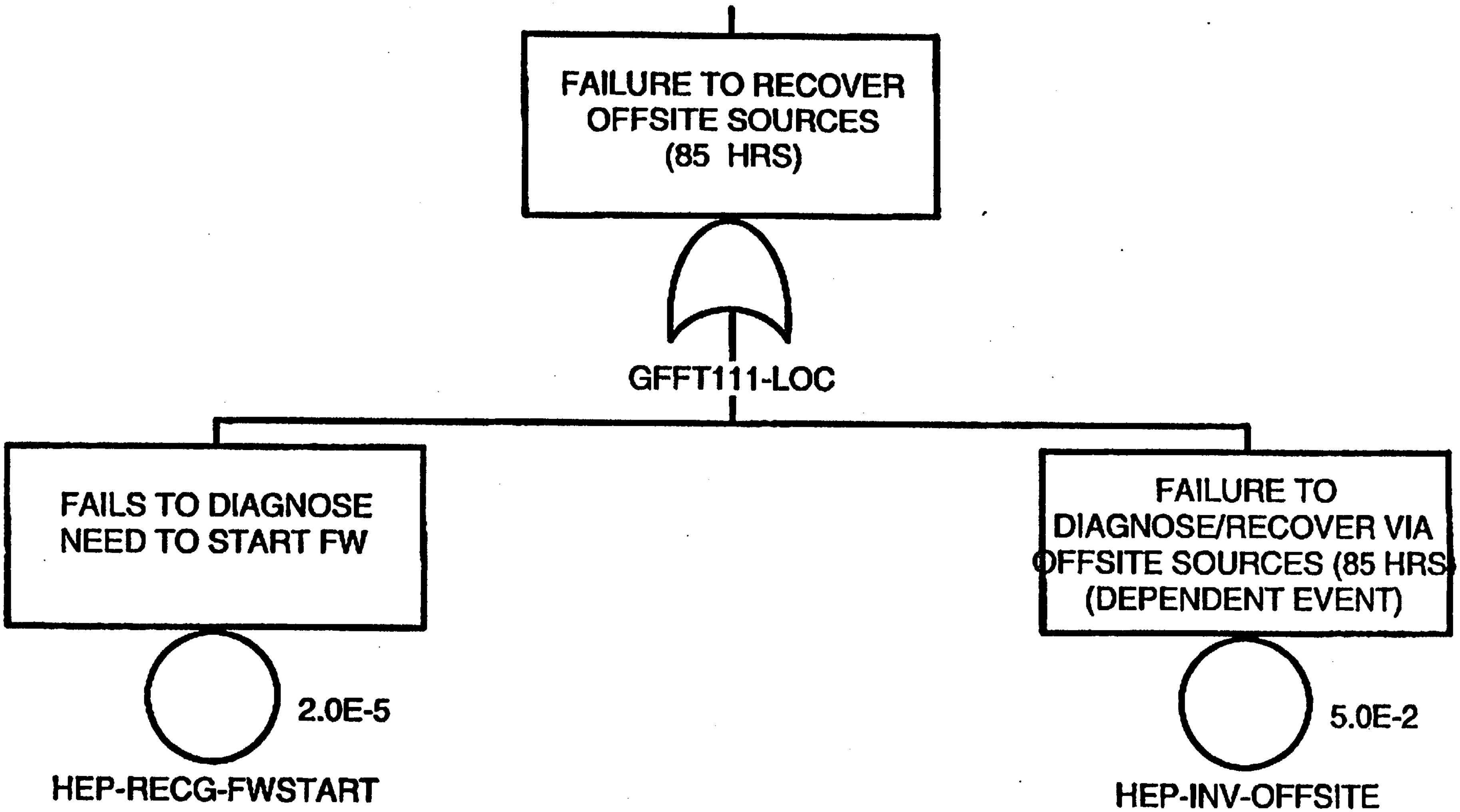

OPERATOR FAILS TO OBSERVE LOC EVENT DURING WALKDOWN
GFFT130
ONLY DIAGNOSIS FAILURES
GFFT130-A
DIAGNOSIS AND HARDWARE FAILURES
GFFT130-B
OPERATOR FAILS TO OBSERVE LSFPC DURING WALKDOWN (DEPENDENT EVENT)
5.0E-2
HEP-WLKDWN-DEPEN
OPERATOR FAILS TO RESPOND GIVEN ALARM
3.0E-4
HEP-DIAG-ALARM
INSTRUMENTATION HARDWARE FAILURES
GCRA112-EQP
OPERATOR FAILS TO OBSERVE LSFPC DURING WALKDOWN (NO DEPENDENCY)
1.0E-5
HEP-WLKDWN-LSFPC


FAILURE TO RECOVER COOLING SYSTEM
GLCR121
OPERATOR FAILS TO RESTORE SFPC-EARLY NO DEPENDENCE
1.8E-1
HEP-COOL-REP-E


FAILURE TO PROVIDE MAKEUP USING FW SYSTEM
GLCR123
FAILS TO DIAGNOSE NEED TO START FW
2.0E-5
HEP-RECG-FWSTART
FAILURE TO MAKEUP INVENTORY BY USE OF FIRE PROTECTION PUMP
GLCR123-A
OPERATOR FAILS TO ESTABLISH ALTERNATE COOLING - EARLY
1.0E-5
HEP-FW-START
DIESEL AND ELECTRIC PUMPS FAIL TO START AND RUN
6.7E-4
FP-2PUMPS-FTF
FAILS TO REPAIR DIESEL OR ELECTRIC PUMP - DEPENDENCY (85 HRS)
5.0E-2
HEP-FW-REP-DEPEN


FAILURE TO RECOVER COOLING SYSTEM
GLCR161
OPERATOR FAILS TO RESTORE SFPC-LATE NO DEPENDENCE
1.0E+0
HEP-COOL-REP-L


FAILURE TO PROVIDE MAKEUP USING FW SYSTEM
GLCR163
FAILS TO DIAGNOSE NEED TO START FW
2.0E-5
HEP-RECG-FWSTART
FAILURE TO MAKEUP INVENTORY BY USE OF FIRE PROTECTION PUMP
GLCR163-A
OPERATOR FAILS TO ESTABLISH ALTERNATE COOLING - LATE
1.0E-5
HEP-FW-START
DIESEL AND ELECTRIC PUMP FAILS TO START AND RUN
6.7E-4
FP-2PUMPS-FTF
FAILS TO REPAIR DIESEL OR ELECTRIC PUMP (85 HRS)
5.0E-2
HEP-FW-REP-DEPEN


FAILURE TO RECOVER
OFFSITE SOURCES
(85 HRS)
GFFT111-LOC
FAILS TO DIAGNOSE
NEED TO START FW
2.0E-5
HEP-RECG-FWSTART
FAILURE TO
DIAGNOSE/RECOVER VIA
OFFSITE SOURCES (85 HRS)
(DEPENDENT EVENT)
5.0E-2
HEP-INV-OFFSITE