Analysis File: Preliminary Risk Analysis of Spent Fuel Pool Accidents at Decommissioning Plants

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Objective of Analysis:

To perform a generic study of spent fuel pool risks at decommissioned plants to:

- examine the full scope of potentially risk-significant issues
- determine which accident sequences are credible
- document the preliminary assessment for public review
- elicit feedback from all stakeholders regarding analysis assumptions and design/operational features, and
- conduct a complete and open discussion of the risk assessment

This analysis will be revised based on stakeholder feedback so that a consistent and predictable basis for future plant-specific decisions can be developed, based on the best available PRA assessment methodology, and actual design/ operational characteristics of the plant

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Risk Analysis of Spent Fuel Pool Accidents at Decommissioning Plants

The staff's preliminary deterministic evaluations of spent fuel pool (SFP) accidents found that zirconium cladding fires could not be ruled out for spent fuel that had been transferred from reactors up to five years previously, based on a simplified, conservative analysis. To assess the risk in the time from shutdown to one year, the staff performed a simplified preliminary PRA, which modeled internal and external initiating events to assess the potential risk associated with SFPs at decommissioned nuclear power plants.

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 and during recent visits to four sites covering all four major nuclear steam supply system vendors (General Electric, Westinghouse, Babcock & Wilcox, and Combustion Engineering). In addition, the staff used several previously published deterministic and probabilistic evaluations of potential risks at both operating and decommissioned plants to help in this study. In the modeling of SFP configurations, this PRA considered three cases:

Case 1 assumes that the SFP and its support systems (including instrumentation and power sources) are similar to that found during staff visits to four decommissioned plants. Figure 1 is a simplified drawing of this system. In Case 1, transfer of the last fuel from the reactor to the SFP is assumed to have occurred one year previously.

Case 2 is the same as Case 1 except that the transfer of the last fuel is assumed to have occurred one month previously. This is a bounding case since it is not expected that a utility would disable all the support systems normally used to provide SFP cooling within one month of the last fuel transfer. In fact, it may not be possible for the sled mounted systems currently available to remove the heat load in the pool one month after the last transfer. However, Case 2 provides a bounding value to help determine the impact that higher decay heat loads (and therefore less recovery time) have on the frequency of fuel uncovery.

Case 3 assumes 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. The staff believes 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 determine if there may be a need for additional regulation in this area. Case 3 assumes that the last fuel from the reactor was transferred one year previously.

Assumptions made for Cases 1 and 2:

- 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 guidance and / or 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).

- The site has two operable fire 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
  Fire pump: 100 - 200 gpm
  Fire Engine: 100 -250 gpm (depending on hose size, 2½"(250 gpm) or 1½"(100 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 walk-downs 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.

Assumptions for Case 3:

- 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. Recovery probabilities are therefore assumed to be lower for Case 3 than for Cases 1 and 2. It is also assumed that the operators would walk-down the pool area less frequently, and the probability of not noticing abnormal conditions at the pool is it therefore higher than in Cases 1 and 2.

- 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 fire 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.

Assumptions that are applicable to all 3 cases:

- 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 time-frame 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, fire 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.

- In the estimation of seismic risk, it is assumed that SFPs are robust and will survive seismic events less than three times the safe shutdown earthquake (SSE).

- 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.

Identification of Initiating Events

To identify potential initiating events that could result in a loss of spent fuel pool cooling (beyond design bases), various references (INEL-96/0334; NUREG-1275, Vol. 12; NUREG-1353; Draft for Comment NUREG "Postulated Accidents for Permanently Shutdown Reactors"; Draft "Risk Analysis for Spent Fuel Pool Cooling at Susquehanna Electric Power Station"; NUREG/CR-6451; NUREG/CR-4982; NUREG/CR-5281; and NUREG/CR-5176) were reviewed. The following were found to potential initiators:

- Loss of offsite power from plant centered and grid related events
- Loss of offsite power from severe weather events
- Internal fire
- Loss of pool cooling
- Loss of coolant inventory
- Seismic event
- Cask drop
- Aircraft impact
- Tornado missile

Event trees were developed for the first six initiators above. For events initiated by a cask drop, aircraft impact or tornado missile, it is assumed that mitigation is not feasible and fuel uncovery will result. Therefore, for these events, the fuel uncovery frequency is equivalent to the initiating event frequency.

Data Used

The data used in the quantification of the fuel uncovery frequency for each of the initiating events and for each of the three cases is provided in Appendix A. The rationale behind the data used is also provided in the appendix.

Human Reliability Analysis

The time available for operator actions is based on staff calculations on the time it would take for level in the pool to reach a height of approximately 3' above the fuel. At this level, it is assumed that radiation levels in the vicinity of the pool will be such that manual recovery actions will not be possible.

In addition to rapid draining events, the staff considered pool heatup after a loss of pool cooling followed by bulk pool boiling as a possible way to uncover the fuel. It takes a relatively long time to uncover the fuel if inventory is lost in this manner due to the large amount of water in a spent fuel pool, the large specific heat of water, and the large latent heat of vaporization for water. Simple calculations for a typical-sized spent fuel pool and conservative decay heat assumptions yield the results in Table 1. These results are based on the following assumptions:

- no heat losses
- 1 atm pressure
- $h_{fg} \approx 2258$ kJ/kg
- base pool heat load for a full pool of 2 MW
- core thermal power of 3293 MW
- typical pool size (based on Tables 2.1 & 2.2 of NUREG/CR-4982)
  typical BWR pool = 40' deep by 26' by 39'
  typical PWR pool = 43' deep by 22' by 40'

Table 1 - Time to Bulk Boiling, and Boil-off Rates

Time after discharge (days)	Decay power from last core (MW)	Total heat load (MW)	Time to bulk boiling (hr)(1)	Boiloff rate (gpm)	Level decrease (ft/hr)(2)
2	16.4	18.4	5.6	130	1.0
10	8.6	10.6	9.8	74	0.6
30	5.5	7.5	14	52	0.42≈0.5
60	3.8	5.8	18	41	0.33
90	3.0	5.0	21	35	0.28
180	1.9	3.9	27	27	0.22
365	1.1	3.1	33	22	0.18≈0.2

Notes: (1) multiply by 0.84 for full pool, and by 0.34 for 20' deep pools (to correct for heat capacity of the fuel racks and fuel)

(2) using the typical pool sizes, it is estimated that, for BWRs we have 1040 ft^3/ft depth, and for PWRs, we have 957 ft^3/ft depth. Assume ≈1000 ft^3/ft depth for level decreases resulting from boil-off.

In a SFP, the depth of water above the fuel is typically 23 to 25 feet. Subtracting 3 feet to account for shielding requirements, it is estimated that approximately 20 feet of water will have to boil-off before the start of fuel uncovery. Therefore, using the above table, the available time for operator actions for the loss of cooling type accidents is estimated as follows:

For 1-year old fuel, time available = time to bulk boiling + time to boildown to 3' above fuel
= 33 hr x 0.84 + 20 ft / 0.2 ft/hr
= 128 hours

For 1-month old fuel, time available = 14 hr x 0.84 + 20 ft / 0.5 ft/hr
= 52 hours

The above simple calculations show that, for 1-year old fuel (Cases 1 & 3), it will take longer than one day to heat the water to the boiling temperature and take almost five hours to boil off every foot of water at one year after shutdown. Therefore it would take about five days to reach the point of fuel uncovery if the only mechanism to lose water is through heat-up and boil-off. Similarly, for 1-month old fuel (Case 2), it would take in excess of 50 hours to reach the point of fuel uncovery from pool heat-up and boil-off. For loss of inventory events, the available times will be less. This is discussed more in detail in the section on accident progression.

Based on the estimation of available times, human error probabilities (HEPs) were estimated for recovery actions to mitigate potential accidents at SFPs. These HEPs are described more in Appendix A and in the section on accident progression. In this PRA, the HEPs for the different operator actions in an accident sequence are assumed to be somewhat dependent. For example, the time available (and therefore the probability of operator failure) to recover inventory using offsite sources will be dependent on the time spent on trying to repair the onsite cooling pumps or time spent trying to start make-up or fire pumps. In addition, operator mis-diagnosis of the problem to begin with will fail all recovery actions. Because of these dependencies, it should be considered that HEPs within an accident sequence are conditional upon the previous events in that sequence. [The fact that this is a generic study, and since it is assumed that no detailed guidance or procedures are present to guide the operator on a time-frame as to when certain actions have to be completed, this operator action dependency has to be accounted for. The presence of more detailed procedures (e.g., ones with time-lines as a function of fuel age) would permit the consideration of the HEPs within a sequence as being more independent.]

Accident Sequence Progression

Given an initiating event, the modeling of accident sequence progression is modeled using the event tree methodology. The split fractions in the event tree branches are quantified using the data provided in Appendix A and the fault trees provided in Appendix B. The relationship of the event tree functional equations and the fault trees is also provided in Appendix B. (Note that the basic event probabilities for the fault trees in Appendix B are estimated based on assumptions for Case 1. These basic event probabilities may be different for the assumptions for Cases 2 or 3. The basic event values for all three cases are provided in Appendix A).

The event trees are provided in Figures 2 through 7. A description of the event trees is provided below.

Seismic Initiating Event (EQE)

Event EQE - Frequency of a seismic event greater than 3 times SSE

In this analysis it is assumed that the spent fuel pools are sufficiently robust for seismic events less than three times the SSE and that the HCLPF value for the spent fuel pool integrity is equal to 3 x SSE. For the majority of plant sites, 3 x SSE is in the range of 0.4g to 0.5g. Seismic hazard curves provided by EPRI (EPRI NP-4726 dated November 1988, and EPRI NP-6395-D dated April 1989) and by LLNL (NUREG-1488 dated April 1994) show that for most plants, the mean frequency of seismic accelerations in the range of 0.4g to 0.5g is on the order of or less than 2×10^{-5} per year - see Table 2.

Event FPI - Fuel pool intact

Using the definition for "HCLPF" (i.e., the acceleration at which there is a 95% confidence that less than 5% of the time the SSC will fail), the probability that the SFP will fail given a seismic event greater than 3xSSE is approximately 0.05.

Note that, failure frequencies obtained by applying the above approximation may be non-conservative when compared to failure frequencies obtained by the convolution of the SFP fragility curve and the seismic hazard curve. (In several test cases, applying the "HCLPF approximation" underestimates the seismic effect by a factor of 2 to 3 when compared to results obtained by the convolution of the fragility curve and the hazard curve.) However, for this generic study where site-specific hazard curves or fragility curves are not used, this approximation is adequate, especially since the assumed initiating event frequency is conservative for the majority of plants.

Event CSI - Structural integrity of the cooling systems

For the cases (95% of the time) where the pool remains intact, the availability of the SFP cooling and makeup systems has to be determined. In this study, it is conservatively assumed that given a seismic event greater than 3xSSE, some portion of the cooling system and regular makeup system will fail. (This includes failure of the piping, the pumps, electrical components like relays, or the loss of offsite power. This also includes failure of the surrounding structures which may damage components related to SFP cooling.) No recovery of these failed systems is assumed. Therefore, the ability for normal cooling and makeup will be lost.

Note that seismic events less than 3xSSE can also fail cooling systems or result in a loss of offsite power. These events are not included in this event tree, but can be subsumed into the "Loss of Cooling" and the "Loss of Offsite Power from Severe Weather" initiating events.

Event OFB - Recovery using on-site or offsite sources

This event accounts for recovery of coolant makeup using portable diesel-powered pumps or use of offsite sources such as the fire brigade. Adequate time is available for this action - in excess of 120 hours in Case 1, and approximately 50 hours in Case 2. However, recovery efforts may be hindered since there could be considerable damage to the infrastructure around the plant site at earthquake accelerations of 0.4g or greater. In addition, it is not clear if there will be adequate procedures to guide operators on recovery efforts given the loss of normal cooling and makeup systems. For this event, a failure probability of 0.05 is used.

Table 2 - Mean Annual Probability of Exceedance for Peak Ground Acceleration from NUREG-1488

Site	400 cm/sec^2	500 cm/sec^2
Arkansas	2.4E-5	1.4E-5
Beaver Valley	2.9E-5	1.8E-5
Bellefonte	2.6E-5	1.4E-5
Big Rock Point	9.6E-6	6.0E-6
Braidwood	7.6E-6	4.1E-6
Browns Ferry	1.3E-5	7.1E-6
Brunswick	3.7E-5	2.3E-5
Byron	1.0E-5	5.5E-6
Callaway	7.5E-6	3.9E-6
Calvert Cliffs	2.3E-5	1.4E-5
Catawba	2.0E-5	1.1E-5
Clinton	3.6E-~~6~~5	2.2E-5
ComanchePeak	2.0E-6	1.1E-6
Cook	1.4E-5	8.8E-6
Cooper	5.9E-5	3.8E-5
Crystal River	3.6E-6	2.1E-6
Davis Besse	1.6E-5	8.5E-6
Dresden	9.4E-6	5.0E-6
Duane Arnold	2.6E-6	1.4E-6
Farley	4.2E-6	2.4E-6
Fermi	7.6E-6	4.1E-6
Fitzpatrick	8.3E-6	4.4E-6
Ft Calhoun	4.9E-5	3.2E-5
Ginna	1.7E-5	9.6E-6
Grand Gulf	7.8E-6	4.6E-6
Haddam Neck	2.6E-5	1.4E-5
Hatch	1.4E-5	8.6E-6
Hope Creek	2.7E-5	1.7E-5
Indian Point	2.6E-5	1.4E-5
Kewaunee	1.1E-5	7.2E-6
Lacrosse	1.3E-5	8.4E-6
Lasalle	2.8E-5	1.7E-5
Limerick	2.8E-5	1.5E-5
Maine Yankee	2.7E-5	1.5E-5
McGuire	1.6E-5	8.1E-6
Millstone	2.2E-5	1.2E-5
Monticello	1.5E-5	9.6E-6
Nine Mile Point	8.3E-6	4.5E-6
North Anna	2.3E-5	1.2E-5
Oconee	2.3E-5	1.3E-5
Oyster Creek	2.5E-5	1.5E-5
Palisades	1.2E-5	7.3E-6
Peach Bottom	2.4E-5	1.3E-5
Perry	8.6E-6	4.7E-6
Pilgrim	1.4E-4	9.4E-5
Point Beach	1.2E-5	7.3E-6
Prairie Island	1.4E-5	9.0E-6
Quad Cities	6.1E-6	3.3E-6
River Bend	4.9E-6	2.9E-6
Robinson	9.0E-5	5.6E-5
Salem	2.7E-5	1.6E-5
Seabrook	5.7E-5	3.2E-5
Sequoyah	2.9E-5	1.6E-5
Shearon Harris	9.2E-6	4.8E-6
Shoreham	4.7E-5	2.9E-5
South Texas	5.0E-6	3.0E-6
St. Lucie	5.0E-6	3.1E-6
Summer	3.2E-5	1.8E-5
Surry	1.6E-5	9.7E-6
Susquehanna	1.7E-5	9.3E-6
TMI	2.5E-5	1.4E-5
Turkey Point	3.1E-6	1.8E-6
Vt Yankee	2.3E-5	1.3E-5
Vogtle	5.7E-5	3.4E-5
Waterford	8.8E-6	5.4E-6
Watts Bar	2.7E-5	1.5E-5
Wolf Creek	4.7E-6	2.5E-6
Yankee Rowe	6.9E-5	4.3E-5
Zion	2.8E-5	1.8E-5

Internal Fire Initiating Event (FIR)

Event FIR - Frequency of a fire event in the building housing the SFP

Typically, the SFP is located in the reactor building (in most BWRs), and either in a separate fuel handling building or the auxiliary building (for PWRs). Generic fire ignition frequencies for different plant locations can be obtained from EPRI's Fire-Induced Vulnerability Evaluation (FIVE) document (EPRI TR-100370s dated April 1992). For BWR reactor buildings, the generic initiating event frequency is 2.5E-2 yr^{-1} from pumps and 5.0E-2 yr^{-1} from electrical cabinets. For PWR auxiliary buildings, the generic initiating event frequency is 1.9E-2 yr^{-1} from pumps and 1.9E-2 yr^{-1} from electrical cabinets. These frequencies are dominated by the larger pumps and cabinets (e.g., those from the ECCS) which are assumed to be no longer present in decommissioned plants. Therefore, these frequencies are not directly applicable to our study. Fire ignition frequencies for fuel handling buildings are not provided in the EPRI FIVE report. The most similar locations would be the "radwaste area" or the "intake structure". For the radwaste area, the only ignition sources listed are for "miscellaneous components" and the ignition frequency for these components is 8.7E-3 yr^{-1}. For the intake structure, ignition frequencies are 2.4E-3 yr^{-1} for electrical cabinets, 4.0E-3 yr^{-1} for fire pumps, and 3.2E-3 yr^{-1} for "others". Therefore, for both the radwaste area and the intake structure, the fire ignition frequency is approximately 9E-3 yr^{-1}. This will be somewhat conservative for this study since some of the equipment considered in the FIVE database will not be present in a decommissioned SFP building. However, other "plant-wide" components such as junction boxes, air compressors, and transients (extension cords, heaters, etc.) which could contribute to this frequency will not be added to this total. Therefore, 9E-3 yr^{-1} will be used as initiating event frequency for Cases 1 and 3.

For Case 2, it is assumed that the dismantling of plant systems will be ongoing. Therefore, fire ignition frequency contribution from welding and cutting has to be included. From Table 1.2 of the EPRI FIVE document, this contribution is 3.1E-2 yr^{-1}. Adding this to the 9E-3 from above yields a frequency of 0.04 yr^{-1} for Case 2.

Note: The above frequencies are comparable to those estimated from operating experience compiled by AEOD (AEOD/S97-03, "Special Study: Fire Events - Feedback of U.S. Operating Experience", dated June 1997). For example, the AEOD data shows the following fire event frequencies (per year) for periods when the plant is operating:

Table 3a - Fire Frequency by Plant Location - Power Operations

Location	1965-1985	1986-1994	1965-1994
Reactor building (BWR)	0.122	0.087	0.105
Auxiliary building (PWR)	0.107	0.056	0.082
Service water pump house	0.004	0.007	0.005
"Other" buildings (includes Radwaste and Fuel Handling buildings)	0.041	0.020	0.031

When the plant is shutdown (0% power), the AEOD report provides the following fire initiator frequencies:

Table 3b - Fire Frequency by Plant Location - Shutdown	
Location	1965-1994
Reactor building (BWR)	0.027
Auxiliary building (PWR)	0.018
Switchgear room	0.0065
Diesel Generator building	0.032

Again, the above frequencies are consistent with those used in this SFP risk analysis.

Event OSP - Probability of fire suppression and probability that the unsuppressed fire will fail the SFP cooling function

The probability of fire suppression is obtained from a EPRI report titled "Fire Requantification Studies" (NSAC-181, dated March 1993). On page 3-17 of NSAC-181, the probabilities of failure to suppress a fire for three damage times are as follows:

Table 4 - Probability of Failure of Fire Suppression				
Damage Time	Automatic Actuation	Manual Recovery	Manual Suppress	Total
3	0.05	1.0	0.7	0.035
13	0.05	0.33	0.4	0.007
20	0.05	0.33	0.33	0.005

The above probabilities were estimated based on information on operating reactors. For decommissioned plants, the fire protection program may be changed (see Draft Regulatory Guide DG-1069 dated July 1998, "Fire Protection Program for Nuclear Power Plants During Decommissioning and Permanent Shutdown"). Depending on changing plant conditions, features such as automatic fire suppression systems or an onsite fire brigade may no longer be required.

The modeling of fire growth and propagation and the determination of the effects of a fire on equipment in a room would optimally take into account the combustible loading in the room, the presence of intervening combustibles, the room size and geometry, and other characteristics such as ventilation rates and presence openings in the room. Since detailed input such as these are not applicable for a generic study such as this, fire growth and propagation will have to be determined based on best estimate assumptions. A damage time in excess of 20 minutes is assumed since typical SFP buildings/areas are relatively large and since equipment within such buildings are usually spread-out. That is, it is assumed that it will take at least 20 minutes before a fire will either fail of the cooling pumps or fail offsite power feed to the pumps. Therefore, from Table 4, the probability of failure of fire suppression is 0.005. However, given the discussion in the above paragraph, it is assumed that suppression is not as effective in a decommissioned plant as it would be in an operating reactor, and the failure probability will be increased by a factor of 10. Thus, the probability of failure of fire suppression, and the probability that this unsuppressed fire will fail the SFP cooling function is 0.05 (for Cases 1 and 3).

In Case 2, it is more likely that the SFP area will be occupied, or that operators in surrounding areas will detect a potential fire and will initiate suppression efforts. Therefore, the probability of failure to suppress in this case will be decreased by a factor of 5 to 0.01.

Event OMK - Operator recovery using diesel fire pumps

Given a fire event that is unsuppressed and that is sufficiently large to fail the SFP cooling function, it is assumed that this fire also fails offsite power feed to the plant (failure of the bus, cabling, etc.). Therefore, recovery of cooling will be through the use of the diesel fire pump for coolant makeup. Given the amount of time available, the failure of this function is dominated by the unavailability of the diesel pump (the pump fails to start or run, or the pump is out for maintenance). Note that there may be a dependency of this event with previous event since the failure of manual suppression may be due to failure of fire pumps. However, given that there is sufficient time (120 hours in Cases 1 & 3, and 50 hours for Case 2) for recovery action, this dependency is not modeled.

The cutsets for this event consist of the unavailability of the diesel fire pump or the failure of the operator to start this pump - see gate GLPR142 in fault tree LOP-REC. For Case 1, the HEP used is 0.01, and for Case 2, the HEP is 0.08. In Case 3, this event is assumed to fail, since fire pumps are assumed to be unavailable in this case.

Event OFD - Recovery using offsite sources

Given the failure of recovery actions using onsite sources, this event accounts for recovery of coolant makeup by use of offsite sources such as the procurement of a portable diesel generator or the use of the fire brigade. Adequate time is available for this action provided that there is a fast enough recognition that recovery of cooling using onsite sources will not be successful, and that offsite sources are the only viable alternatives. It is not clear what plant procedures (if any) will direct the operator to do, and what the time-line would be before the operator is to resort to offsite sources. However, given adequate time and trained operators, a failure probability of 0.01 is estimated for this event.

Loss of Cooling Initiating Event (LOC)

Event LOC - Frequency of a loss of SFP cooling event

The initiating event frequency includes the loss of coolant system flow from 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., electrical connections.) Operational data from NUREG-1275, Volume 12 shows that the frequency of loss of spent fuel pool cooling events in which a temperature increase of more than 20°F occurred can be estimated to be on the order of two to three events per 1000 reactor years. The data also showed that, for the majority of events, the duration of the loss of cooling was less than one hour. Only three events exceeded 24 hours, with the maximum duration being 32 hours. There were four events where the temperature increase exceeded 20°F, with the maximum increase being 50°F.

Event CRA - Control room alarms

An NRR survey of SFP systems performed as part of NUREG-1275, Vol 12 identified a wide range of instrumentation designs at existing plants. Typically, each plant has some type of instrumentation to monitor the SFP system performance, although the type and extent of instrumentation varied significantly among plants. The parameters monitored include SFP level, temperature, liner leakage, pump discharge pressure, and system flow. Typically, only important parameters are monitored in the control room, while most of the other parameters are monitored/displayed on the local panel. However, many local alarms initiate a common "trouble" alarm in the control room.

For half the plants surveyed in the NUREG-1275 study, SFP temperature is indicated or recorded in the control room, for the other half, indication is on a local panel. For most plants, an abnormal temperature is individually alarmed in the control room, and for the rest of the plants, the alarm is on the local panel that initiates a common trouble alarm in the control room.

Sections 3.3 and 6.2 of NUREG-1275 Vol 12 provide an assessment of the instrumentation for SFPs, and point to the fact that the availability of instrumentation would be an important factor in the results of a risk assessment.

In this event tree, the failure of this branch event is modeled as the failure of the instrumentation (hardware failures), or the failure of the operator to respond given that the instrumentation works as designed. Hardware failures include failure of control room indicators or alarms, instrumentation channel loss of function, local electrical faults, etc.

To quantify the failure of the operator to respond to a signal, several references were researched. In Table 20-23 of NUREG/CR-1278 (Handbook of Human Reliability Analysis with Emphasis on Nuclear Power plant Applications: Final Report, dated August 1983), the estimated HEP for the annunciator response model for two competing signals (e.g., level, temperature, "trouble", radiation) is 6E-4. In a DOE report (Savannah River Site Human Error Data Base Development for Nonreactor Nuclear Facilities, WSRC-TR-

93-581, February 1994), the HEP of 3E-3 is estimated for the failure of operators to respond to a compelling signal given that there are few competing signals. For the SFP analysis, the DOE estimate of 3E-3 is used.

The fault tree combining the HEP and hardware failures is CR-ALARM.

Event IND - Other indications of loss of cooling

Given that control room indication is not available (or is ignored or misinterpreted by the operator), other indications of a loss of SFP cooling can come from operator walk-downs of the pool area. Indications could be from the local area alarms, steaming over the pool, temperature and humidity in the area, or low pool level once boiling starts.

From DOE report WSRC-TR-93-581, the HEP provided for the "failure of visual inspection to observe abnormal characteristics" had a range of 0.1 to 0.01. Based on the time available, and assuming an area walk-down once a shift (every 8 to 12 hours), and assuming that the walk-down is performed by a different crew member for each shift, the lower range of the value is used for this HEP.

Event OCS - Operator recovery of cooling system

On successfully recognizing the loss of cooling condition (via control room alarms or area walk-downs), the initial focus of the operator action (and this is the HEP) will likely be on the repair of the cooling system.

Conservatively assume mean repair time of 10 hours. (Note: from industry data, mean repair time for pumps is approximately 10 hours. For repair of instrumentation or other local electrical faults, the mean time is typically 1 to 2 hours.)

Probability of failure to repair = $e^{-\lambda t}$, where λ = 1/10hrs, and t = available time in hours

In the cases when the operator action is initiated by control room alarms, the time available for Cases 1 and 3 is 128 hours. In Case 2, 52 hours is available. Therefore,

Case 1 ⇛ probability of failure to repair = $e^{-1/10 \cdot 128}$ = 3E-6 (cap off at 1E-4)

Case 2 ⇛ probability of failure to repair = $e^{-1/10 \cdot 52}$ = 5.5E-3

In Case 3, it is assumed that there are less procedures and training with regard to repair of failed equipment, and that a maintenance crew will not be available onsite. Therefore, the mean time to repair is assumed to be 40 hours.

Case 3 ⇛ probability of failure to repair = $e^{-1/40 \cdot 128}$ = 4.2E-2

In cases when control room indication is not available (or is ignored or misinterpreted by the operator), the following assumptions apply. During walk-downs, the loss of pool cooling will not be obvious until bulk boiling begins. Therefore the available time in

Cases 1 & 3 will be (20 ft) /(0.2 ft per hour) = 100 hours; for Case 2, the available time will be (20 ft) /(0.5 ft per hour) = 40 hours. In addition, it is conservatively assumed that it will be two shifts before the operator will recognize the pool boiling or the loss of level. Therefore, the time available is: 100 - 16 = 84 hours for Cases 1 & 3; and 40 - 16 = 24 hours for Case 2. Therefore,

Case 1 ⇛ probability of failure to repair = $e^{-1/10 \cdot 84}$ = 2.2E-4

Case 2 ⇛ probability of failure to repair = $e^{-1/10 \cdot 24}$ = 9.1E-2

Case 3 ⇛ probability of failure to repair = $e^{-1/40 \cdot 84}$ = 1.2E-1

Event OFD - Operator initiates makeup using fire pumps

Given failure to restore pool cooling using normal equipment, the operator could initiate coolant makeup by use of the makeup pumps or the fire pumps. Failure of this event consists of the failure of the operator to establish alternate cooling, or the failure of both the electric fire pump and the diesel fire pump.

This event is quantified using gates GLCR123 and GLCR163 in fault tree LOC-REC. In gate GLCR123, a HEP of 0.01 is estimated and this is used for the case where the control room alarms are functional and the operator is alerted early that a potential problem exists. In gate GLCR163, a HEP of 0.02 is estimated and this is used for the case where the control room alarms are either non-functional and operator response time is reduced. The above HEPs are for Case 1. For Case 2, the operator response time is less and HEPs of 0.08 and 0.16 are used for the control room alarm and no control room alarm scenarios respectively. In Case 3, this event is assumed to fail, since fire pumps are assumed to be unavailable in this case.

Event OFB - Recovery using offsite sources

This event is similar to event OFB in the internal fire event tree. A failure probability of 0.01 is used for this event.

Loss of Coolant Inventory Initiating Event (LOI)

Event LOI - Frequency of a loss of coolant inventory event

This initiator includes loss of coolant inventory from events such as those resulting from configuration control errors, siphoning, piping failures, and gate and seal failures. Operational data provided in NUREG-1275, Volume 12 show that the frequency of loss of inventory events in which a level decrease of more than one foot occurred can be estimated to be (on the order of) less than one event per 100 reactor years. Most of these events were the result of operator error and were recoverable. NUREG-1275 shows that, except for one event that lasted for 72 hours, there were no events that lasted more than 24 hours. Eight events resulted in a level decrease of between one and five feet, and another two events resulted in an inventory loss of between five and 10 feet.

Event NLL - Loss exceeds normal makeup capacity and isolation of break is required

Using the information from NUREG-1275, it can be estimated that 6% of the loss of inventory events will be large enough and/or occur for a duration that is long enough so that isolation of the loss is required if the only system available for makeup is the spent fuel pool makeup system. For the other 94% of the cases, operation of the makeup pump is sufficient to prevent fuel uncovery.

From Table 3.2 of NUREG-1275, there were 38 events that led to a loss of pool inventory. If we do not consider the load drop event (since this is treated in a separate event tree), we have 37 events. Of these, 2 events involved level drops of greater than 5 feet. Therefore it is estimated that 2 / 37 or approximately 6 percent of events result in large loss of inventories.

Event CRA - Control room alarms

A discussion of this event is provided in the writeup for the "Loss of Coolant" event tree. Specific to level alarms, the SFP level sensor usually has a narrow range, typically 4 feet, covering high and low alarm setpoints and the minimum Technical Specification level. The control room level indicator provided by this sensor is good only for this narrow range. Therefore the control room indicator cannot monitor a level below this range and may not be useful for lower level conditions expected of a gross loss of SFP coolant inventory event. The HEP of 3E-3 used in this analysis reflects this condition (i.e., some competing signals).

Event IND - Other indications of loss of cooling

Given that control room indication is not available (or is ignored or misinterpreted by the operator), other indications of a loss of SFP inventory can come from operator walk-downs of the pool area. Indications could be from the local area alarms (radiation alarms, building sump high level alarm, etc.), low pool level, accumulation of water in unexpected locations, etc.

From DOE report WSRC-TR-93-581, the HEP provided for the "failure of visual inspection to observe abnormal characteristics" had a range of 0.1 to 0.01. Based on the time available, and assuming an area walk-down once a shift (every 8 to 12 hours), and assuming that the walk-down is performed by a different crew member for each shift, the lower range of the value (i.e., 0.01) is used for this HEP for the small inventory loss cases. For the large losses where the available time will be much less, the upper range (i.e., 0.1) is used for this HEP. These HEP values are applicable for both Cases 1 and 2. For Case 3, where walkdown requirements may be less, and operators may be less experienced, HEPs of 0.05 and 0.2 are used for the small and large losses respectively.

Event OIS - Operator isolates inventory loss and initiates makeup through makeup pumps

This event applies for the "large" loss of inventory events. On successfully recognizing the loss of inventory condition (via control room alarms or area walk-downs), the initial focus of the operator action will likely be on the isolation of the inventory loss, and on the initiation of makeup using the makeup pumps. Failure of this event is modeled as the failure of the operator to isolate the loss and initiate the makeup system or the failure of the makeup system itself. Gate GLIR121 of fault tree LOI-REC quantifies this event for the case where control room alarms are effective, and Gate GLIR151 of fault tree LOI-REC quantifies this event for the case where operator action is initiated by area walkdowns (and therefore, less time is available). In both these cases, hardware failure of the makeup system is the dominant cause of failure.

Timing for the "large" loss of inventory event is estimated as follows: From NUREG-1275 V12, the largest inventory loss resulted in a level drop of between 5 to 10 ft. In a foreign plant, an incident resulted in a level drop of 16'. For this analysis, assume a drop of between approximately 15 ft leaving approximately 8 ft of water above the fuel assemblies. Using similar methodology as that used to calculate timing for LOC events:

For 1-yr fuel, time available = time to bulk boiling + time to boildown to 3' above fuel
= 33 hr x 0.34 + 5 ft / 0.2 ft/hr
= 36 hours

For 1-month fuel, time available = 14 hr x 0.34 + 5 ft / 0.5 ft/hr
= 15 hours

Event OIL - Operator initiates makeup using makeup pumps

This event is similar to event OIS except that, in this case, isolation of the inventory loss is not required since the failure size is such that the makeup pumps is of sufficient capacity to overcome the loss. In this case, the operator action is simpler and there is more time to perform the action. However, similar to event OIS, hardware failure of the makeup system is the dominant cause of failure.

The time available for operator actions in this event is similar to that for a loss of cooling event, i.e., approximately 120 hours for Cases 1 and 3, and 50 hours for Case 2.

Event OMK - Operator initiates makeup using fire pumps

Given failure to restore pool cooling using normal equipment, the operator could initiate coolant makeup by use of the fire pumps. Failure of this event consists of the failure of the operator to establish alternate cooling, or the failure of both the electric fire pump and the diesel fire pump.

This event is quantified using gates GLIR123, GLIR153 and GLIR183 in fault tree LOI-REC. In gate GLIR123, the HEP is estimated for the case where the control room alarms are functional and the operator is alerted early that a large loss of inventory event exists. In gate GLIR153, the HEP is estimated for the case where the control room alarms are either non-functional and operator response time is reduced. In gate GLIR183, the HEP is estimated for the case where the inventory loss is small and operator response time is expansive. Note that the HEP basic events used to quantify this event are the same as those used in events OIS and OIL to account for the potential dependencies in these events.

Event OFD - Recovery using offsite sources

Given the failure of recovery actions using onsite sources, this event accounts for recovery of coolant makeup by use of offsite sources such as the procurement of a portable diesel generator or the use of the fire brigade. For the small loss of inventory events, adequate time is available for this action provided that there is a fast enough recognition that recovery of cooling using onsite sources will not be successful, and that offsite sources are the only viable alternatives. It is not clear what plant procedures (if any) will direct the operator to do, and what the time-line would be before the operator is to resort to offsite sources. However, given adequate time and trained operators, a failure probability of 0.05 is estimated for this event. Note that this is higher than the 0.01 estimated for the loss of cooling type events since there will be less time available for this event. For larger leaks, even less time will be available (see timing estimated in the event OIS) Therefore, for these events, failure probabilities of 0.1 and 0.2 for were estimated for scenarios with and without control room alarms respectively

Loss of Offsite Power from Plant Centered and Grid Related Events (LP1)

Event LP1 - Frequency of a loss of offsite power from plant centered and grid related events

Plant centered events typically involve hardware failures, design deficiencies, human errors (in maintenance and switching), localized weather induced faults (e.g., lightning), or combinations of these. Grid related events are those in which problems in the offsite power grid cause the loss of offsite power. For this study, a frequency of 0.08 per year is used to be consistent with INEL-96/0334. This is also consistent with operating data as discussed below.

Using operating data at nuclear power plants for the years 1980 to 1996, NUREG/CR-5496 estimated an initiating event frequency of LOSP from plant-centered events during power operation to be 0.04 per unit critical year. In NUREG/CR-5496, LOSP is defined as an event that results in a loss of power to all safety (vital) buses and a signal for all available emergency AC generators to start and power their respective buses. Events were included if a reactor trip occurs. For these reasons, the NUREG/CR-5496 frequency may be slightly non-conservative when applied to decommissioned SFPs since LOSP could be defined to loss of power to a non-vital bus.

NUREG/CR-5496 also estimates the frequency of LOSP from plant-centered events during shutdown to be 0.18 per shutdown year. Finally, grid-related events were estimated to be relatively minor contributors at 0.0019 per site calendar year.

Event DG - Diesel for fire pump starts and runs

This event represents the failure of the diesel fire pump to start and run and consists of the failure of the operator to manually start the pump or hardware failure of the pump itself. Gate GLPR142 of fault tree LOP-REC models this event.

Note that the unavailability of the diesel pump is relatively high (0.18 for Cases 1 and 2, and unity for Case 3). This is consistent with data used in INEL-96/0334 and is also consistent with reliability data on non-Class 1E diesel pumps and unavailability of plant equipment not controlled by technical specifications.

Event OPR - Offsite power recovery prior to fuel uncovery

The probability of recovery of offsite power was estimated using the methodology in NUREG/CR-5032. Given in excess of 50 hours for power recovery, a non-recovery probability of 0.001 was estimated.

Event OCS - Cooling system re-start and run

On recovering offsite power, the normal SFP cooling pumps will have to be re-started manually. Failure of this event consists of failure of the operator to re-start the pumps or hardware failure of the pump or the support systems. The fault tree used to quantify this event is CS-REC.

This event is not applicable for the sequences where offsite power is not recovered.

Event OMK - Operator initiates makeup using fire pumps

Given the failure to restore pool cooling using normal equipment, the operator could initiate coolant makeup by use of the fire pumps. Failure of this event consists of the failure of the operator to establish alternate cooling, or the failure of the fire protection pumps. Fault tree LOP-REC models this event. In the sequence where the diesel successfully starts and offsite power is recovered (i.e., events DG and OPR are successful), both the electric fire pump and the diesel fire pump will be available - gate GLPR112 of LOP-REC. In the sequence where the diesel fails but offsite power is recovered, only the electric fire pump will be available - gate GLPR172 of LOP-REC.

Event CFD - Recovery using offsite sources

This event accounts for recovery of coolant makeup using offsite sources such as portable pumps or the fire brigade. Although a failure probability of 0.01 was used for the other loss of cooling type initiators (see events LOC and FIR), a higher failure probability of 0.05 was assigned here since it is uncertain (without the benefit of plant procedures) as to how long the operator will wait for the recovery of offsite power before initiating other actions to makeup inventory.

Loss of Offsite Power from Severe Weather Events (LP2)

Event LP2 - Frequency of a loss of offsite power from severe weather events

Severe weather is defined as forceful and non-localized effects. A loss of offsite power was classified as a severe weather event if the weather was widespread and capable of major disruption. Examples of severe weather include hurricanes, tornadoes, snow and ice storms. When modeling the LOSP initiator, severe weather events are separated from the plant-centered and grid-related events because the probability of recovery of offsite power from these events could be substantially different.

The frequency of a LOSP from severe weather events is 0.007 per year (from NUREG/CR-5496).

Event DG - Diesel for fire pump starts and runs

This is similar to event DG in the LP1 event tree.

Event OPR - Offsite power recovery prior to fuel uncovery

The probability of failure to recover offsite power is obtained from Figure B-19 of NUREG/CR-5496. For Cases 1 and 3, the time to fuel uncovery is approximately 120 hours, and the probability of failure to recover power is 0.02. For Case 2, the time to fuel uncovery is approximately 50 hours, and the probability of failure to recover power is 0.1.

Event OCS - Cooling system re-start and run

This is similar to event OCS in the LP1 event tree. This is slightly non-conservative since offsite power recovery is likely to occur later in the sequence, thereby allowing less time for operator action.

Event OMK - Operator initiates makeup using fire pumps

This is similar to event OMK in the LP1 event tree.

Event OFD - Recovery using offsite sources

This is similar to event OFD in the LP1 event tree.

Analysis Results

Results are summarized in the table below

Table 4 Spent Fuel Pool Cooling Risk Analysis Frequency of Fuel Uncovery (per year)			
INITIATING EVENT	**CASE 1**	**CASE 2**	**CASE 3**
Loss of Offsite Power - Plant centered and grid related events	1.3E-06 (11%)	4.2E-06 (5%)	8.0E-05 (30%)
Loss of Offsite Power - severe weather events	1.4E-06 (12%)	9.4E-06 (12%)	1.4E-05 (5%)
Internal Fire	8.6E-07 (7%)	1.0E-06 (1%)	9.0E-06 (3%)
Loss of Pool Cooling	1.5E-07 (1%)	1.7E-07 (0.2%)	1.7E-05 (6%)
Loss of Coolant Inventory	2.9E-06(25%)	6.0E-05 (75%)	1.3E-04 (49%)
Seismic Event	2.0E-06 (17%)	2.0E-06 (3%)	2.0E-06 (0.7%)
Cask Drop	2.5E-06 (21%)	2.5E-06 (3%)	1.5E-05 (6%)
Aircraft Impact	4.0E-08 (0.3%)	4.0E-08 (ε)	4.0E-08 (ε)
Tornado Missile	5.6E-07 (5%)	5.6E-07(0.7%)	5.6E-07 (0.2%)
Total	1.2E-05	8.0E-05	2.7E-04

The preliminary results suggest that there may be non-negligible risk associated with spent fuel pools at decommissioned plants during the period analyzed in the risk assessment (one month after removal of last fuel from the reactor to one year after removal of the last fuel.)

A breakdown of the results by accident sequences is provided in Table 5. The cutsets for Cases 1, 2 and 3 are provided in Tables 6a, 6b and 6c respectively. These cutsets are ordered by frequency, and include all the initiating events. Finally, importance rankings for a combination of all initiators are provided in Tables 7a, 7b and 7c for Cases 1, 2 and 3 respectively.

Sensitivity Studies

Sensitivity cases to determine the effect of various parameter changes on the fuel uncovery frequency is provided in Table 8. These sensitivity cases are for Case 1 SFP model.

Some Suggestions for Future Updates

Table 9 lists an expanded version of the cutsets provided in Table 6a. Together with the results of the sensitivity studies in Table 8, this list highlights the events where future refinement may be useful. Table 9 also shows that some modifications to the model are necessary - see for example, cutset number 17 which describes a sequence where the diesel fire pump successfully starts, but where both fire pumps fail (event FP-MKUP-FTF). So that non-minimal cutsets such as these do not occur, future revisions of the model should replace the event FP-MKUP-FTF with an AND gate consisting of the events FP-DGPUMP-FTP and FP-ELPUMP-FTF.

Table 5 - Summary of Sequence Frequencies

INITIATOR	SEQUENCE	DESCRIPTION	FREQUENCYOF CORE UNCOVERY (per year)		
			Case 1	Case 2	Case 3
AIR	S02	AIR-FPI	4.000E-008	4.000E-008	4.000E-008
CSK	S02	CSK-FPI	2.500E-006	2.500E-006	1.500E-005
EQE	S06	EQE-CSI-OFD	9.500E-007	9.500E-007	9.500E-007
	S07	EQE-FPI	1.000E-006	1.000E-006	1.000E-006
FIR	S04	FIR-OSP-OMK-OFD	8.550E-007	1.040E-006	9.000E-006
LOC	S04	LOC-OCS-OFB-OFD	6.000E-011	1.485E-008	1.128E-006
	S08	LOC-CRA-OCS-OFB-OFD	< 1.0E-012	2.325E-009	3.591E-007
	S09	LOC-CRA-IND	1.503E-007	1.503E-007	1.575E-005
LOI	S04	LOI-OIS-OMK-OFD	6.600E-007	3.060E-005	1.074E-005
	S08	LOI-CRA-OIS-OMK-OFD	2.760E-008	2.732E-007	4.032E-006
	S09	LOI-CRA-IND	3.006E-007	3.006E-007	1.260E-005
	S13	LOI-NLL-OIL-OMK-OFD	1.410E-006	2.820E-005	4.627E-005
	S17	LOI-NLL-CRA-OIL-OMK-OFD	7.064E-009	1.413E-007	5.157E-006
	S18	LOI-NLL-CRA-IND	4.709E-007	4.709E-007	4.935E-005
LP1	S04	LP1-OCS-OMK-OFD	1.438E-007	2.349E-007	0.000E+000
	S11	LP1-DG-OCS-OMK-OFD	3.692E-007	2.883E-006	7.575E-005
	S13	LP1-DG-OPR-OFD	7.600E-007	1.040E-006	4.000E-006
LP2	S04	LP2-OCS-OMK-OFD	1.258E-008	1.850E-008	0.000E+000
	S11	LP2-DG-OCS-OMK-OFD	3.230E-008	2.270E-007	6.628E-006
	S13	LP2-DG-OPR-OFD	1.330E-006	9.100E-006	7.000E-006
TOR	SO2	TOR-FPI	5.600E-007	5.600E-007	5.600E-007

NOTES:	AIR	Aircraft crash initiating event
	CRA	Control room alarms alert the operator of initiator
	CSI	Structural integrity of cooling systems
	CSK	Cask drop initiating event
	DG	Diesel for fire pump fails to start and run
	EQE	Seismic event greater than 3 times SSE
	FIR	Internal fire initiating event
	FPI	Fuel pool intact
	IND	Operator alerted of initiator fron plant walkdowns
	LOC	Loss of cooling initiating event
	LOI	Loss of coolant inventory initiating event
	LP1	Loss of offsite power from plant centered or grid related events
	LP2	Loss of offsite power from severe weather events
	NLL	Loss of inventory exceeds makeup capacity and isolation of break is required
	OCS	Cooling system re-start and run
	OFB	Operator initiates makeup using fire pumps
	OFD	Recovery using offsite sources (procurement of pumps, fire engine, etc)
	OIL	Operator initiates makeup using makeup pumps
	OIS	Operator isolates inventory loss and initiates makeup thru makeup pumps
	OMK	Operator recovery using makeup system or fire pumps
	OPR	Offsite power recovery prior to fuel uncovery
	OSP	Fire suppression or no effect on SFP function
	TOR	Tornado missile initiating event

Table 6a - Cutsets for Case 1

Equation File	= CASE1.EQN
Basic Event Data file referenced	= SFP-1.BED
Number of cut sets in equation	= 86
Top event unavailability (rare event)	= 1.158E-005

1	2.5000E-006	XEQN-UNITY	IE-CASK-DROP			
2	1.2600E-006	REC-OSP-SW	REC-INV-OFFSITE	IE-LOOP-LP2	FP-DGPUMP-FTF	
3	1.0000E-006	SFP-INTEG-HCLPF	IE-SEISMIC			
4	9.5000E-007	XCOM-SFP-INT	XEQN-UNITY	REC-INV-OFFSITE	IE-SEISMIC	
5	9.4000E-007	REC-INV-OFFSITE	HEP-INV-MKUP-SML	LOI-SMALL	IE-LO-POOL-INV	
6	8.1000E-007	REC-INV-OFFSITE1	REC-FIRE-EVT	FP-DGPUMP-FTF	IE-INT-FIRE	
7	7.2000E-007	REC-OSP-PC	REC-INV-OFFSITE	IE-LOOP-LP1	FP-DGPUMP-FTF	
8	6.0000E-007	XCOM-LOI-SML	REC-INV-OFFSITE2	HEP-INV-MKUP-E	IE-LO-POOL-INV	
9	5.6000E-007	XEQN-UNITY	IE-TORNADO-MIS			
10	4.7000E-007	REC-INV-OFFSITE	FP-MKUP-FTF	LOI-SMALL	IE-LO-POOL-INV	SFP-REGMKUP-F
11	2.8200E-007	REC-WLKDWN-LOI-S	LOI-SMALL	IE-LO-POOL-INV	HEP-RES-ALARM	
12	1.8800E-007	REC-WLKDWN-LOI-S	LOI-SMALL	IE-LO-POOL-INV	SPC-LVL-LOP	
13	1.8000E-007	XCOM-LOI-SML	REC-WLKDWN-LOI-L	IE-LO-POOL-INV	HEP-RES-ALARM	
14	1.5120E-007	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	HEP-COOL-LOP-E
15	1.4000E-007	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP1	HEP-COOL-LOP-E	
16	1.2000E-007	XCOM-LOI-SML	REC-WLKDWN-LOI-L	IE-LO-POOL-INV	SPC-LVL-LOP	
17	1.1340E-007	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	HEP-COOL-LOP-E
18	9.0000E-008	REC-WLKDWN-LOC	IE-LO-POOL-COOL	HEP-RES-ALARM		
19	7.0000E-008	REC-OSP-SW	REC-INV-OFFSITE	IE-LOOP-LP2	HEP-ALTCL-LP-E	
20	6.0000E-008	REC-WLKDWN-LOC	IE-LO-POOL-COOL	SPC-LVL-LOP		
21	6.0000E-008	XCOM-LOI-SML	REC-INV-OFFSITE2	FP-MKUP-FTF	SFP-REGMKUP-F	IE-LO-POOL-INV
22	4.5000E-008	REC-INV-OFFSITE1	REC-FIRE-EVT	HEP-ALTCL-LP-E	IE-INT-FIRE	
23	4.0000E-008	REC-OSP-PC	REC-INV-OFFSITE	IE-LOOP-LP1	HEP-ALTCL-LP-E	
24	4.0000E-008	XEQN-UNITY	IE-AIRCRAFT-IMP			
25	2.5488E-008	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-PMP-CCF
26	2.3600E-008	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-PMP-CCF	
27	1.9116E-008	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-PMP-CCF
28	1.6200E-008	XCOM-IND-LOIL	XCOM-LOI-SML	REC-INV-OFFSITE3	HEP-INV-MKUP-L	IE-LO-POOL-INV
		HEP-RES-ALARM				
29	1.3230E-008	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2	HEP-COOL-LOP-E
30	1.2250E-008	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP2	HEP-COOL-LOP-E	
31	1.0800E-008	XCOM-IND-LOIL	XCOM-LOI-SML	REC-INV-OFFSITE3	HEP-INV-MKUP-L	IE-LO-POOL-INV
		PC-LVL-LOP				
32	1.0368E-008	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-FTR
33	9.9225E-009	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2	HEP-COOL-LOP-E
34	9.6000E-009	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-FTR	
35	7.7760E-009	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-FTR
36	2.8200E-009	REC-INV-OFFSITE	HEP-INV-MKUP-SML	LOI-SMALL	IE-LO-POOL-INV	HEP-RES-ALARM
37	2.2302E-009	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-PMP-CCF
38	2.0650E-009	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-PMP-CCF	
39	1.8800E-009	REC-INV-OFFSITE	HEP-INV-MKUP-SML	LOI-SMALL	IE-LO-POOL-INV	SPC-LVL-LOP
40	1.6727E-009	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-PMP-CCF
41	1.4100E-009	REC-INV-OFFSITE	FP-MKUP-FTF	SFP-REGMKUP-F	LOI-SMALL	IE-LO-POOL-INV
		HEP-RES-ALARM				
42	1.3824E-009	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-CKV-CCF-M
43	1.2800E-009	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-CKV-CCF-M	
44	1.0368E-009	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-CKV-CCF-M
45	9.5040E-010	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-PLG
46	9.4000E-010	REC-INV-OFFSITE	FP-MKUP-FTF	SFP-REGMKUP-F	LOI-SMALL	IE-LO-POOL-INV
		SPC-LVL-LOP				
47	9.4000E-010	REC-WLKDWN-LOI-S	LOI-SMALL	IE-LO-POOL-INV	SPC-LVL-LOF	
48	9.0720E-010	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-HTX-FTR
49	8.8000E-010	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-PLG	
50	8.4000E-010	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-HTX-FTR	
51	8.2080E-010	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-CCF
52	8.2080E-010	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-CKV-CCF-H
53	7.6000E-010	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-CCF	
54	7.6000E-010	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-CKV-CCF-H	
55	7.1280E-010	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-PLG
56	6.8040E-010	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-HTX-FTR
57	6.5707E-010	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-PMP-FTF-1
		SPC-PMP-FTF-2				
58	6.1560E-010	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-CKV-CCF-H

Table 6a (continued)

59	6.1560E-010	XCOM-DG-STAR	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-CCF
60	6.0840E-010	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-PMP-FTF-1	SPC-PMP-FTF-2
61	6.0000E-010	XCOM-LOI-SML	REC-WLKDWN-LOI-L	IE-LO-POOL-INV	SPC-LVL-LOF	
62	4.9280E-010	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-PMP-FTF-1
		SPC-PMP-FTF-2				
63	3.2400E-010	XCOM-IND-LOIL	XCOM-LOI-SML	REC-INV-OFFSITE3	FP-MKUP-FTF	SFP-REGMKUP-F
		IE-LO-POOL-INV	HEP-RES-ALARM			
64	3.0000E-010	REC-WLKDWN-LOC	IE-LO-POOL-COOL	SPC-LVL-LOF		
65	2.1600E-010	XCOM-IND-LOIL	XCOM-LOI-SML	REC-INV-OFFSITE3	FP-MKUP-FTF	SFP-REGMKUP-F
		IE-LO-POOL-INV	SPC-LVL-LOP			
66	1.2096E-010	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-CKV-CCF-M
67	1.1200E-010	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-CKV-CCF-M	
68	9.0720E-011	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-CKV-CCF-M
69	8.3160E-011	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-HTX-PLG
70	7.7000E-011	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-HTX-PLG	
71	7.1820E-011	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-CKV-CCF-H
72	7.1820E-011	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-HTX-CCF
73	6.6500E-011	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-CKV-CCF-H	
74	6.6500E-011	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-HTX-CCF	
75	6.2370E-011	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-HTX-PLG
76	5.7494E-011	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-PMP-FTF-1
		SPC-PMP-FTF-2				
77	5.4000E-011	XCOM-IND-LOIL	XCOM-LOI-SML	REC-INV-OFFSITE3	HEP-INV-MKUP-L	IE-LO-POOL-INV
		SPC-LVL-LOF				
78	5.3865E-011	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-CKV-CCF-H
79	5.3865E-011	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-HTX-CCF
80	5.3235E-011	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-PMP-FTF-1	SPC-PMP-FTF-2
81	4.3120E-011	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-PMP-FTF-1
		SPC-PMP-FTF-2				
82	3.0000E-011	HEP-COOL-LOC-E	REC-INV-OFFSITE1	IE-LO-POOL-COOL	HEP-ALTCL-E	
83	3.0000E-011	HEP-COOL-LOC-E	REC-INV-OFFSITE1	IE-LO-POOL-COOL	FP-MKUP-FTF	
84	9.4000E-012	REC-INV-OFFSITE	HEP-INV-MKUP-SML	LOI-SMALL	IE-LO-POOL-INV	SPC-LVL-LOF
85	4.7000E-012	REC-INV-OFFSITE	FP-MKUP-FTF	SFP-REGMKUP-F	LOI-SMALL	IE-LO-POOL-INV
		SPC-LVL-LOF				
86	1.0800E-012	XCOM-IND-LOIL	XCOM-LOI-SML	REC-INV-OFFSITE3	FP-MKUP-FTF	SFP-REGMKUP-F
		IE-LO-POOL-INV	SPC-LVL-LOF			

Table 6b - Cutsets for Case 2

Equation File = CASE2.EQN
Basic Event Data file referenced = SFP-2.BED
Number of cut sets in equation = 91
Top event unavailability (rare event) = 7.975E-005

1	3.0000E-005	XCOM-LOI-SML	HEP-INV-MKUP-E	XEQN-UNITY	IE-LO-POOL-INV	
2	1.8800E-005	HEP-INV-MKUP-SML	LOI-SMALL	XEQN-UNITY	IE-LO-POOL-INV	
3	9.4000E-006	FP-MKUP-FTF	LOI-SMALL	XEQN-UNITY	IE-LO-POOL-INV	SFP-REGMKUP-F
4	6.3000E-006	REC-OSP-SW	REC-INV-OFFSITE	IE-LOOP-LP2	FP-DGPUMP-FTF	
5	2.8000E-006	REC-OSP-SW	REC-INV-OFFSITE	IE-LOOP-LP2	HEP-ALTCL-LP-E	
6	2.5000E-006	XEQN-UNITY	IE-CASK-DROP			
7	2.2400E-006	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP1	HEP-COOL-LOP-E	
8	1.0000E-006	SFP-INTEG-HCLPF	IE-SEISMIC			
9	9.5000E-007	XCOM-SFP-INT	XEQN-UNITY	REC-INV-OFFSITE	IE-SEISMIC	
10	7.2000E-007	REC-OSP-PC	REC-INV-OFFSITE	IE-LOOP-LP1	FP-DGPUMP-FTF	
11	7.2000E-007	REC-INV-OFFSITE1	REC-FIRE-EVT	FP-DGPUMP-FTF	IE-INT-FIRE	
12	6.0000E-007	XCOM-LOI-SML	FP-MKUP-FTF	XEQN-UNITY	IE-LO-POOL-INV	SFP-REGMKUP-F
13	5.6000E-007	XEQN-UNITY	IE-TORNADO-MIS			
14	3.2000E-007	REC-OSP-PC	REC-INV-OFFSITE	IE-LOOP-LP1	HEP-ALTCL-LP-E	
15	3.2000E-007	REC-INV-OFFSITE1	REC-FIRE-EVT	HEP-ALTCL-LP-E	IE-INT-FIRE	
16	3.0240E-007	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	HEP-COOL-LOP-E
17	2.8200E-007	REC-WLKDWN-LOI-S	LOI-SMALL	IE-LO-POOL-INV	HEP-RES-ALARM	
18	2.0720E-007	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	HEP-COOL-LOP-E
19	1.8880E-007	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-PMP-CCF	
20	1.8800E-007	REC-WLKDWN-LOI-S	LOI-SMALL	IE-LO-POOL-INV	SPC-LVL-LOP	
21	1.8000E-007	XCOM-LOI-SML	REC-WLKDWN-LOI-L	IE-LO-POOL-INV	HEP-RES-ALARM	
22	1.7640E-007	XCOM-REC-OSP2	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP2	HEP-COOL-LOP-E
23	1.6200E-007	XCOM-IND-LOIL	XCOM-LOI-SML	HEP-INV-MKUP-L	XEQN-UNITY	IE-LO-POOL-INV
		HEP-RES-ALARM				
24	1.2000E-007	XCOM-LOI-SML	REC-WLKDWN-LOI-L	IE-LO-POOL-INV	SPC-LVL-LOP	
25	1.0800E-007	XCOM-IND-LOIL	XCOM-LOI-SML	HEP-INV-MKUP-L	XEQN-UNITY	IE-LO-POOL-INV
		SPC-LVL-LOP				
26	9.0000E-008	REC-WLKDWN-LOC	IE-LO-POOL-COOL	HEP-RES-ALARM		
27	7.6800E-008	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-FTR	
28	6.0000E-008	REC-WLKDWN-LOC	IE-LO-POOL-COOL	SPC-LVL-LOP		
29	5.6400E-008	HEP-INV-MKUP-SML	LOI-SMALL	XEQN-UNITY	IE-LO-POOL-INV	HEP-RES-ALARM
30	4.0000E-008	XEQN-UNITY	IE-AIRCRAFT-IMP			
31	3.7600E-008	HEP-INV-MKUP-SML	LOI-SMALL	XEQN-UNITY	IE-LO-POOL-INV	SPC-LVL-LOP
32	2.8200E-008	FP-MKUP-FTF	SFP-REGMKUP-F	LOI-SMALL	XEQN-UNITY	IE-LO-POOL-INV
		HEP-RES-ALARM				
33	2.5488E-008	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-PMP-CCF
34	2.3814E-008	XCOM-REC-OSP2	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2
		HEP-COOL-LOP-E				
35	1.8800E-008	FP-MKUP-FTF	SFP-REGMKUP-F	LOI-SMALL	XEQN-UNITY	IE-LO-POOL-INV
		SPC-LVL-LOP				
36	1.7464E-008	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-PMP-CCF
37	1.6317E-008	XCOM-REC-OSP2	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2
		HEP-COOL-LOP-E				
38	1.4868E-008	XCOM-REC-OSP2	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-PMP-CCF
39	1.3200E-008	HEP-COOL-LOC-E	REC-INV-OFFSITE1	IE-LO-POOL-COOL	HEP-ALTCL-E	
40	1.0368E-008	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-FTR
41	1.0240E-008	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-CKV-CCF-M	
42	7.1040E-009	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-FTR
43	7.0400E-009	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-PLG	
44	6.0800E-009	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-CCF	
45	6.0800E-009	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-CKV-CCF-H	
46	6.0480E-009	XCOM-REC-OSP2	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-HTX-FTR
47	4.8672E-009	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-PMP-FTF-1	SPC-PMP-FTF-2
48	2.0072E-009	XCOM-REC-OSP2	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2
		SPC-PMP-CCF				
49	1.6500E-009	HEP-COOL-LOC-E	REC-INV-OFFSITE1	IE-LO-POOL-COOL	FP-MKUP-FTF	
50	1.6200E-009	XCOM-IND-LOIL	XCOM-LOI-SML	FP-MKUP-FTF	SFP-REGMKUP-F	XEQN-UNITY
		IE-LO-POOL-INV	HEP-RES-ALARM			
51	1.3824E-009	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-CKV-CCF-M
52	1.3753E-009	XCOM-REC-OSP2	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2
		SPC-PMP-CCF				
53	1.3104E-009	HEP-ALTCL-L	HEP-COOL-LOC-L	REC-INV-OFFSITE	IE-LO-POOL-COOL	HEP-RES-ALARM

Table 6b (continued)

54	1.0800E-009	XCOM-IND-LOIL IE-LO-POOL-INV	XCOM-LOI-SML SPC-LVL-LOP	FP-MKUP-FTF	SFP-REGMKUP-F	XEQN-UNITY
55	9.5040E-010	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-PLG
56	9.4720E-010	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-CKV-CCF-M
57	9.4000E-010	REC-WLKDWN-LOI-S	LOI-SMALL	IE-LO-POOL-INV	SPC-LVL-LOF	
58	8.7360E-010	HEP-ALTCL-L	HEP-COOL-LOC-L	REC-INV-OFFSITE1	IE-LO-POOL-COOL	SPC-LVL-LOP
59	8.2080E-010	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-CKV-CCF-H
60	8.2080E-010	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-CCF
61	8.1648E-010	XCOM-REC-OSP2 SPC-HTX-FTR	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2
62	8.0640E-010	XCOM-REC-OSP2	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-CKV-CCF-M
63	6.5707E-010	FP-ELPUMP-FTF SPC-PMP-FTF-2	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-PMP-FTF-1
64	6.5120E-010	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-PLG
65	6.0000E-010	XCOM-LOI-SML	REC-WLKDWN-LOI-L	IE-LO-POOL-INV	SPC-LVL-LOF	
66	5.6240E-010	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-CKV-CCF-H
67	5.6240E-010	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-CCF
68	5.5944E-010	XCOM-REC-OSP2 SPC-HTX-FTR	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2
69	5.5440E-010	XCOM-REC-OSP2	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-HTX-PLG
70	5.4000E-010	XCOM-IND-LOIL SPC-LVL-LOF	XCOM-LOI-SML	HEP-INV-MKUP-L	XEQN-UNITY	IE-LO-POOL-INV
71	4.7880E-010	XCOM-REC-OSP2	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-HTX-CCF
72	4.7880E-010	XCOM-REC-OSP2	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-CKV-CCF-H
73	4.5022E-010	XCOM-DG-START SPC-PMP-FTF-2	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-PMP-FTF-1
74	3.8329E-010	XCOM-REC-OSP2 SPC-PMP-FTF-2	HEP-ALTCL-LP-E	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-PMP-FTF-1
75	3.0000E-010	REC-WLKDWN-LOC	IE-LO-POOL-COOL	SPC-LVL-LOF		
76	1.8800E-010	HEP-INV-MKUP-SML	LOI-SMALL	XEQN-UNITY	IE-LO-POOL-INV	SPC-LVL-LOF
77	1.0886E-010	XCOM-REC-OSP2 SPC-CKV-CCF-M	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2
78	9.4000E-011	FP-MKUP-FTF SPC-LVL-LOF	SFP-REGMKUP-F	LOI-SMALL	XEQN-UNITY	IE-LO-POOL-INV
79	8.1900E-011	FP-MKUP-FTF	HEP-COOL-LOC-L	REC-INV-OFFSITE1	IE-LO-POOL-COOL	HEP-RES-ALARM
80	7.4844E-011	XCOM-REC-OSP2 SPC-HTX-PLG	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2
81	7.4592E-011	XCOM-REC-OSP2 SPC-CKV-CCF-M	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2
82	6.4638E-011	XCOM-REC-OSP2 SPC-CKV-CCF-H	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2
83	6.4638E-011	XCOM-REC-OSP2 SPC-HTX-CCF	FP-ELPUMP-FTF	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2
84	5.4600E-011	FP-MKUP-FTF	HEP-COOL-LOC-L	REC-INV-OFFSITE1	IE-LO-POOL-COOL	SPC-LVL-LOP
85	5.1744E-011	XCOM-REC-OSP2 SPC-PMP-FTF-1	FP-ELPUMP-FTF SPC-PMP-FTF-2	FP-DGPUMP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2
86	5.1282E-011	XCOM-REC-OSP2 SPC-HTX-PLG	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2
87	4.4289E-011	XCOM-REC-OSP2 SPC-HTX-CCF	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2
88	4.4289E-011	XCOM-REC-OSP2 SPC-CKV-CCF-H	XCOM-DG-START	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2
89	3.5455E-011	XCOM-REC-OSP2 SPC-PMP-FTF-1	XCOM-DG-START SPC-PMP-FTF-2	FP-MKUP-FTF	REC-INV-OFFSITE	IE-LOOP-LP2
90	5.4000E-012	XCOM-IND-LOIL IE-LO-POOL-INV	XCOM-LOI-SML SPC-LVL-LOF	FP-MKUP-FTF	SFP-REGMKUP-F	XEQN-UNITY
91	4.3680E-012	HEP-ALTCL-L	HEP-COOL-LOC-L	REC-INV-OFFSITE1	IE-LO-POOL-COOL	SPC-LVL-LOF

Table 6c - Cutsets for Case 3

Equation File = CASE3.EQN
Basic Event Data file referenced = SFP-3.BED
Number of cut sets in equation = 53
Top event unavailability (rare event) = 2.653E-004

1	7.2000E-005	XEQN-UNITY	REC-INV-OFFSITE	IE-LOOP-LP1	HEP-COOL-LOP-E	
2	4.7000E-005	REC-WLKDWN-LOI-S	LOI-SMALL	IE-LO-POOL-INV	SPC-LVL-LOF	
3	4.2065E-005	XCOM-CR-ALARM	REC-INV-OFFSITE	LOI-SMALL	XEQN-UNITY	IE-LO-POOL-INV
		SFP-REGMKUP-F				
4	1.5000E-005	REC-WLKDWN-LOC	IE-LO-POOL-COOL	SPC-LVL-LOF		
5	1.5000E-005	XEQN-UNITY	IE-CASK-DROP			
6	1.2000E-005	XCOM-LOI-SML	REC-WLKDWN-LOI-L	IE-LO-POOL-INV	SPC-LVL-LOF	
7	9.0000E-006	XEQN-UNITY	REC-INV-OFFSITE1	REC-FIRE-EVT	IE-INT-FIRE	
8	7.0000E-006	XEQN-UNITY	REC-OSP-SW	REC-INV-OFFSITE	IE-LOOP-LP2	
9	6.3000E-006	XEQN-UNITY	REC-INV-OFFSITE	IE-LOOP-LP2	HEP-COOL-LOP-E	
10	5.3700E-006	XCOM-CR-ALARM	XCOM-LOI-SML	REC-INV-OFFSITE2	XEQN-UNITY	IE-LO-POOL-INV
		HEP-INV-MKUP-E				
11	5.3700E-006	XCOM-CR-ALARM	XCOM-LOI-SML	REC-INV-OFFSITE2	XEQN-UNITY	IE-LO-POOL-INV
		SFP-REGMKUP-F				
12	4.4650E-006	XCOM-IND-LOIS	REC-INV-OFFSITE	SFP-REGMKUP-F	LOI-SMALL	XEQN-UNITY
		IE-LO-POOL-INV	SPC-LVL-LOF			
13	4.2065E-006	XCOM-CR-ALARM	REC-INV-OFFSITE	LOI-SMALL	XEQN-UNITY	IE-LO-POOL-INV
		HEP-INV-MKUP-SML				
14	4.0000E-006	XEQN-UNITY	REC-OSP-PC	REC-INV-OFFSITE	IE-LOOP-LP1	
15	2.8800E-006	XCOM-IND-LOIL	XCOM-LOI-SML	REC-INV-OFFSITE3	HEP-INV-MKUP-L	XEQN-UNITY
		IE-LO-POOL-INV	SPC-LVL-LOF			
16	2.3600E-006	XEQN-UNITY	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-PMP-CCF	
17	1.4100E-006	REC-WLKDWN-LOI-S	LOI-SMALL	IE-LO-POOL-INV	HEP-RES-ALARM	
18	1.1277E-006	XCOM-CR-ALARM	HEP-COOL-LOC-E	XEQN-UNITY	REC-INV-OFFSITE1	IE-LO-POOL-COOL
19	1.0000E-006	SFP-INTEG-HCLPF	IE-SEISMIC			
20	9.6000E-007	XCOM-IND-LOIL	XCOM-LOI-SML	REC-INV-OFFSITE3	SFP-REGMKUP-F	XEQN-UNITY
		IE-LO-POOL-INV	SPC-LVL-LOF			
21	9.6000E-007	XEQN-UNITY	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-FTR	
22	9.5000E-007	XCOM-SFP-INT	XEQN-UNITY	REC-INV-OFFSITE	IE-SEISMIC	
23	9.4000E-007	REC-WLKDWN-LOI-S	LOI-SMALL	IE-LO-POOL-INV	SPC-LVL-LOP	
24	5.6000E-007	XEQN-UNITY	IE-TORNADO-MIS			
25	4.5000E-007	REC-WLKDWN-LOC	IE-LO-POOL-COOL	HEP-RES-ALARM		
26	4.4650E-007	XCOM-IND-LOIS	REC-INV-OFFSITE	HEP-INV-MKUP-SML	LOI-SMALL	XEQN-UNITY
		IE-LO-POOL-INV	SPC-LVL-LOF			
27	3.6000E-007	XCOM-LOI-SML	REC-WLKDWN-LOI-L	IE-LO-POOL-INV	HEP-RES-ALARM	
28	3.4200E-007	XCOM-IND-LOC	HEP-COOL-LOC-L	XEQN-UNITY	REC-INV-OFFSITE1	IE-LO-POOL-COOL
		SPC-LVL-LOF				
29	3.0000E-007	REC-WLKDWN-LOC	IE-LO-POOL-COOL	SPC-LVL-LOP		
30	2.4000E-007	XCOM-LOI-SML	REC-WLKDWN-LOI-L	IE-LO-POOL-INV	SPC-LVL-LOP	
31	2.0650E-007	XEQN-UNITY	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-PMP-CCF	
32	1.3395E-007	XCOM-IND-LOIS	REC-INV-OFFSITE	SFP-REGMKUP-F	LOI-SMALL	XEQN-UNITY
		IE-LO-POOL-INV	HEP-RES-ALARM			
33	1.2800E-007	XEQN-UNITY	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-CKV-CCF-M	
34	8.9300E-008	XCOM-IND-LOIS	REC-INV-OFFSITE	SFP-REGMKUP-F	LOI-SMALL	XEQN-UNITY
		IE-LO-POOL-INV	SPC-LVL-LOP			
35	8.8000E-008	XEQN-UNITY	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-PLG	
36	8.6400E-008	XCOM-IND-LOIL	XCOM-LOI-SML	REC-INV-OFFSITE3	HEP-INV-MKUP-L	XEQN-UNITY
		IE-LO-POOL-INV	HEP-RES-ALARM			
37	8.4000E-008	XEQN-UNITY	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-HTX-FTR	
38	7.6000E-008	XEQN-UNITY	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-CKV-CCF-H	
39	7.6000E-008	XEQN-UNITY	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-HTX-CCF	
40	6.0840E-008	XEQN-UNITY	REC-INV-OFFSITE	IE-LOOP-LP1	SPC-PMP-FTF-1	SPC-PMP-FTF-2
41	5.7600E-008	XCOM-IND-LOIL	XCOM-LOI-SML	REC-INV-OFFSITE3	HEP-INV-MKUP-L	XEQN-UNITY
		IE-LO-POOL-INV	SPC-LVL-LOP			
42	4.0000E-008	XEQN-UNITY	IE-AIRCRAFT-IMP			
43	2.8800E-008	XCOM-IND-LOIL	XCOM-LOI-SML	REC-INV-OFFSITE3	SFP-REGMKUP-F	XEQN-UNITY
		IE-LO-POOL-INV	HEP-RES-ALARM			
44	1.9200E-008	XCOM-IND-LOIL	XCOM-LOI-SML	REC-INV-OFFSITE3	SFP-REGMKUP-F	XEQN-UNITY
		IE-LO-POOL-INV	SPC-LVL-LOP			
45	1.3395E-008	XCOM-IND-LOIS	REC-INV-OFFSITE	HEP-INV-MKUP-SML	LOI-SMALL	XEQN-UNITY
		IE-LO-POOL-INV	HEP-RES-ALARM			
46	1.1200E-008	XEQN-UNITY	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-CKV-CCF-M	

Table 6c (continued)

47	1.0260E-008	XCOM-IND-LOC	HEP-COOL-LOC-L	XEQN-UNITY	REC-INV-OFFSITE1	IE-LO-POOL-COOL
		HEP-RES-ALARM				
48	8.9300E-009	XCOM-IND-LOIS	REC-INV-OFFSITE	HEP-INV-MKUP-SML	LOI-SMALL	XEQN-UNITY
		IE-LO-POOL-INV	SPC-LVL-LOP			
49	7.7000E-009	XEQN-UNITY	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-HTX-PLG	
50	6.8400E-009	XCOM-IND-LOC	HEP-COOL-LOC-L	XEQN-UNITY	REC-INV-OFFSITE1	IE-LO-POOL-COOL
		SPC-LVL-LOP				
51	6.6500E-009	XEQN-UNITY	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-CKV-CCF-H	
52	6.6500E-009	XEQN-UNITY	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-HTX-CCF	
53	5.3235E-009	XEQN-UNITY	REC-INV-OFFSITE	IE-LOOP-LP2	SPC-PMP-FTF-1	SPC-PMP-FTF-2

Table 7a - Importance Ranking for Case 1

Rank	EVENT NAME	Point Estimate	Fussell-Vesely Importance	Risk Achievement Worth	Risk Reduction Worth
1	REC-INV-OFFSITE	5.000E-002	4.331E-001	9.23	1.764
2	XEQN-UNITY	1.000E+000	3.498E-001	1.00	1.538
3	FP-DGPUMP-FTF	1.800E-001	2.589E-001	2.18	1.349
4	IE-LO-POOL-INV	1.000E-002	2.484E-001	25.59	1.330
5	IE-CASK-DROP	2.500E-006	2.159E-001	86361.17	1.275
6	IE-SEISMIC	2.000E-005	1.684E-001	8420.97	1.203
7	LOI-SMALL	9.400E-001	1.630E-001	1.01	1.195
8	IE-LOOP-LP2	7.000E-003	1.187E-001	17.84	1.135
9	REC-OSP-SW	2.000E-002	1.149E-001	6.63	1.130
10	IE-LOOP-LP1	8.000E-002	1.099E-001	2.26	1.124
11	SFP-INTEG-HCLPF	5.000E-002	8.636E-002	2.64	1.095
12	XCOM-LOI-SML	6.000E-002	8.534E-002	2.34	1.093
13	XCOM-SFP-INT	9.500E-001	8.204E-002	1.00	1.089
14	HEP-INV-MKUP-SML	2.000E-003	8.159E-002	41.71	1.089
15	REC-INV-OFFSITE1	1.000E-002	7.384E-002	8.31	1.080
16	REC-FIRE-EVT	5.000E-002	7.384E-002	2.40	1.080
17	IE-INT-FIRE	9.000E-003	7.384E-002	9.13	1.080
18	REC-OSP-PC	1.000E-003	6.563E-002	66.57	1.070
19	FP-MKUP-FTF	1.000E-002	5.953E-002	6.89	1.063
20	REC-INV-OFFSITE2	1.000E-001	5.700E-002	1.51	1.060
21	HEP-INV-MKUP-E	1.000E-002	5.182E-002	6.13	1.055
22	HEP-RES-ALARM	3.000E-003	4.946E-002	17.44	1.052
23	IE-TORNADO-MIS	5.600E-007	4.836E-002	86361.34	1.051
24	SFP-REGMKUP-F	1.000E-001	4.602E-002	1.41	1.048
25	REC-WLKDWN-LOI-S	1.000E-002	4.067E-002	5.03	1.042
26	HEP-COOL-LOP-E	3.500E-003	3.800E-002	11.82	1.039
27	SPC-LVL-LOP	2.000E-003	3.298E-002	17.45	1.034
28	HEP-ALTCL-LP-E	1.000E-002	3.006E-002	3.98	1.031
29	REC-WLKDWN-LOI-L	1.000E-001	2.596E-002	1.23	1.027
30	FP-ELPUMP-FTF	6.000E-002	1.800E-002	1.28	1.018
31	XCOM-DG-START	8.100E-001	1.350E-002	1.00	1.014
32	IE-LO-POOL-COOL	3.000E-003	1.299E-002	5.32	1.013
33	REC-WLKDWN-LOC	1.000E-002	1.298E-002	2.29	1.013
34	SPC-PMP-CCF	5.900E-004	6.406E-003	11.85	1.006
35	IE-AIRCRAFT-IMP	4.000E-008	3.454E-003	86361.39	1.003
36	SPC-HTX-FTR	2.400E-004	2.606E-003	11.85	1.003
37	XCOM-IND-LOIL	9.000E-001	2.383E-003	1.00	1.002
38	REC-INV-OFFSITE3	2.000E-001	2.383E-003	1.01	1.002
39	HEP-INV-MKUP-L	5.000E-002	2.336E-003	1.04	1.002
40	SPC-CKV-CCF-M	3.200E-005	3.474E-004	11.86	1.000
41	SPC-HTX-PLG	2.200E-005	2.388E-004	11.86	1.000
42	SPC-HTX-CCF	1.900E-005	2.063E-004	11.86	1.000
43	SPC-CKV-CCF-H	1.900E-005	2.063E-004	11.86	1.000
44	SPC-PMP-FTF-1	3.900E-003	1.651E-004	1.04	1.000
45	SPC-PMP-FTF-2	3.900E-003	1.651E-004	1.04	1.000
46	SPC-LVL-LOF	1.000E-005	1.649E-004	17.49	1.000
47	HEP-COOL-LOC-E	1.000E-004	5.182E-006	1.05	1.000
48	HEP-ALTCL-E	1.000E-002	2.591E-006	1.00	1.000

Table 7b - Importance Ranking for Case 2

Rank	EVENT NAME	Point Estimate	Fussell-Vesely Importance	Risk Achievement Worth	Risk Reduction Worth
1	XEQN-UNITY	1.000E+000	7.933E-001	1.00	4.838
2	IE-LO-POOL-INV	1.000E-002	7.522E-001	75.47	4.036
3	XCOM-LOI-SML	6.000E-002	3.909E-001	7.12	1.642
4	HEP-INV-MKUP-E	5.000E-002	3.762E-001	8.15	1.603
5	LOI-SMALL	9.400E-001	3.613E-001	1.02	1.566
6	HEP-INV-MKUP-SML	2.000E-003	2.369E-001	119.23	1.310
7	REC-INV-OFFSITE	5.000E-002	1.812E-001	4.44	1.221
8	FP-MKUP-FTF	1.000E-002	1.292E-001	13.79	1.148
9	SFP-REGMKUP-F	1.000E-001	1.260E-001	2.13	1.144
10	IE-LOOP-LP2	7.000E-003	1.172E-001	17.62	1.133
11	REC-OSP-SW	1.000E-001	1.141E-001	2.03	1.129
12	FP-DGPUMP-FTF	1.800E-001	1.017E-001	1.46	1.113
13	HEP-ALTCL-LP-E	8.000E-002	7.749E-002	1.89	1.084
14	IE-LOOP-LP1	8.000E-002	5.214E-002	1.60	1.055
15	HEP-COOL-LOP-E	7.000E-003	3.719E-002	6.28	1.039
16	IE-CASK-DROP	2.500E-006	3.135E-002	12540.66	1.032
17	IE-SEISMIC	2.000E-005	2.445E-002	1223.60	1.025
18	REC-INV-OFFSITE1	1.000E-002	1.326E-002	2.31	1.013
19	REC-OSP-PC	1.000E-003	1.304E-002	14.03	1.013
20	IE-INT-FIRE	4.000E-002	1.304E-002	1.31	1.013
21	REC-FIRE-EVT	1.000E-002	1.304E-002	2.29	1.013
22	SFP-INTEG-HCLPF	5.000E-002	1.254E-002	1.24	1.013
23	XCOM-SFP-INT	9.500E-001	1.191E-002	1.00	1.012
24	HEP-RES-ALARM	3.000E-003	1.005E-002	4.34	1.010
25	IE-TORNADO-MIS	5.600E-007	7.022E-003	12540.68	1.007
26	SPC-LVL-LOP	2.000E-003	6.701E-003	4.34	1.007
27	REC-WLKDWN-LOI-S	1.000E-002	5.905E-003	1.58	1.006
28	FP-ELPUMP-FTF	6.000E-002	4.638E-003	1.07	1.005
29	REC-WLKDWN-LOI-L	1.000E-001	3.769E-003	1.03	1.004
30	XCOM-IND-LOIL	9.000E-001	3.426E-003	1.00	1.003
31	HEP-INV-MKUP-L	1.000E-001	3.392E-003	1.03	1.003
32	XCOM-DG-START	7.400E-001	3.178E-003	1.00	1.003
33	SPC-PMP-CCF	5.900E-004	3.135E-003	6.31	1.003
34	XCOM-REC-OSP2	9.000E-001	3.079E-003	1.00	1.003
35	IE-LO-POOL-COOL	3.000E-003	2.100E-003	1.70	1.002
36	REC-WLKDWN-LOC	1.000E-002	1.885E-003	1.19	1.002
37	SPC-HTX-FTR	2.400E-004	1.275E-003	6.31	1.001
38	IE-AIRCRAFT-IMP	4.000E-008	5.016E-004	12540.69	1.001
39	HEP-COOL-LOC-E	5.500E-003	1.862E-004	1.03	1.000
40	SPC-CKV-CCF-M	3.200E-005	1.700E-004	6.31	1.000
41	HEP-ALTCL-E	8.000E-002	1.655E-004	1.00	1.000
42	SPC-HTX-PLG	2.200E-005	1.169E-004	6.31	1.000
43	SPC-CKV-CCF-H	1.900E-005	1.010E-004	6.31	1.000
44	SPC-HTX-CCF	1.900E-005	1.010E-004	6.31	1.000
45	SPC-PMP-FTF-2	3.900E-003	8.082E-005	1.02	1.000
46	SPC-PMP-FTF-1	3.900E-003	8.082E-005	1.02	1.000
47	SPC-LVL-LOF	1.000E-005	3.350E-005	4.35	1.000
48	HEP-COOL-LOC-L	9.100E-002	2.915E-005	1.00	1.000
49	HEP-ALTCL-L	1.600E-001	2.744E-005	1.00	1.000

Table 7c - Importance Ranking for Case 3

Rank	EVENT NAME	Point Estimate	Fussell-Vesely Importance	Risk Achievement Worth	Risk Reduction Worth
1	XEQN-UNITY	1.000E+000	7.034E-001	1.00	3.371
2	REC-INV-OFFSITE	5.000E-002	5.494E-001	11.44	2.219
3	IE-LO-POOL-INV	1.000E-002	4.830E-001	48.82	1.934
4	LOI-SMALL	9.400E-001	3.798E-001	1.02	1.613
5	SPC-LVL-LOF	1.000E-001	3.132E-001	3.82	1.456
6	IE-LOOP-LP1	8.000E-002	3.006E-001	4.46	1.430
7	HEP-COOL-LOP-E	1.800E-002	2.951E-001	17.10	1.419
8	XCOM-CR-ALARM	8.950E-001	2.191E-001	1.03	1.281
9	SFP-REGMKUP-F	1.000E-001	2.003E-001	2.80	1.250
10	REC-WLKDWN-LOI-S	5.000E-002	1.860E-001	4.53	1.229
11	XCOM-LOI-SML	6.000E-002	1.032E-001	2.62	1.115
12	IE-LO-POOL-COOL	3.000E-003	6.497E-002	22.59	1.069
13	REC-WLKDWN-LOC	5.000E-002	5.936E-002	2.13	1.063
14	IE-CASK-DROP	1.500E-005	5.654E-002	3770.06	1.060
15	IE-LOOP-LP2	7.000E-003	5.137E-002	8.29	1.054
16	REC-WLKDWN-LOI-L	2.000E-001	4.749E-002	1.19	1.050
17	REC-INV-OFFSITE2	1.000E-001	4.048E-002	1.36	1.042
18	REC-INV-OFFSITE1	1.000E-002	3.953E-002	4.91	1.041
19	IE-INT-FIRE	9.000E-003	3.392E-002	4.74	1.035
20	REC-FIRE-EVT	1.000E-001	3.392E-002	1.31	1.035
21	REC-OSP-SW	2.000E-002	2.638E-002	2.29	1.027
22	HEP-INV-MKUP-E	1.000E-001	2.024E-002	1.18	1.021
23	XCOM-IND-LOIS	9.500E-001	1.944E-002	1.00	1.020
24	HEP-INV-MKUP-SML	1.000E-002	1.762E-002	2.74	1.018
25	REC-INV-OFFSITE3	2.000E-001	1.520E-002	1.06	1.015
26	XCOM-IND-LOIL	8.000E-001	1.520E-002	1.00	1.015
27	REC-OSP-PC	1.000E-003	1.508E-002	16.06	1.015
28	HEP-INV-MKUP-L	3.000E-001	1.140E-002	1.03	1.012
29	SPC-PMP-CCF	5.900E-004	9.673E-003	17.39	1.010
30	HEP-RES-ALARM	3.000E-003	9.396E-003	4.12	1.009
31	IE-SEISMIC	2.000E-005	7.350E-003	368.48	1.007
32	SPC-LVL-LOP	2.000E-003	6.264E-003	4.13	1.006
33	HEP-COOL-LOC-E	4.200E-002	4.250E-003	1.10	1.004
34	SPC-HTX-FTR	2.400E-004	3.935E-003	17.39	1.004
35	SFP-INTEG-HCLPF	5.000E-002	3.769E-003	1.07	1.004
36	XCOM-SFP-INT	9.500E-001	3.581E-003	1.00	1.004
37	IE-TORNADO-MIS	5.600E-007	2.111E-003	3770.11	1.002
38	XCOM-IND-LOC	9.500E-001	1.353E-003	1.00	1.001
39	HEP-COOL-LOC-L	1.200E-001	1.353E-003	1.01	1.001
40	SPC-CKV-CCF-M	3.200E-005	5.247E-004	17.40	1.001
41	SPC-HTX-PLG	2.200E-005	3.607E-004	17.40	1.000
42	SPC-HTX-CCF	1.900E-005	3.115E-004	17.40	1.000
43	SPC-CKV-CCF-H	1.900E-005	3.115E-004	17.40	1.000
44	SPC-PMP-FTF-1	3.900E-003	2.494E-004	1.06	1.000
45	SPC-PMP-FTF-2	3.900E-003	2.494E-004	1.06	1.000
46	IE-AIRCRAFT-IMP	4.000E-008	1.508E-004	3770.11	1.000

Table 8 - Results of Sensitivity Analysis for Case 1

Sensitivity Case	Description	Basic Events Affected	Frequency of Fuel Uncovery (per year)	Comments
S0a	Base case (all initiators) - all basic event probabilities as shown in Appendix A	n/a	1.158E-05	This case is based on the "Case 1" analysis assumptions
S0b	Base case - only initiators that lead directly to fuel uncovery (includes cask drop, aircraft impact, tornado missiles, and seismic events that fail the SFP)	n/a	4.100E-06	This fuel uncovery frequency is independent of human error probability or equipment availability since the contributing IEs are assumed to lead directly to fuel uncovery
S1a	All human actions to mitigate the initiating event is assumed failed, i.e., event probabilities set to 1.0. Human actions to related to "recognition" of the event is not included in this sensitivity case	HEP-ALTCL-E HEP-ALTCL-LP-E HEP-COOL-LOC-E HEP-COOL-LOP-E HEP-INV-MKUP-E HEP-INV-MKUP-L HEP-INV-MKUP-SML REC-INV-OFFSITE REC-INV-OFFSITE1 REC-INV-OFFSITE2 REC-INV-OFFSITE3	1.026E-01	Note that, the fuel uncovery frequency in this case approaches the sum of the initiating events of 1.090E-01 per year
S1b	All human actions assumed to be successful, i.e., event probabilities set to 0.0	same as in case S1a	5.022E-06	Even with all human actions assumed successful, this frequency is not equal to the case S0b frequency because the failure of the operator to recognize the event (control room indications or walkdowns) also contribute to this frequency.

Table 8 - Results of Sensitivity Analysis for Case 1				
Sensitivity Case	**Description**	**Basic Events Affected**	**Frequency of Fuel Uncovery (per year)**	**Comments**
S1c	The probability of failure of all human actions were assumed 10 times higher than in the base case. When event probabilities exceed 1.0, these probabilities are capped at a value of 1.0	same as in case S1a	4.050E-04	
S1d	The probability of failure of all human actions were assumed 10 times lower than in the base case	same as in case S1a	5.478E-06	
S2a	All recovery actions using offsite sources (i.e., procurement of pumps, fire engines, etc.) assumed failed, i.e., event probabilities set to 1.0	REC-INV-OFFSITE REC-INV-OFFSITE1 REC-INV-OFFSITE2 REC-INV-OFFSITE3	1.976E-04	
S2b	All recovery actions using offsite sources assumed successful, i.e., event probabilities set to 0.0	same as in case S2a	5.022E-06	Note that this frequency is the same as that in case S1b since offsite recovery events are modeled in all sequences where operator action is feasible.
S2c	The probability of failure of all recovery actions using offsite sources were assumed 10 times higher than in the base case. When event probabilities exceed 1.0, these probabilities are capped at a value of 1.0	same as in case S2a	7.046E-05	
S2d	The probability of failure of all recovery actions using offsite sources were assumed 10 times lower than in the base case	same as in case S2a	5.678E-06	

Table 8 - Results of Sensitivity Analysis for Case 1				
Sensitivity Case	**Description**	**Basic Events Affected**	**Frequency of Fuel Uncovery (per year)**	**Comments**
S3a	All operator actions to mitigate accident using onsite equipment (i.e., restarting or repairing cooling pumps, use of makeup pumps or fire pumps, etc.) assumed failed, i.e., event probabilities set to 1.0	HEP-ALTCL-E HEP-ALTCL-LP-E HEP-COOL-LOC-E HEP-COOL-LOP-E HEP-INV-MKUP-E HEP-INV-MKUP-L HEP-INV-MKUP-SML	5.024E-03	
S3b	All operator actions to mitigate accident using onsite equipment assumed to be successful, i.e., event probabilities set to 0.0	same as in case S3a	9.372E-06	Note that this frequency is not the same as those in cases S1b and S2b because onsite recovery events are not modeled in all sequences where offsite operator action may be feasible (e.g., seismic events where SFP is intact but where other equipment fails; or in LOSP sequences where power is not restored and the onsite diesel fire pump fails to start)
S3c	The probability of failure of all operator actions to mitigate accident using onsite equipment were assumed 10 times higher than in the base case. When event probabilities exceed 1.0, these probabilities are capped at a value of 1.0	same as in case S3a	4.515E-05	
S3d	The probability of failure of all operator actions to mitigate accident using onsite equipment were assumed 10 times lower than in the base case	same as in case S3a	9.579E-06	

Table 8 - Results of Sensitivity Analysis for Case 1				
Sensitivity Case	**Description**	**Basic Events Affected**	**Frequency of Fuel Uncovery (per year)**	**Comments**
S4a	All onsite equipment assumed to be failed. This "equipment" does not include the SFP structure itself, i.e., the fragility of the SFP is assumed to be the same as in the base case.	FP-DGPUMP-FTF FP-ELPUMP-FTF FP-MKUP-FTF SFP-REGMKUP-F SPC-CKV-CCF-H SPC-CKV-CCF-M SPC-HTX-CCF SPC-HTX-FTR SPC-HTX-PLG SPC-LVL-LOF SPC-LVL-LOP SPC-PMP-CCF SPC-PMP-FTF-1 SPC-PMP-FTF-2	5.754E-02	Note that the results in cases S4a thru S4d are not quite the same as those for cases S3a thru S3d since the S4 sensitivity cases include equipment used for control room indication.
S4b	All onsite equipment assumed to be successful	same as in case S4a	7.468E-06	
S4c	The probability of failure of all onsite equipment assumed to be 10 times higher. When event probabilities exceed 1.0, these probabilities are capped at a value of 1.0	same as in case S4a	1.238E-04	
S4d	The probability of failure of all onsite equipment assumed to be 10 times lower	same as in case S4a	7.809E-06	
S5a	Operator recognition of initiator, either from control room or from walkdowns, assumed to be failed	HEP-RES-ALARM REC-WLKDWN-LOC REC-WLKDWN-LOI-L REC-WLKDWN-LOI-S	1.304E-02	
S5b	Operator recognition of initiator, either from control room or from walkdowns, assumed to be always successful	same as in case S5a	1.064E-05	

Table 8 - Results of Sensitivity Analysis for Case 1				
Sensitivity Case	**Description**	**Basic Events Affected**	**Frequency of Fuel Uncovery (per year)**	**Comments**
S5c	Probability of the failure of operator recognition of initiator, either from control room or from walkdowns, increased by a factor of 10. When event probabilities exceed 1.0, these probabilities are capped at a value of 1.0	same as in case S5a	6.974E-05	
S5d	Probability of the failure of operator recognition of initiator, either from control room or from walkdowns, decreased by a factor of 10	same as in case S5a	1.068E-05	

Table 8 - Results of Sensitivity Analysis for Case 1

Sensitivity Case	Description	Basic Events Affected	Frequency of Fuel Uncovery (per year)	Comments
S6a	All onsite and offsite recovery actions and all equipment assumed to be failed.	FP-DGPUMP-FTF FP-ELPUMP-FTF FP-MKUP-FTF HEP-ALTCL-E HEP-ALTCL-LP-E HEP-COOL-LOC-E HEP-COOL-LOP-E HEP-INV-MKUP-E HEP-INV-MKUP-L HEP-INV-MKUP-SML HEP-RES-ALARM REC-FIRE-EVT REC-INV-OFFSITE REC-INV-OFFSITE1 REC-INV-OFFSITE2 REC-INV-OFFSITE3 REC-WLKDWN-LOC REC-WLKDWN-LOI-L REC-WLKDWN-LOI-S SFP-REGMKUP-F SPC-CKV-CCF-H SPC-CKV-CCF-M SPC-HTX-CCF SPC-HTX-FTR SPC-HTX-PLG SPC-LVL-LOF SPC-LVL-LOP SPC-PMP-CCF SPC-PMP-FTF-1 SPC-PMP-FTF-2	1.090E-01	This is equal to the sum of all the initiating event frequencies

Table 8 - Results of Sensitivity Analysis for Case 1

Sensitivity Case	Description	Basic Events Affected	Frequency of Fuel Uncovery (per year)	Comments
S6b	All onsite and offsite recovery actions and all equipment assumed to be successful.	same as in case S6a	4.100E-06	This is the same as the frequency for the "non-recoverable" initiators - see case S0b
S6c	The probability of failure of all onsite and offsite recovery actions and all equipment increased by a factor of 10. When event probabilities exceed 1.0, these probabilities are capped at a value of 1.0	same as in case S6a	3.004E-03	
S6d	The probability of failure of all onsite and offsite recovery actions and all equipment decreased by a factor of 10	same as in case S6a	4.242E-06	
S7	Availability of diesel fire pump set to be the same as that for the electric fire pump, i.e., from 0.18 to 0.06	FP-DGPUMP-FTF XCOM-DG-START	9.604E-06	
S8	Probability that a fire event will affect SFP function, i.e., fire will be suppressed or will not be large enough to affect function. Probability changed from 0.05 to 0.01	REC-FIRE-EVT	1.090E-05	
S9	Conditional probability that a loss of inventory event will be "large" changed from 6% to 1%	LOI-SMALL XCOM-LOI-SML	1.086E-05	

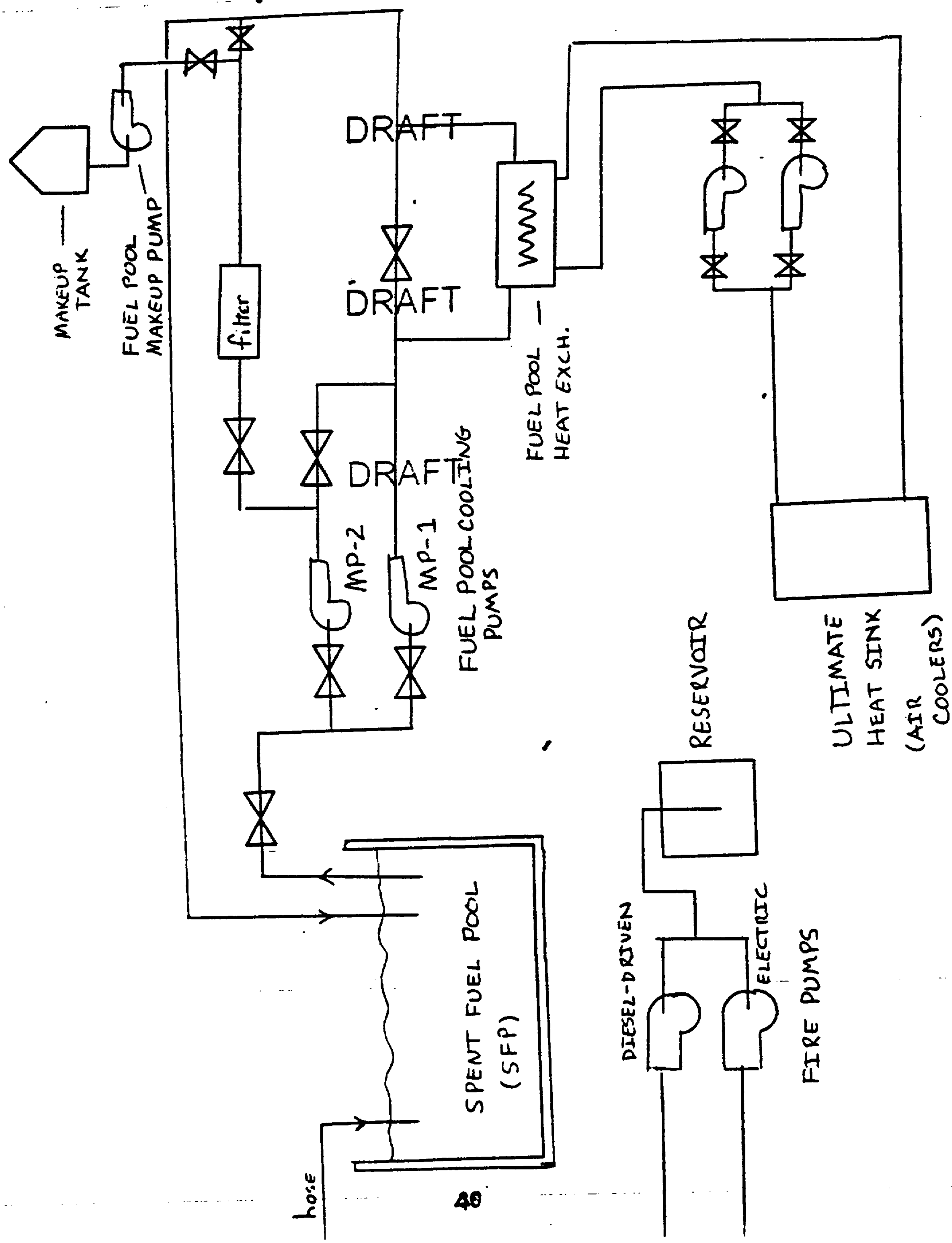
Table 9 - A Simplified Explanation of the Dominant Cutsets for Case 1

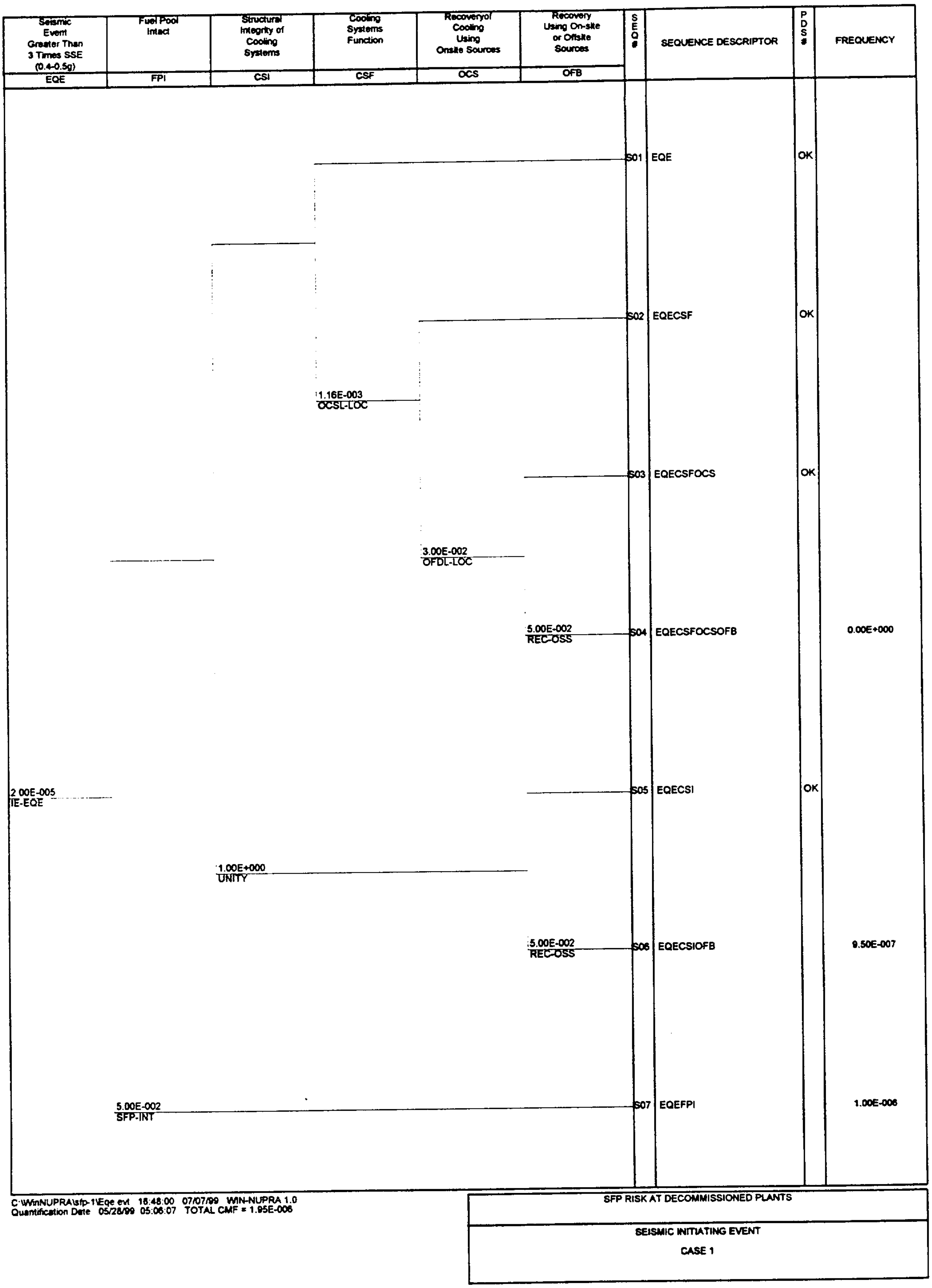
1	2.50E-06	Cask drop event leading to failure of SFP structure			
		2.5E-06 per year			
2	1.26E-06	LOSP from severe weather events	Diesel fire protection pump fails to start and run	Failure to recover offsite power	Failure to recover inventory using offsite sources
		7.0E-03 per year	0.18	0.02	0.05
3	1.00E-06	Seismic event greater than 3 times SSE	Probability of SFP failure given event		
		2.0E-05 per year	0.05		
4	9.50E-07	Seismic event greater than 3 times SSE	Probability that SFP does not fail given event	Failure of onsite equipment from direct & indirect failure modes	Failure to recover inventory using offsite sources
		2.0E-05 per year	0.95	1.0	0.05
5	9.40E-07	Loss of inventory initiating event	Probability that loss is small	Operator fails to initiate makeup of inventory	Failure to recover inventory using offsite sources
		0.01 per year	0.94	2.0E-03	0.05
6	8.10E-07	Internal fire initiating event	Probability that fire event is not suppressed or is not large enough to affect SFP function	Diesel fire protection pump fails to start and run	Failure to recover inventory using offsite sources
		9.0E-03 per year	0.05	0.18	0.01
7	7.20E-07	Loss of offsite power from plant centered & grid related events	Diesel fire protection pump fails to start and run	Failure to recover offsite power	Failure to recover inventory using offsite sources
		0.08 per year	0.18	1.0E-03	0.05
8	6.00E-07	Loss of inventory initiating event	Probability that loss is large	Operator fails to initiate makeup of inventory	Failure to recover inventory using offsite sources
		0.01 per year	0.06	0.01	0.1
9	5.60E-07	Tornado event leading to SFP failure			
		5.6E-07 per year			

Table 9 - A Simplified Explanation of the Dominant Cutsets for Case 1

10	4.70E-07	Loss of inventory initiating event	Probability that loss is small	SFP make-up pumps fails (hardware failure)	Both fire pumps fail (hardware failure)	Failure to recover inventory using offsite sources
		0.01 per year	0.06	0.01	0.01	0.05
11	2.82E-07	Loss of inventory initiating event	Probability that loss is small	Operator fails to respond to control room alarm	Operator fails to note condition during walkdown	
		0.01 per year	0.06	3.0E-03	0.01	
12	1.88E-07	Loss of inventory initiating event	Probability that loss is small	SFP level instrumentation fails due to local electrical faults	Operator fails to note condition during walkdown	
		0.01 per year	0.06	2.0E-03	0.01	
13	1.80E-07	Loss of inventory initiating event	Probability that loss is large	Operator fails to respond to control room alarm	Operator fails to note condition during walkdown	
		0.01 per year	0.94	3.0E-03	0.1	
14	1.51E-07	Loss of offsite power from plant centered & grid related events	Operator fails to re-start or re-align cooling system	Diesel fire protection pump fails to start and run	Electric fire pump fails to start and run	Failure to recover inventory using offsite sources
		0.08 per year	3.5E-03	0.18	0.06	0.05
15	1.40E-07	Loss of offsite power from plant centered & grid related events	Operator fails to re-start or re-align cooling system	Operator fails to start fire pumps	Failure to recover inventory using offsite sources	
		0.08 per year	3.5E-03	0.01	0.05	
16	1.20E-07	Loss of inventory initiating event	Probability that loss is large	SFP level instrumentation fails due to local electrical faults	Operator fails to note condition during walkdown	
		0.01 per year	0.94	2.0E-03	0.01	
17	1.13E-07	Loss of offsite power from plant centered & grid related events	Operator fails to re-start or re-align cooling system	Both fire pumps fail (hardware failure)	Failure to recover inventory using offsite sources	
		0.08 per year	3.5E-03	0.01	0.05	
18	9.00E-08	Loss of pool cooling initiating event	Operator fails to respond to control room alarm	Operator fails to note condition during walkdown		
		3.0E-03 per year	3.0E-03	0.01		

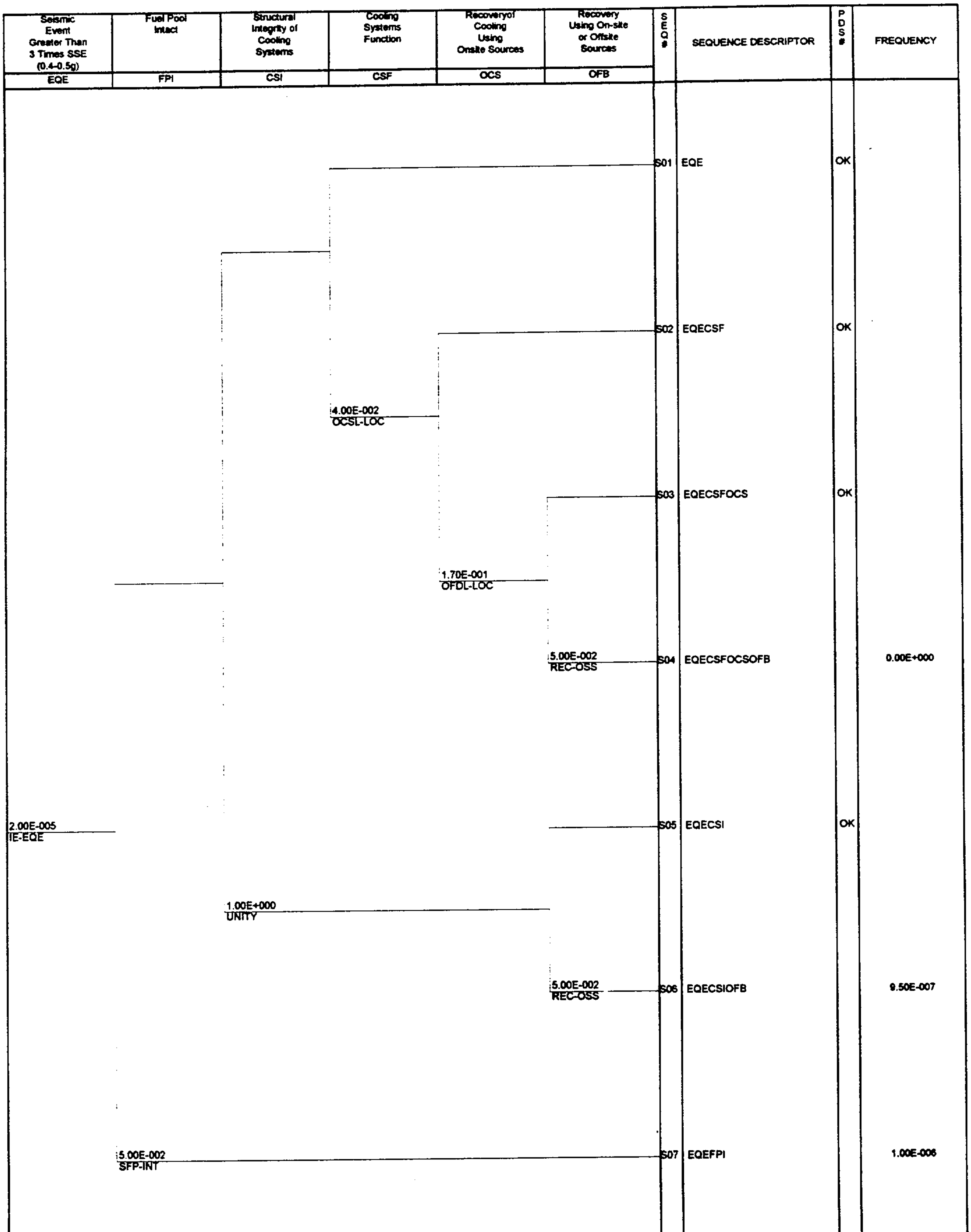
Figure 1 Representative Spent Fuel Pool Model





Seismic Event Greater Than 3 Times SSE (0.4-0.5g)
EQE
Fuel Pool Intact
FPI
Structural Integrity of Cooling Systems
CSI
Cooling Systems Function
CSF
Recoveryof Cooling Using Onsite Sources
OCS
Recovery Using On-site or Offsite Sources
OFB
SEQ #
SEQUENCE DESCRIPTOR
PDS #
FREQUENCY
S01 EQE OK
S02 EQECSF OK
S03 EQECSFOCS OK
S04 EQECSFOCSOFB 0.00E+000
S05 EQECSI OK
S06 EQECSIOFB 9.50E-007
S07 EQEFPI 1.00E-006
2.00E-005
IE-EQE
1.16E-003
OCSL-LOC
3.00E-002
OFDL-LOC
5.00E-002
REC-OSS
1.00E+000
UNITY
5.00E-002
REC-OSS
5.00E-002
SFP-INT
C:\WinNUPRA\sfp-1\Eqe.evt 16:48:00 07/07/99 WIN-NUPRA 1.0
Quantification Date 05/28/99 05:06:07 TOTAL CMF = 1.95E-006
SFP RISK AT DECOMMISSIONED PLANTS
SEISMIC INITIATING EVENT
CASE 1

Figure 2a



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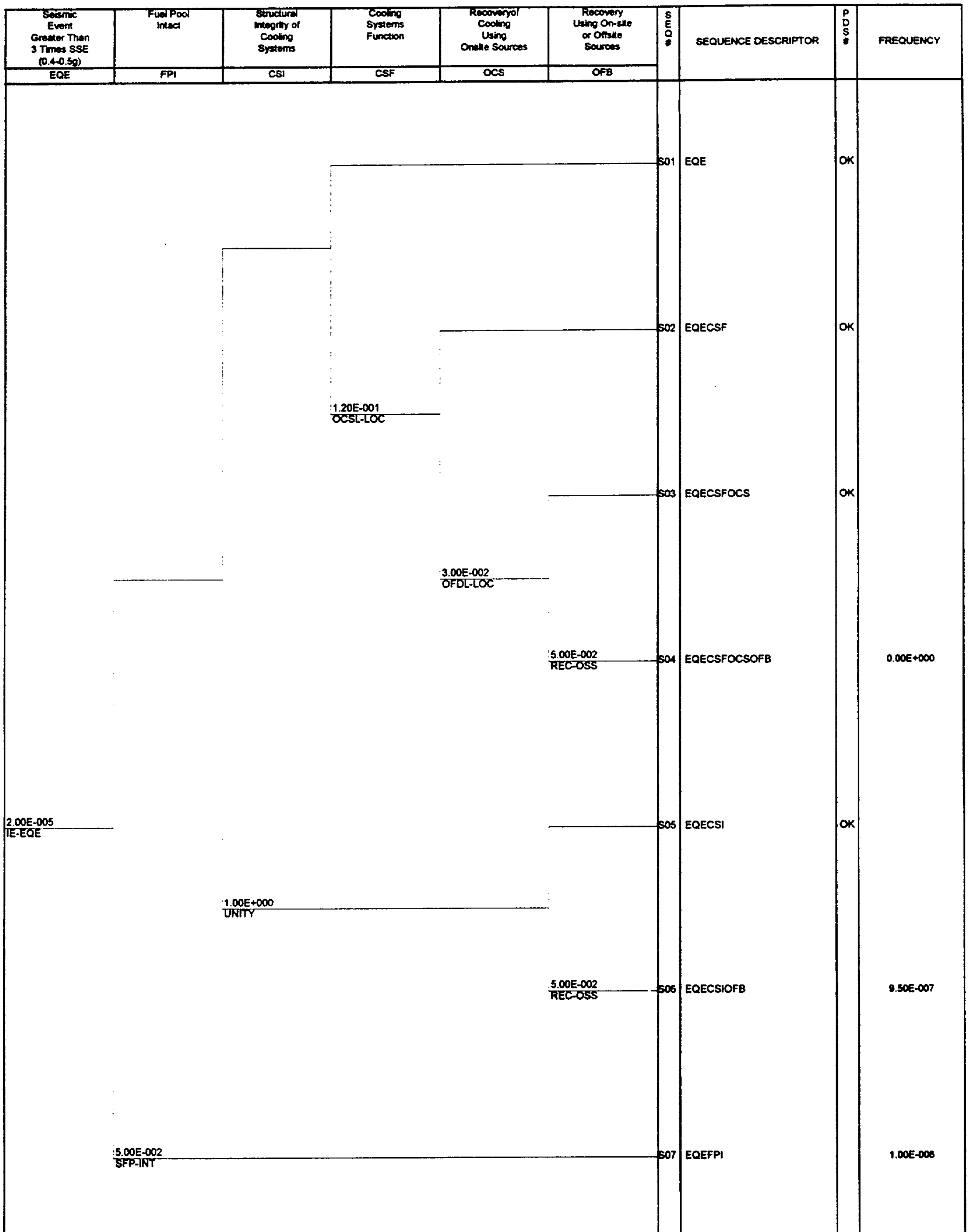
Quantification Date: 05/28/99 06:14:31 TOTAL CMF = 1.95E-006

SFP RISK AT DECOMMISSIONED PLANTS

SEISMIC INITIATING EVENT

CASE 2

Figure 2b



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Quantification Date: 05/28/99 07:59:56 TOTAL CMF = 1.95E-006

SFP RISK AT DECOMMISSIONED PLANTS
SEISMIC INITIATING EVENT CASE 3

Figure 2c

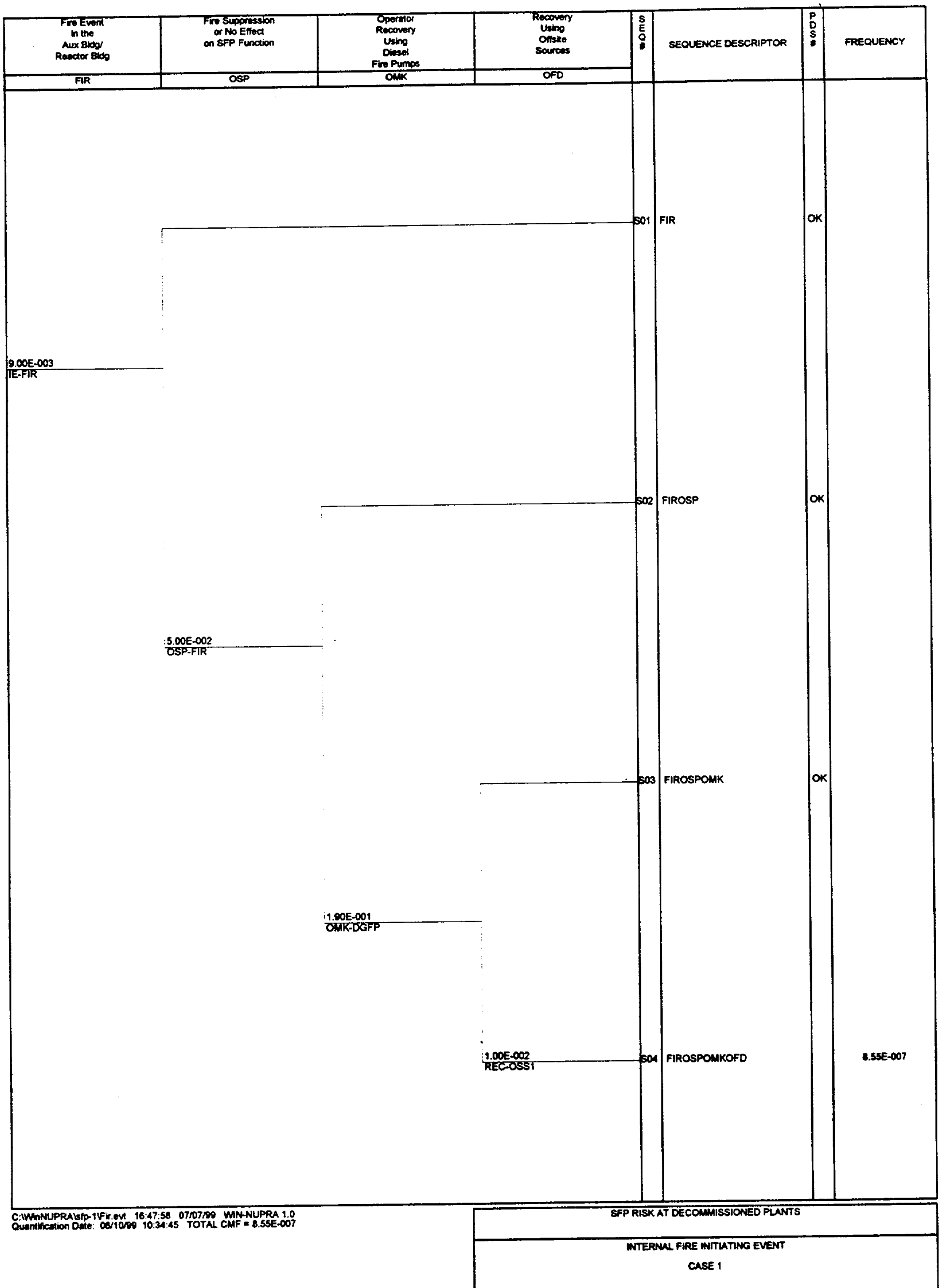
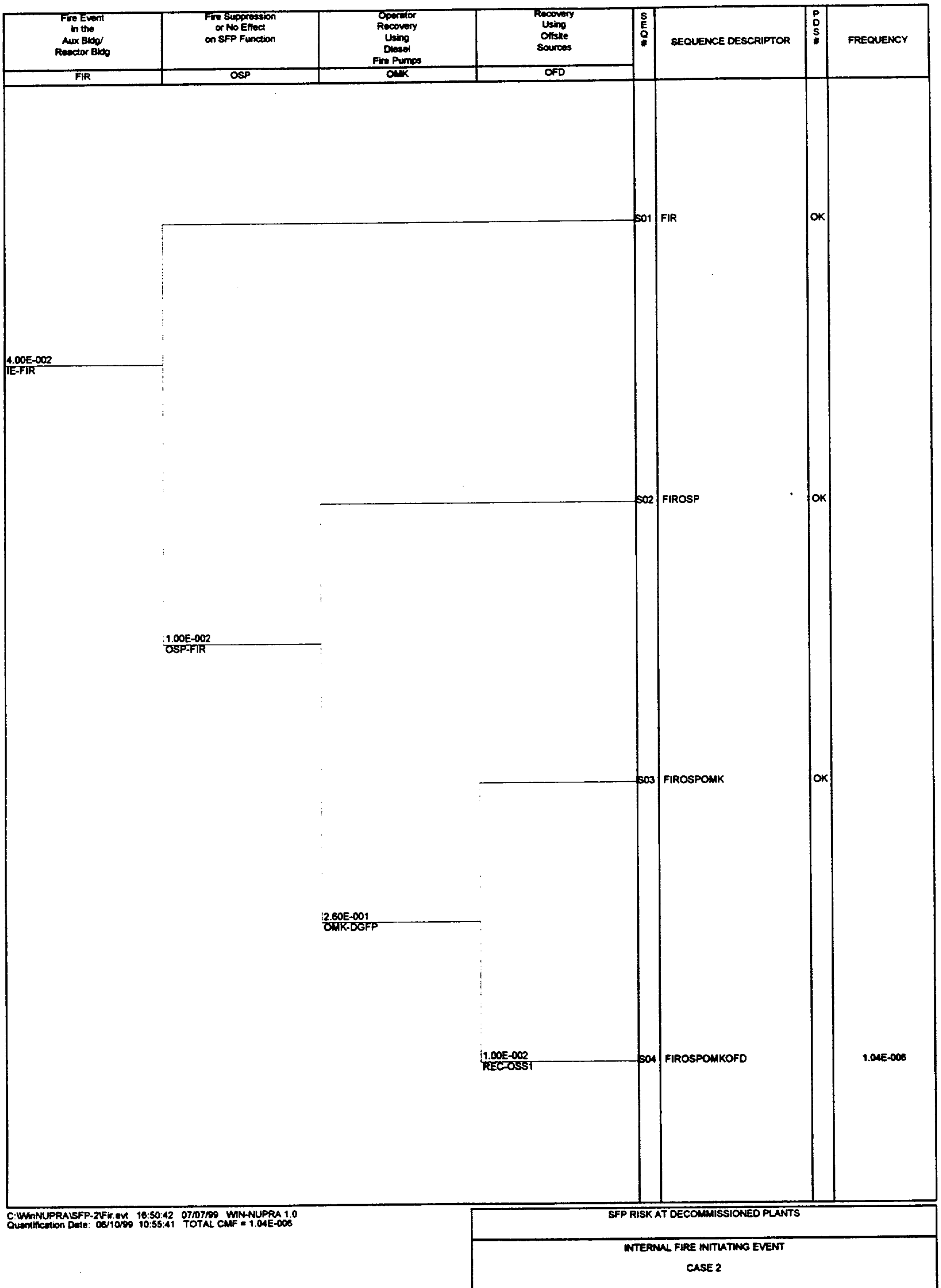

Fire Event In the Aux Bldg/ Reactor Bldg
FIR
Fire Suppression or No Effect on SFP Function
OSP
Operator Recovery Using Diesel Fire Pumps
OMK
Recovery Using Offsite Sources
OFD
SEQ #
SEQUENCE DESCRIPTOR
PDS #
FREQUENCY
S01 FIR OK
S02 FIROSP OK
S03 FIROSPOMK OK
S04 FIROSPOMKOFD 8.55E-007
9.00E-003
IE-FIR
5.00E-002
OSP-FIR
1.90E-001
OMK-DGFP
1.00E-002
REC-OSS1
C:\WinNUPRA\sfp-1\Fir.evt 16:47:58 07/07/99 WIN-NUPRA 1.0
Quantification Date: 06/10/99 10:34:45 TOTAL CMF = 8.55E-007
SFP RISK AT DECOMMISSIONED PLANTS
INTERNAL FIRE INITIATING EVENT
CASE 1

Figure 3a


Fire Event in the Aux Bldg/ Reactor Bldg
FIR
Fire Suppression or No Effect on SFP Function
OSP
Operator Recovery Using Diesel Fire Pumps
OMK
Recovery Using Offsite Sources
OFD
SEQ #
SEQUENCE DESCRIPTOR
PDS #
FREQUENCY
4.00E-002
IE-FIR
1.00E-002
OSP-FIR
2.60E-001
OMK-DGFP
1.00E-002
REC-OSS1
S01 FIR OK
S02 FIROSP OK
S03 FIROSPOMK OK
S04 FIROSPOMKOFD 1.04E-006
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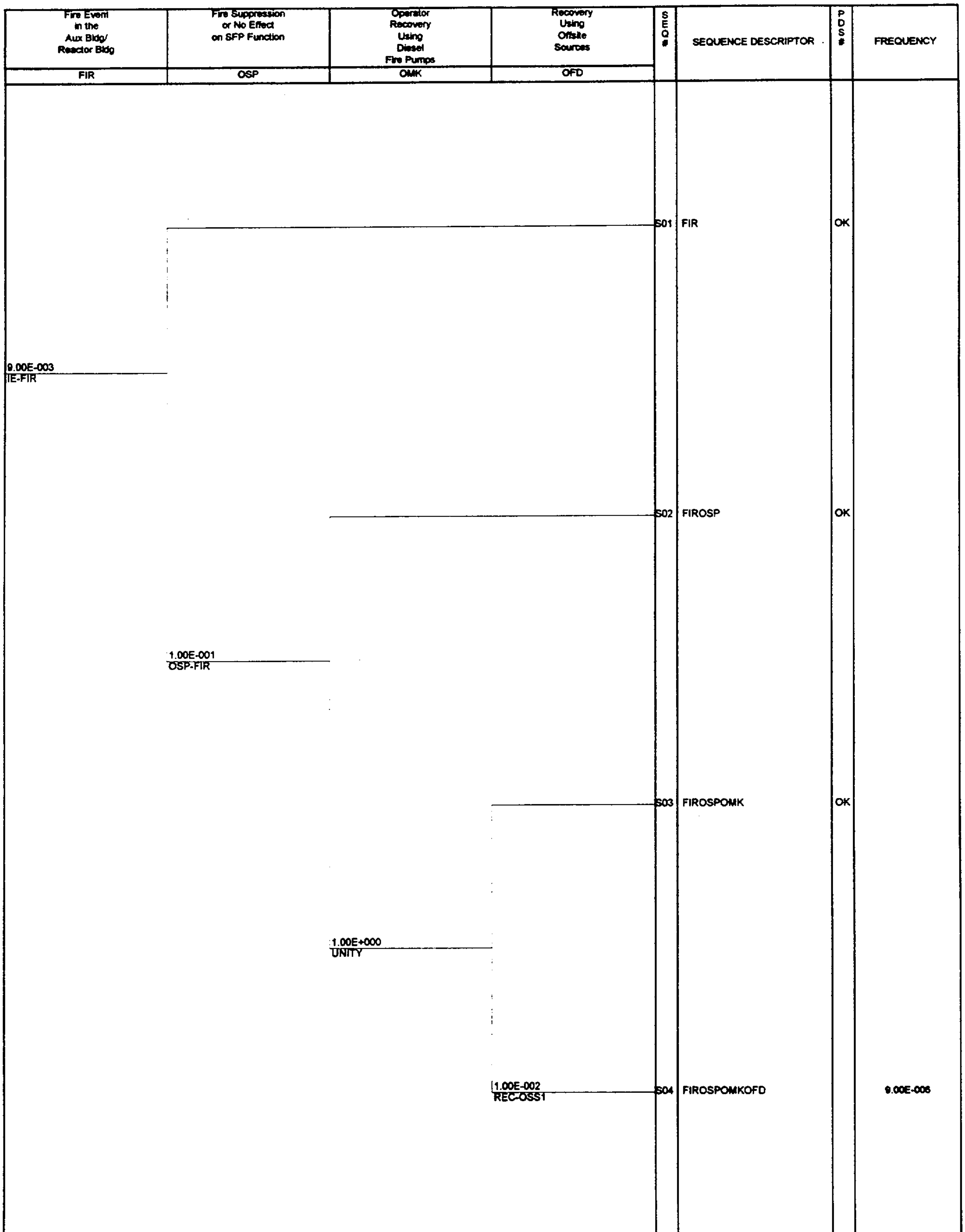
SFP RISK AT DECOMMISSIONED PLANTS
INTERNAL FIRE INITIATING EVENT
CASE 2

Figure 3b



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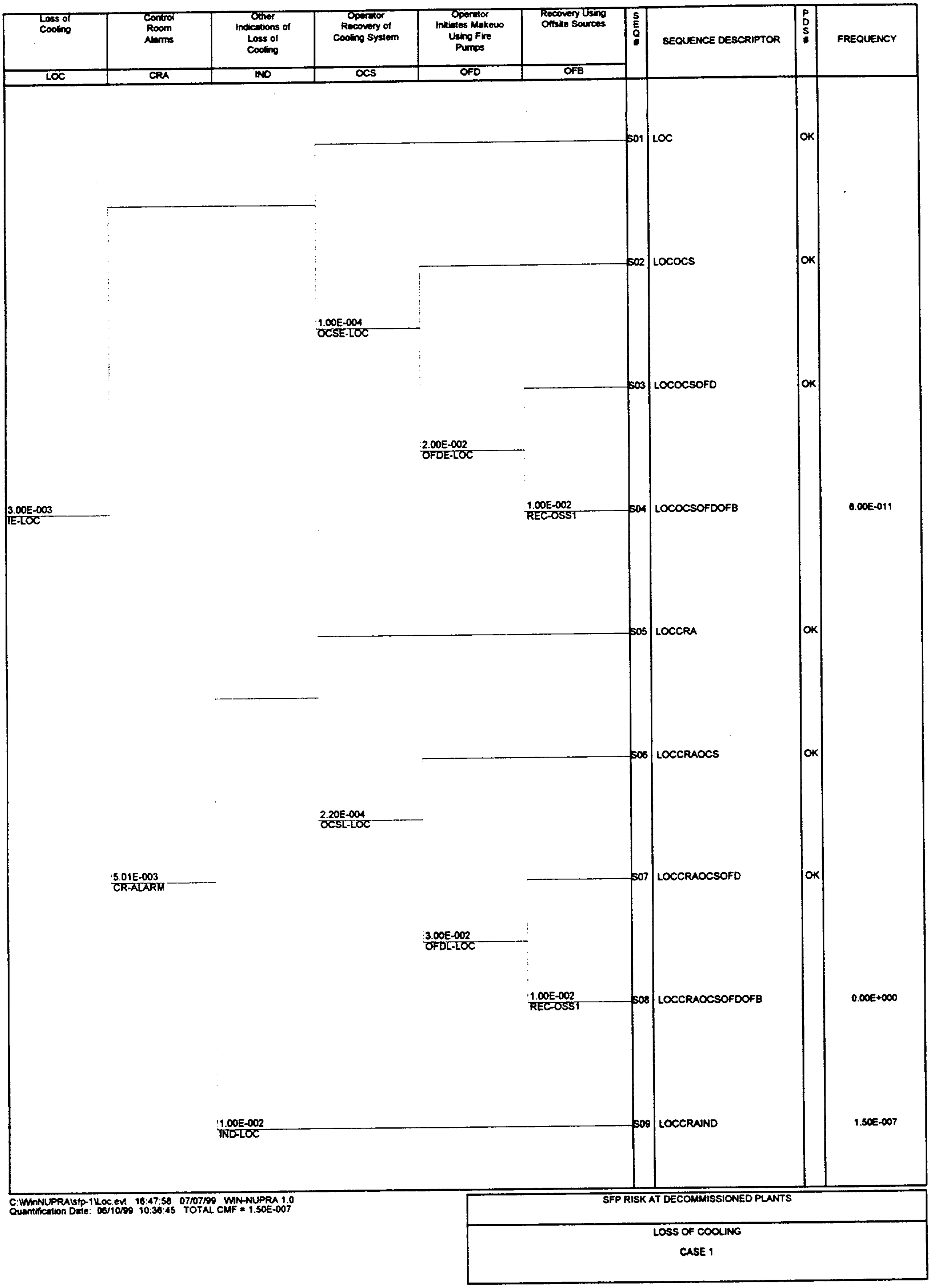
Quantification Date 06/10/99 11:03:02 TOTAL CMF = 9.00E-006

SFP RISK AT DECOMMISSIONED PLANTS

INTERNAL FIRE INITIATING EVENT

CASE 3

Figure 3c



Loss of Cooling
Control Room Alarms
Other Indications of Loss of Cooling
Operator Recovery of Cooling System
Operator Initiates Makeuo Using Fire Pumps
Recovery Using Offsite Sources
SEQ #
SEQUENCE DESCRIPTOR
PDS #
FREQUENCY
LOC
CRA
IND
OCS
OFD
OFB
3.00E-003
IE-LOC
5.01E-003
CR-ALARM
1.00E-002
IND-LOC
1.00E-004
OCSE-LOC
2.20E-004
OCSL-LOC
2.00E-002
OFDE-LOC
3.00E-002
OFDL-LOC
1.00E-002
REC-OSS1
1.00E-002
REC-OSS1
S01 LOC OK
S02 LOCOCS OK
S03 LOCOCSOFD OK
S04 LOCOCSOFDOFB 6.00E-011
S05 LOCCRA OK
S06 LOCCRAOCS OK
S07 LOCCRAOCSOFD OK
S08 LOCCRAOCSOFDOFB 0.00E+000
S09 LOCCRAIND 1.50E-007
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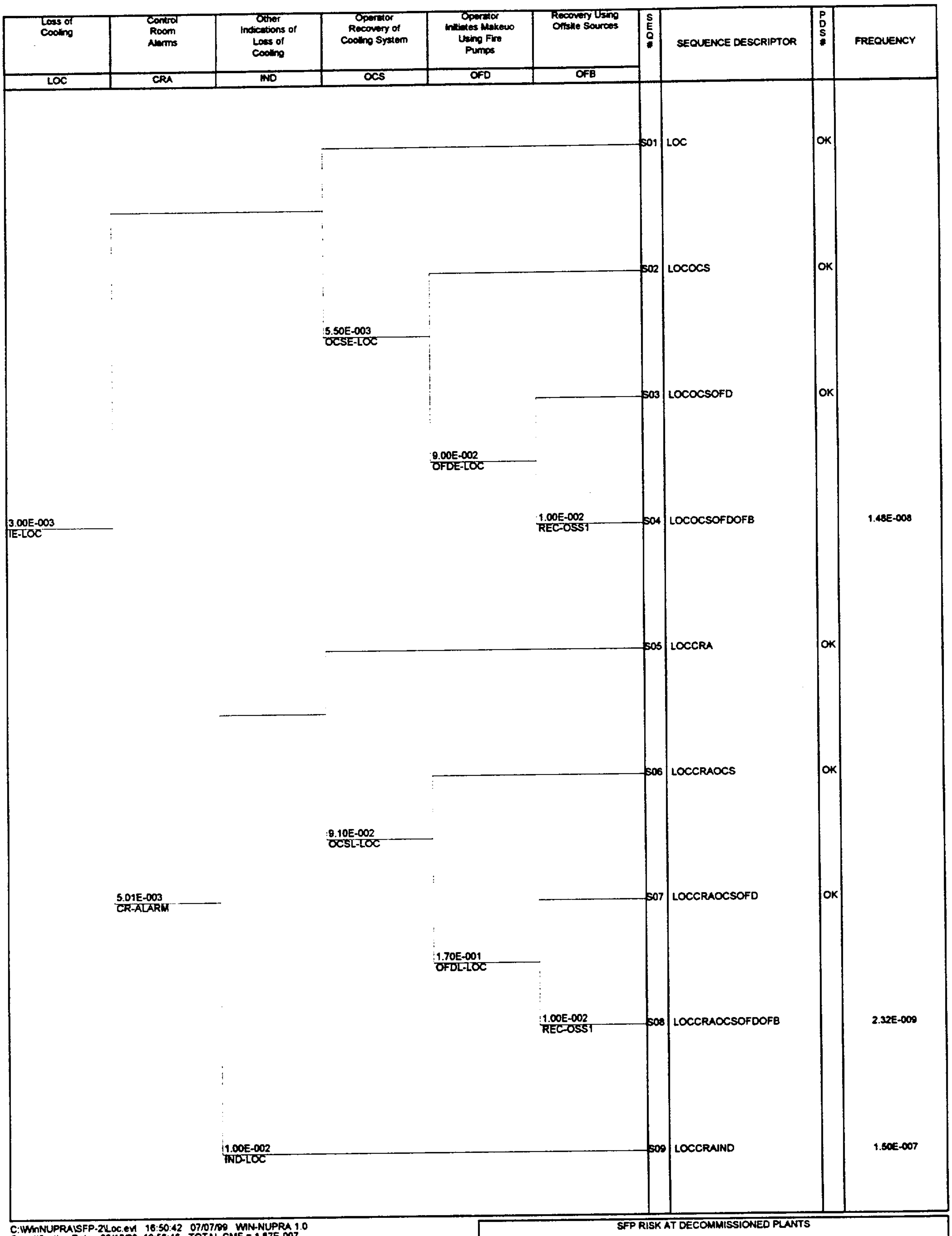
SFP RISK AT DECOMMISSIONED PLANTS
LOSS OF COOLING
CASE 1

Figure 4a

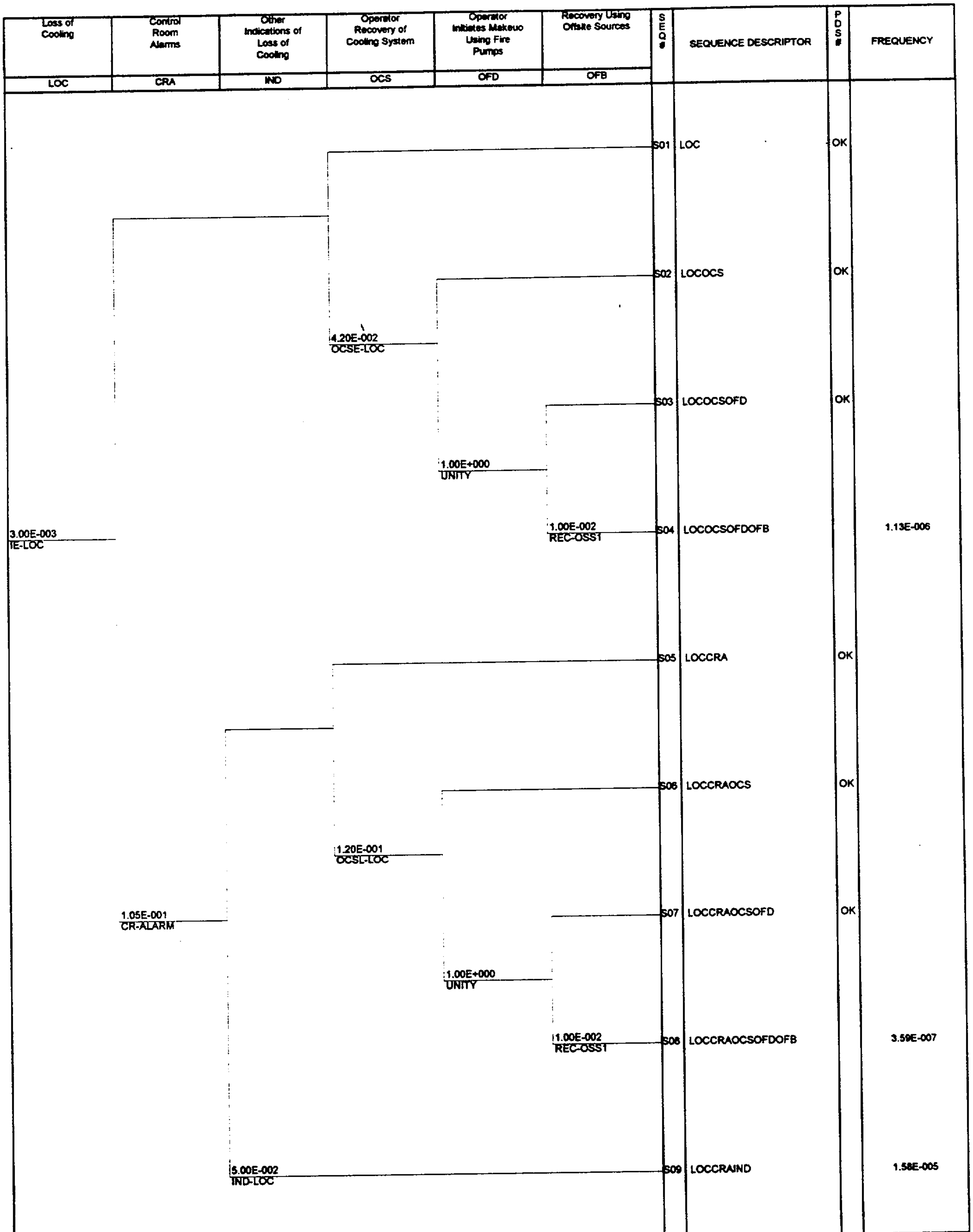


SFP RISK AT DECOMMISSIONED PLANTS

LOSS OF COOLING

CASE 2

Figure 4b



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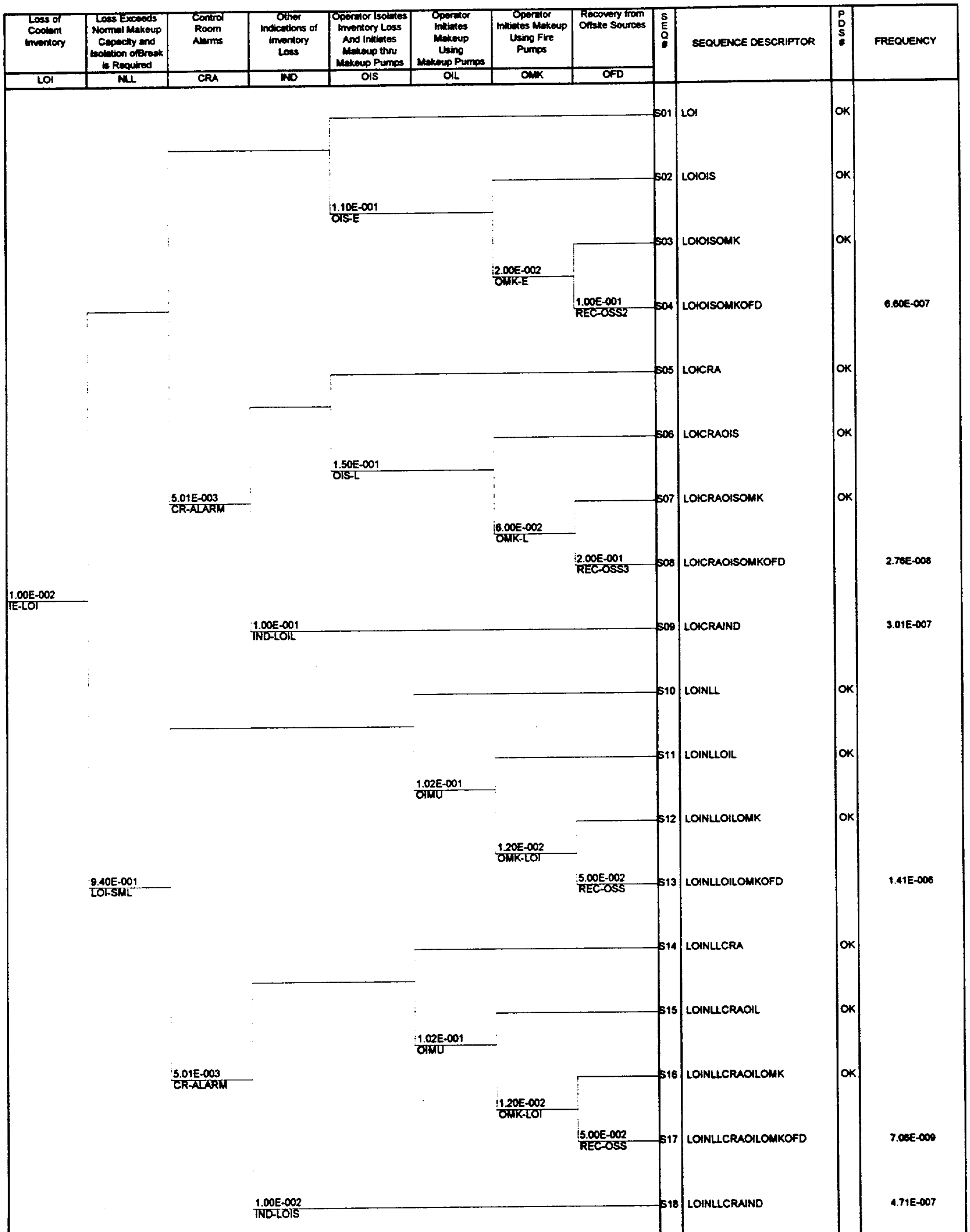
SFP RISK AT DECOMMISSIONED PLANTS

LOSS OF COOLING

CASE 3

Figure 4c



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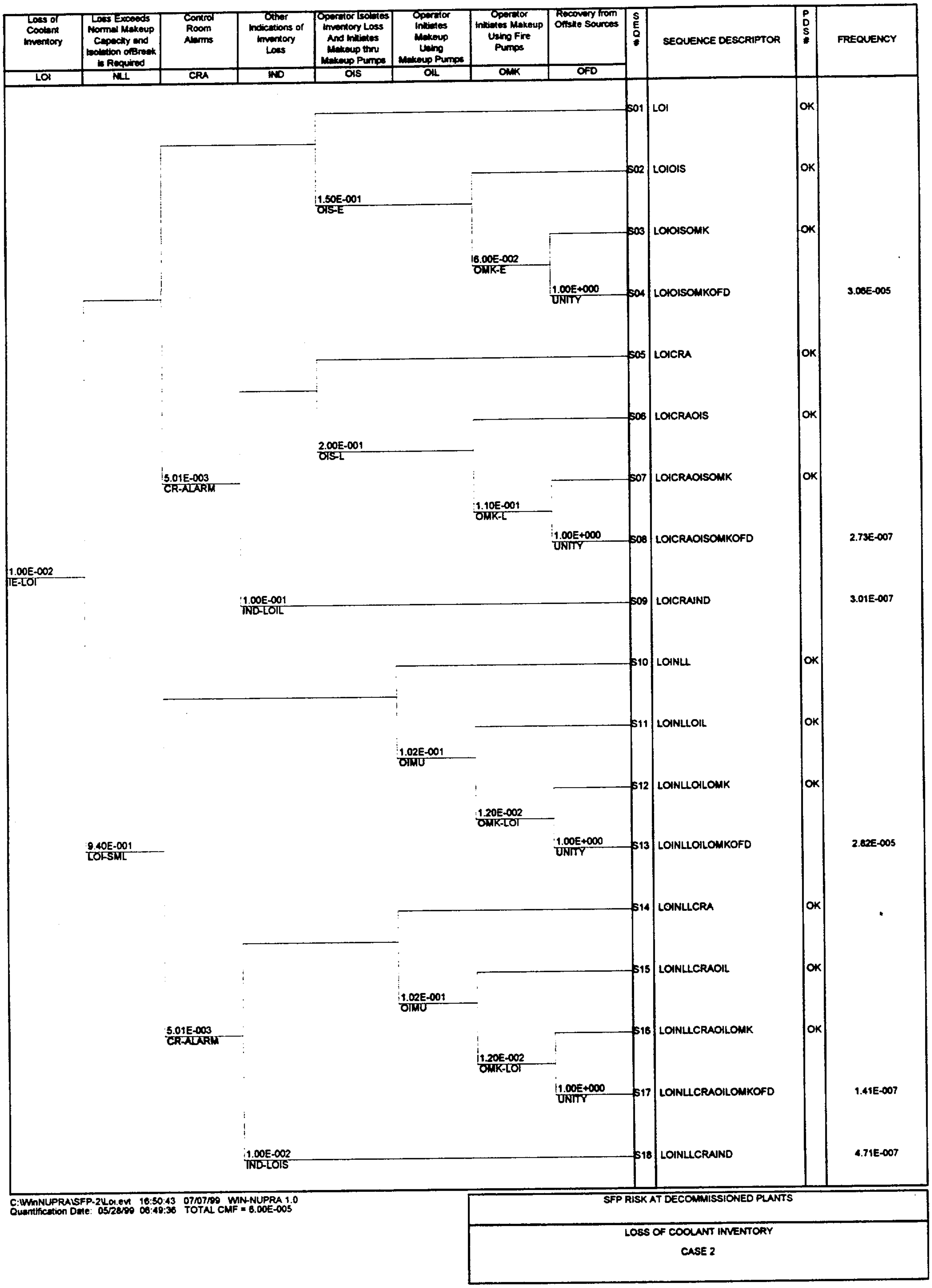
Quantification Date: 05/28/99 05:47:31 TOTAL CMF = 2.88E-006

SFP RISK AT DECOMMISSIONED PLANTS

LOSS OF COOLANT INVENTORY
CASE 1

Figure 5a


Loss of Coolant Inventory
LOI
Loss Exceeds Normal Makeup Capacity and Isolation of Break is Required
NLL
Control Room Alarms
CRA
Other Indications of Inventory Loss
IND
Operator Isolates Inventory Loss And Initiates Makeup thru Makeup Pumps
OIS
Operator Initiates Makeup Using Makeup Pumps
OIL
Operator Initiates Makeup Using Fire Pumps
OMK
Recovery from Offsite Sources
OFD
SEQ #
SEQUENCE DESCRIPTOR
PDS #
FREQUENCY
1.00E-002
IE-LOI
9.40E-001
LOI-SML
5.01E-003
CR-ALARM
1.00E-001
IND-LOIL
1.00E-002
IND-LOIS
1.50E-001
OIS-E
2.00E-001
OIS-L
1.02E-001
OIMU
6.00E-002
OMK-E
1.10E-001
OMK-L
1.20E-002
OMK-LOI
1.00E+000
UNITY
S01 LOI OK
S02 LOIOIS OK
S03 LOIOISOMK OK
S04 LOIOISOMKOFD 3.06E-005
S05 LOICRA OK
S06 LOICRAOIS OK
S07 LOICRAOISOMK OK
S08 LOICRAOISOMKOFD 2.73E-007
S09 LOICRAIND 3.01E-007
S10 LOINLL OK
S11 LOINLLOIL OK
S12 LOINLLOILOMK OK
S13 LOINLLOILOMKOFD 2.82E-005
S14 LOINLLCRA OK
S15 LOINLLCRAOIL OK
S16 LOINLLCRAOILOMK OK
S17 LOINLLCRAOILOMKOFD 1.41E-007
S18 LOINLLCRAIND 4.71E-007
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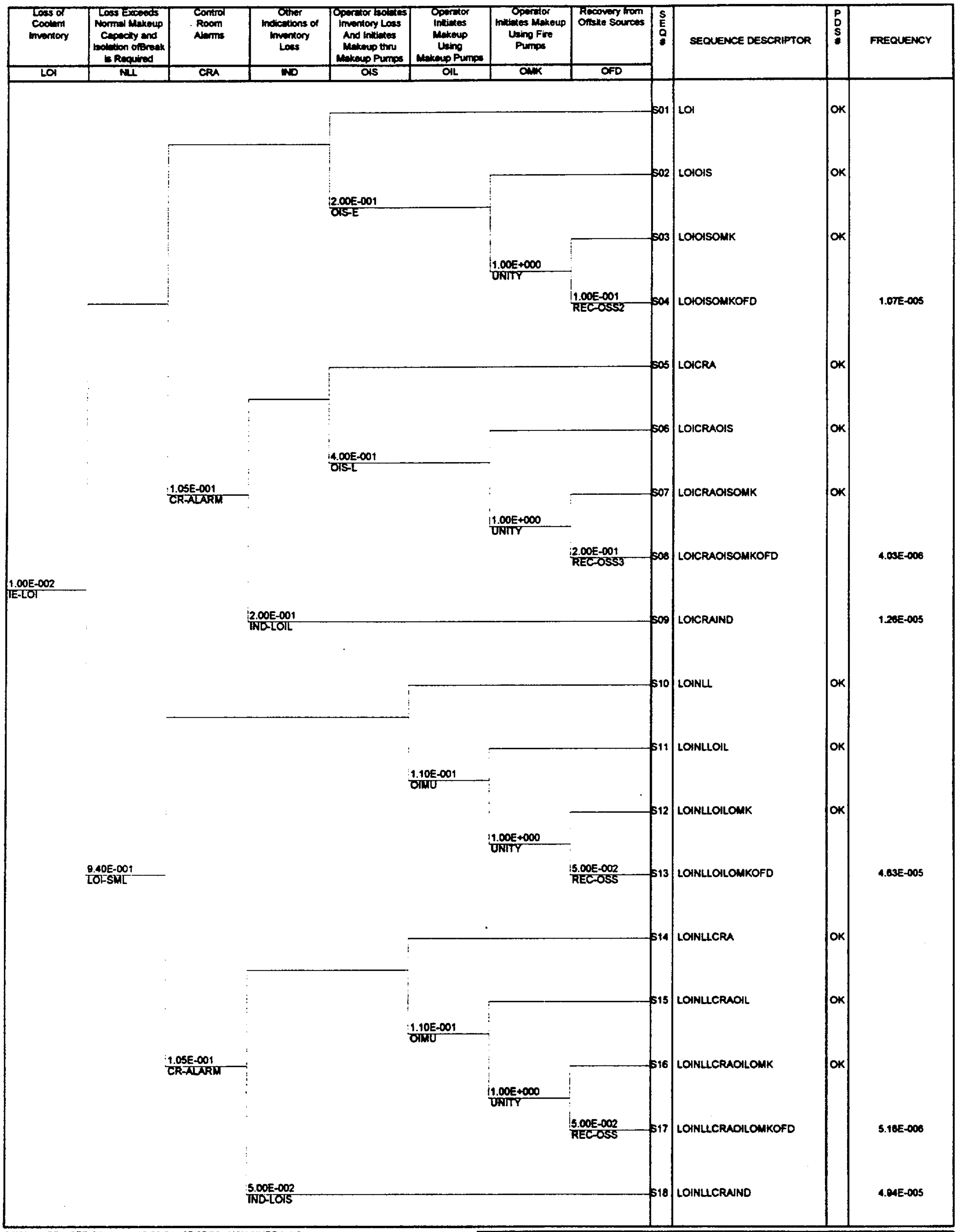
SFP RISK AT DECOMMISSIONED PLANTS
LOSS OF COOLANT INVENTORY
CASE 2

Figure 5b



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SFP RISK AT DECOMMISSIONED PLANTS

LOSS OF COOLANT INVENTORY

CASE 3

Figure 5c

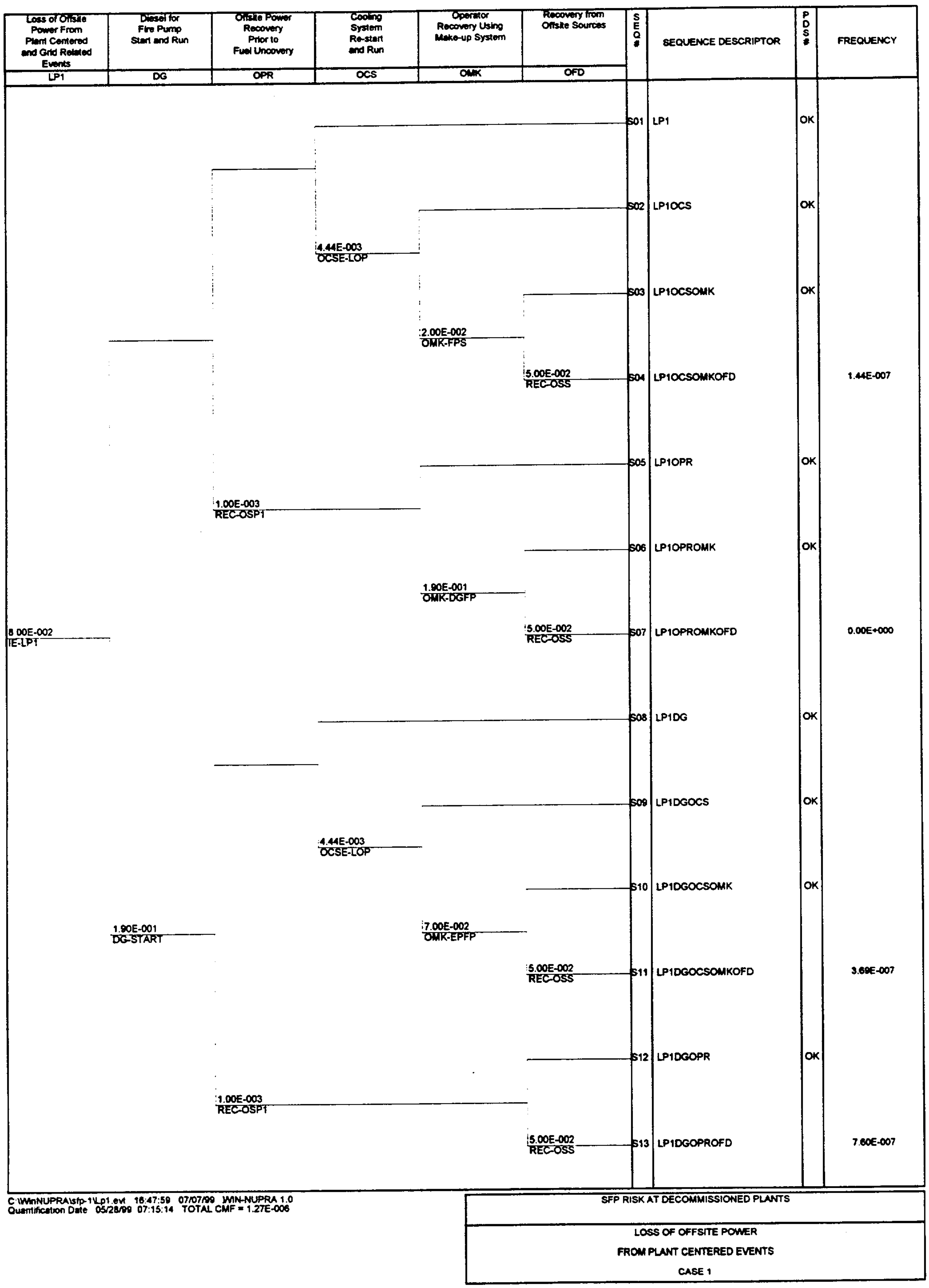
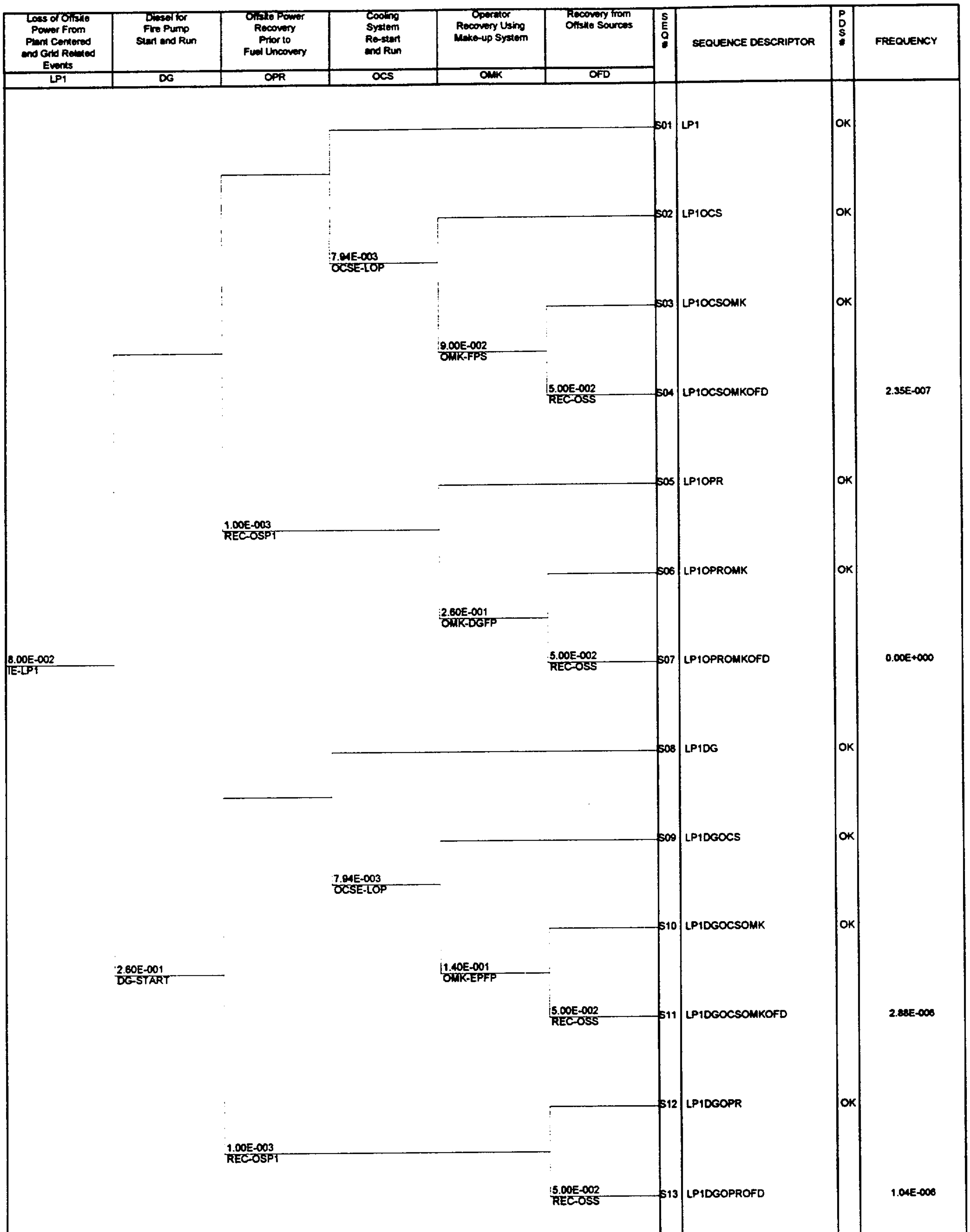

Loss of Offsite Power From Plant Centered and Grid Related Events
LP1
Diesel for Fire Pump Start and Run
DG
Offsite Power Recovery Prior to Fuel Uncovery
OPR
Cooling System Re-start and Run
OCS
Operator Recovery Using Make-up System
OMK
Recovery from Offsite Sources
OFD
SEQ #
SEQUENCE DESCRIPTOR
PDS #
FREQUENCY
8.00E-002
IE-LP1
1.90E-001
DG-START
1.00E-003
REC-OSP1
4.44E-003
OCSE-LOP
2.00E-002
OMK-FPS
1.90E-001
OMK-DGFP
7.00E-002
OMK-EPFP
5.00E-002
REC-OSS
S01 LP1 OK
S02 LP1OCS OK
S03 LP1OCSOMK OK
S04 LP1OCSOMKOFD 1.44E-007
S05 LP1OPR OK
S06 LP1OPROMK OK
S07 LP1OPROMKOFD 0.00E+000
S08 LP1DG OK
S09 LP1DGOCS OK
S10 LP1DGOCSOMK OK
S11 LP1DGOCSOMKOFD 3.69E-007
S12 LP1DGOPR OK
S13 LP1DGOPROFD 7.60E-007
C:\WinNUPRA\sfp-1\Lp1.evt 16:47:59 07/07/99 WIN-NUPRA 1.0
Quantification Date 05/28/99 07:15:14 TOTAL CMF = 1.27E-006
SFP RISK AT DECOMMISSIONED PLANTS
LOSS OF OFFSITE POWER
FROM PLANT CENTERED EVENTS
CASE 1

Figure 6a



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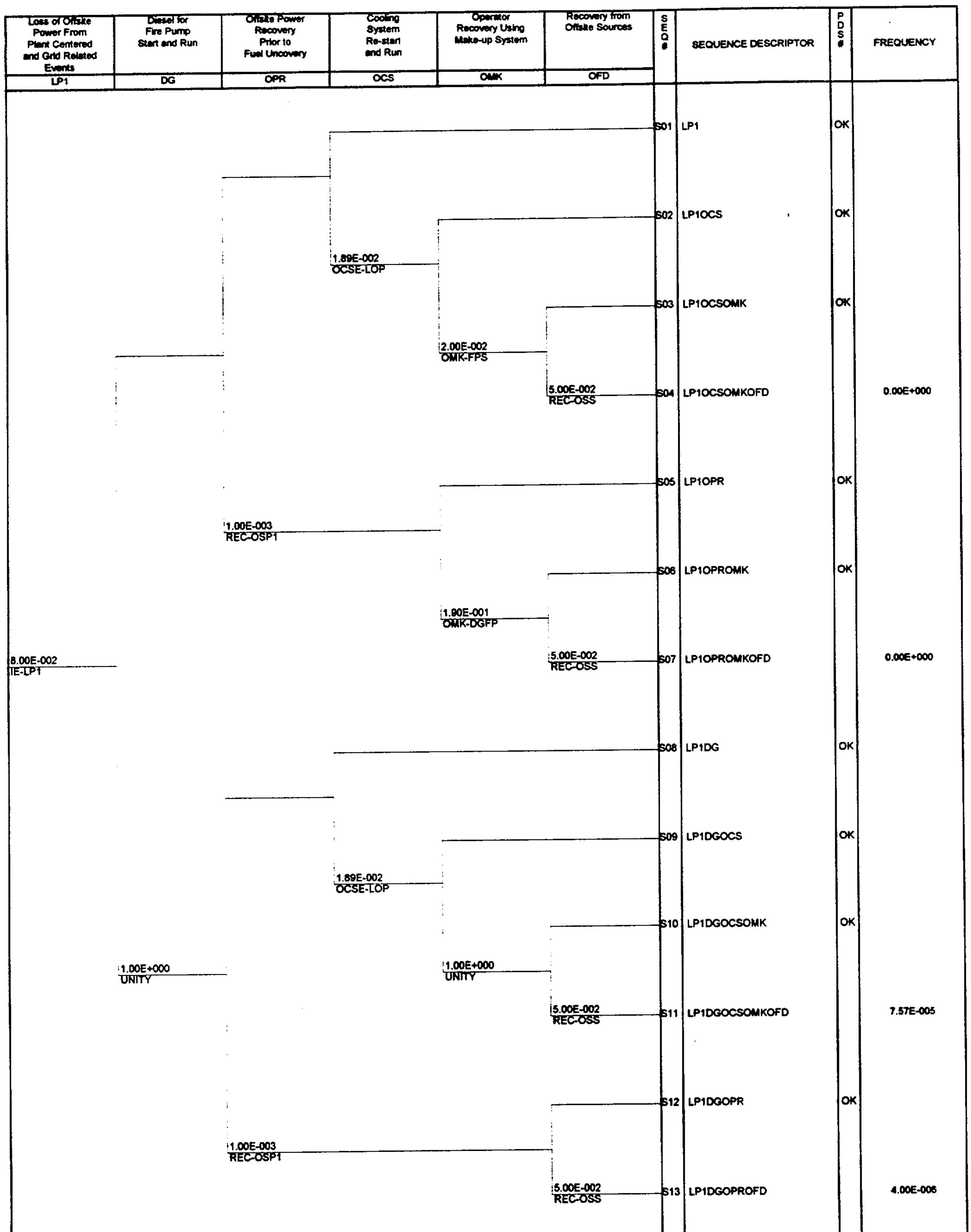
Quantification Date: 05/28/99 07:33:04 TOTAL CMF = 4.16E-006

SFP RISK AT DECOMMISSIONED PLANTS

LOSS OF OFFSITE POWER
FROM PLANT CENTERED EVENTS
CASE 2

Figure 6b



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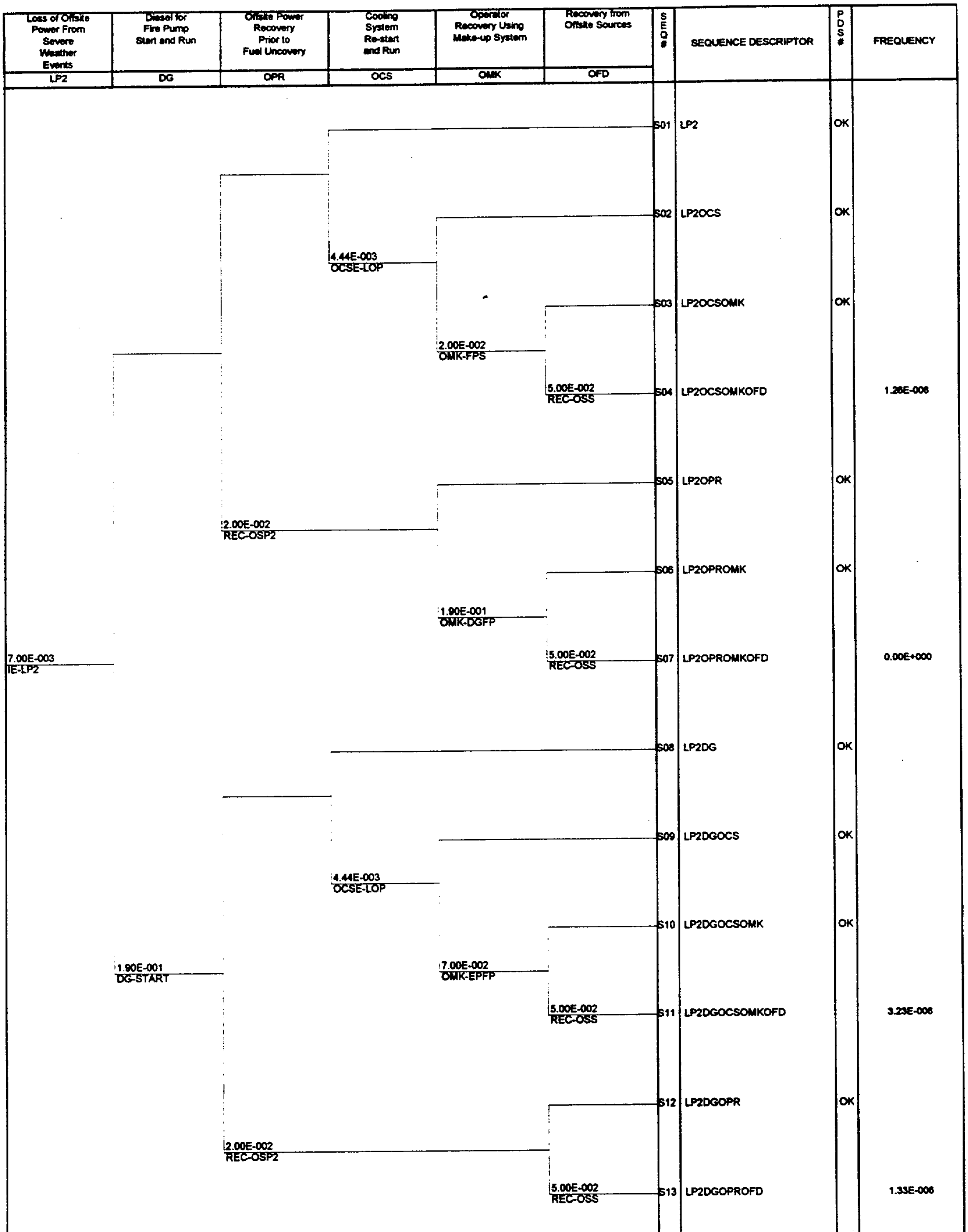
SFP RISK AT DECOMMISSIONED PLANTS

LOSS OF OFFSITE POWER
FROM PLANT CENTERED EVENTS
CASE 3

Figure 6c



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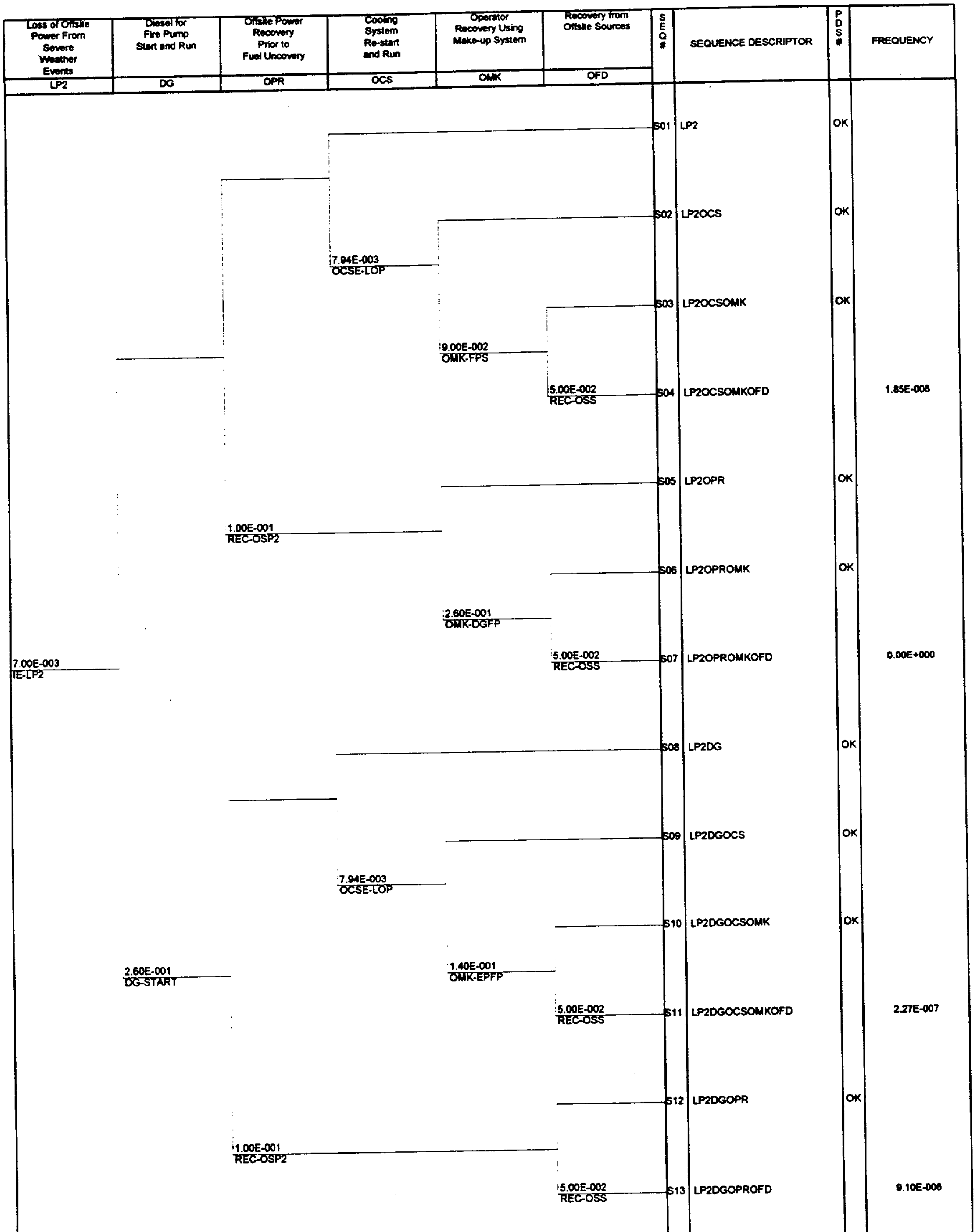
Quantification Date: 05/28/99 07:16:18 TOTAL CMF = 1.37E-006

SFP RISK AT DECOMMISSIONED PLANTS

LOSS OF OFFSITE POWER
FROM SEVERE WEATHER EVENTS
CASE 1

Figure 7a



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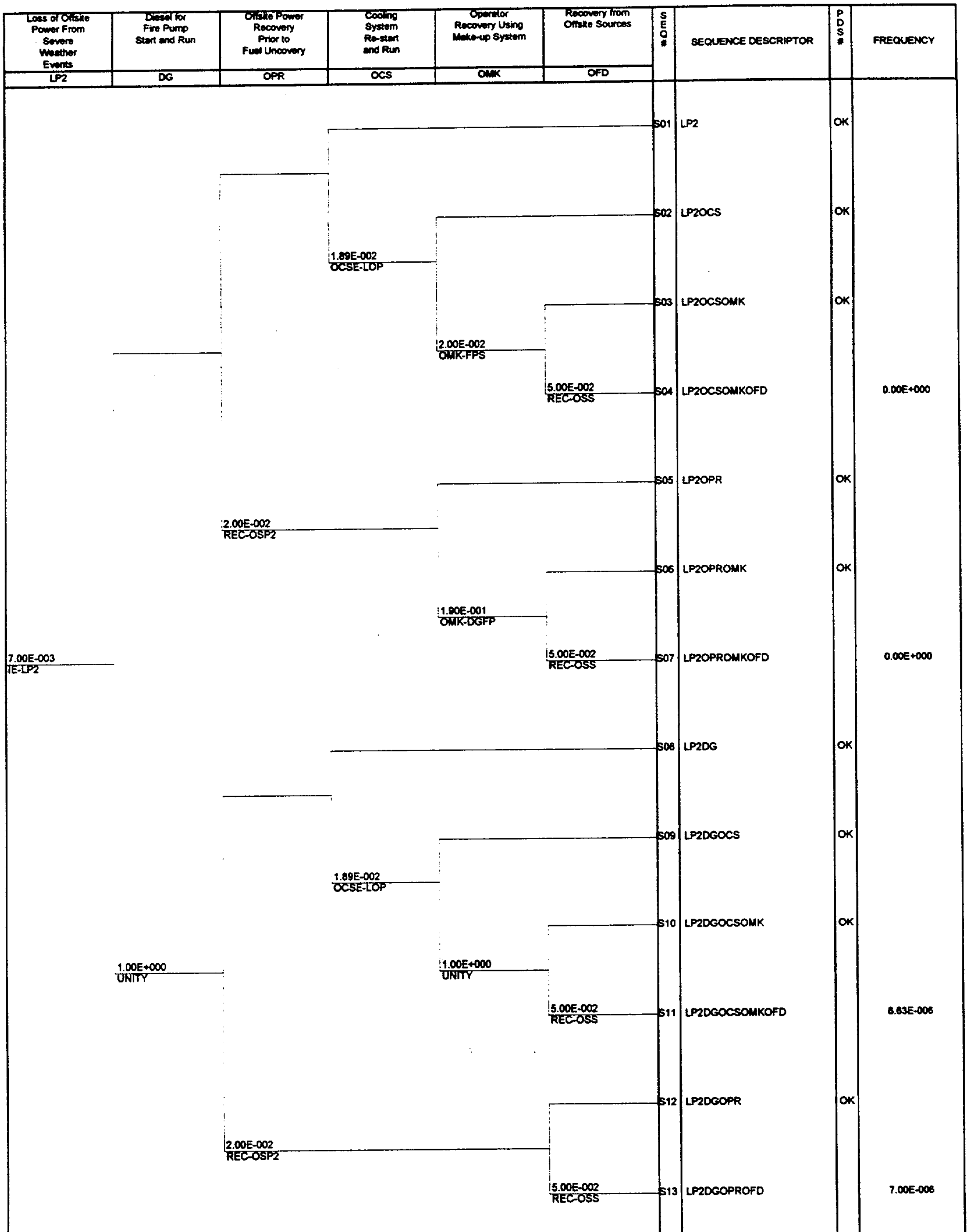
SFP RISK AT DECOMMISSIONED PLANTS

LOSS OF OFFSITE POWER
FROM SEVERE WEATHER EVENTS
CASE 2

Figure 7b



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SFP RISK AT DECOMMISSIONED PLANTS

LOSS OF OFFSITE POWER
FROM SEVERE WEATHER EVENTS
CASE 3

Figure 7c

APPENDIX A

Event Probabilities/Frequencies Used in the SFP Risk Analysis

EVENT NAME	DESCRIPTION	EVENT PROBABILITY	SOURCE/REFERENCE
FP-DGPUMP-FTF	Diesel powered fire pump fails to start and run	Cases 1,2,3: 1.8E-01	estimate based on event EPS-DGN-FC-1ARE in INEL-96/0334
FP-ELPUMP-FTF	Electric fire pump fails to start and run	Cases 1,2,3: 6.0E-02	estimate based on event FP-DGPUMP-FTF and on operating experience.
FP-MKUP-FTF	Failure to makeup inventory in SPF using either the electric or diesel fire protection pumps	Cases 1,2,3: 1.0E-02	based on event SPF-MKUP-ALT-F in INEL-96/0334
HEP-ALTCL-E	Operator fails to establish alternate cooling (use of fire pumps) given a loss of "normal" SFP cooling - early indication from control room alarms. There is in excess of 120 hrs available in Cases 1and 3 and approximately 52 hrs available in Case 2. [Timing for Case 1 is based on time to bulk boiling of 27 hours and a boildown rate of 0.2ft/hr. Timing for Case 2 is based on time to bulk boiling of 12 hours and a boildown rate of 0.5ft/hr.]	Case 1: 1.0E-02	based on event ALT-XHE-XM-SFP in INEL-96/0334
		Case 2: 8.0E-02	based on event ALT-XHE-XM-SFPL in INEL-96/0334
		Case 3: N/A	fire pumps are assumed to be unavailable in Case 3
HEP-ALTCL-L	Operator fails to establish alternate cooling (use of fire pumps) given a loss of "normal" SFP cooling - indication from walkdowns. Less time is available than in HEP-ALTCL-E since time will elapse for bulk pool boiling to begin and for pool level to decrease (to a level that will be obvious to the operator)	Case 1: 2.0E-02	assume twice the probability for HEP-ALTCL-E
		Case 2: 1.6E-01	assume twice the probability for HEP-ALTCL-E
		Case 3: N/A	fire pumps are assumed to be unavailable in Case 3

EVENT NAME	DESCRIPTION	EVENT PROBABILITY	SOURCE/REFERENCE
HEP-ALTCL-LP-E	Operator fails to establish alternate cooling (use of fire pumps) given a loss of offsite power. There is in excess of 120 hrs available in Cases 1 & 3 and approximately 52 hrs available in Case 2.	Case 1: 1.0E-02	based on event ALT-XHE-XM-SFPP in INEL-96/0334 this should be 3E-2. However, in a decommissioned plant, this HEP is more similar to event HEP-ALTCL-E. Therefore use 1E-2
		Case 2: 8.0E-02	similar to HEP-ALTCL-E
		Case 3: N/A	fire pumps are assumed to be unavailable in Case 3
HEP-COOL-LOC-E	Operator fails to restore cooling system given a loss of cooling event -early indication from control room alarms. There is in excess of 120 hrs available in Cases 1 & 3 and approximately 52 hrs available in Case 2. Mean time to repair is assumed to be 10 hours for Cases 1 & 3 and 40 hours for Case 2.	Case 1: 1.0E-04	assume probability of failure to repair = exp (-lambda * time available) = exp (-1/10 * 128) = 3E-6 (cap off at 1E-4)
		Case 2: 5.5E-03	probability of failure to repair = exp (-1/10 * 52) = 5.5E-3
		Case 3: 4.2E-02	probability of failure to repair = exp (-1/40 * 128) = 4.2E-2
HEP-COOL-LOC-L	Operator fails to restore cooling system given a loss of cooling event - indication from walkdowns. Less time is available than in HEP-ALTCL-E since time will elapse for bulk pool boiling to begin and for pool level to decrease (to a level that will be obvious to the operator). Assume that it is the second shift (i.e., time to bulk boiling plus 16 hours) that recognizes the need for action. Therefore time available for Cases 1 & 3 is 84 hours and 24 hours for Case 2.	Case 1: 2.2E-04	assume probability of failure to repair = exp (-lambda * time available) = exp (-1/10 * 84) = 2.2E-4
		Case 2: 9.1E-02	probability of failure to repair = exp (-1/10 * 24) = 9.1E-2
		Case 3: 1.2E-01	probability of failure to repair = exp (-1/40 * 84) = 1.2E-1
HEP-COOL-LOP-E	Operator fails to restart/re-align cooling system given a loss of offsite power -early indication from control room alarms. There is in excess of 120 hrs available in Cases 1 & 3 and approximately 52 hrs available in Case 2.	Case 1: 3.5E-03	based on methodology provided in INEL-96/0334 for event SFP-XHE-XE-LP but for low stress, and for a response type action. See also event SFP-XHE-XE-PLR in INEL-96/0334

EVENT NAME	DESCRIPTION	EVENT PROBABILITY	SOURCE/REFERENCE
		Case 2: 7.0E-03	Same as Case 1 except for less time and higher stress levels. The factor of 2 increase is consistent with INEL-96/0334 methodology.
		Case 3: 1.8E-02	Factor of 5 higher than HEP-COOL-LOC-E to account for less operator training. The 5 times is consistent with INEL-96/0334 methodology.
HEP-INV-MKUP-E	Operator fails to isolate a large inventory loss and initiate normal coolant makeup - early indication from control room alarms. From NUREG-1275 V12, the largest inventory loss resulted in a level drop of between 5 to 10 ft. In a foreign plant, an incident resulted in a level drop of 16'. Assume a drop of between 15 to 20ft leaving 5ft of water above the fuel assemblies. Therefore, time available for Case 1 is 36 hours and 15hrs for Case 2.	Case 1: 1.0E-02	based on events SFP-XHE-MANIOS-E (7E-3)and SFP-XHE-XE-LINVR (4E-3) in INEL-96/0334
		Case 2: 5.0E-02	Assume 5 times Case 1
		Case 3: 1.0E-01	based on event SFP-XHE-MANIOS-L (8E-2) in INEL-96/0334
HEP-INV-MKUP-L	Operator fails to isolate a large inventory loss and initiate normal coolant makeup - indication from walkdowns. Less time is available than in HEP-INV-MKUP-E since the walkdown could take place as much as 8 hours later	Case 1: 5.0E-02	assume 5 times HEP-INV-MKUP-E
		Case 2: 1.0E-01	Estimate
		Case 3: 3.0E-01	Estimate
HEP-INV-MKUP-SML	Operator fails to initiate normal coolant makeupfor small leaks. There is in excess of 120 hrs available in Cases 1 & 3and approximately 50 hrs available in Case 2.	Case 1: 2.0E-03	based on event SFP-XHE-XE-LINVR in INEL-96/0334, but divide by 2 since there is less stress than in re-fueling situations
		Case 2: 2.0E-03	same as Case 1
		Case 3: 1.0E-02	a factor of 5 higher due to lack of guidance and operator training
HEP-RES-ALARM	Operator fails to respond given an alarm in the control room	Cases 1,2,3: 3.0E-03	DOE Savannah River report WSRC-TR-93-581, and NUREG-1278

EVENT NAME	DESCRIPTION	EVENT PROBABILITY	SOURCE/REFERENCE
IE-AIRCRAFT-IMP	Frequency (per year) of an aircraft impact event causing damage to SFP integrity - this event is assumed to lead directly to fuel uncovery	Cases 1,2,3: 4.0E-08	Estimate based on DOE-STD-3014-96 and other studies (see Appendix 10I)
IE-CASK-DROP	Frequency (per year) of a cask drop event causing damage to SFP integrity - this event is assumed to lead directly to fuel uncovery. For this event, plant procedures for the moving of heavy loads is assumed to be present and followed.	Case 1: 2.5E-06	Estimate based on industrial data (NUREG-0612 and other studies - see Appendix 9)
		Case 2: 2.5E-06	Estimate based on industrial data (NUREG-0612 and other studies - see Appendix 9)
		Case 3: 1.5E-05	Estimate based on industrial data (NUREG-0612 and other studies - see Appendix 9)
IE-INT-FIRE	Frequency (per year) for an internally initiated fire event - postulated plant conditions one year after shutdown	Case 1: 9.0E-03	Derived using methodology given in EPRI TR-100370s
		Case 2: 4.0E-02	Derived using methodology given in EPRI TR-100370s - postulated plant conditions one month after shutdown - welding and cutting operations are ongoing
		Case 3: 9.0E-03	Similar to Case 1
IE-LOOP-LP1	Initiating event frequency (per year) for loss of offsite power from plant centered and grid related events	Cases 1,2,3: 8.0E-02	INEL-96/0334 NUREG/CR-5496
IE-LOOP-LP2	Initiating event frequency (per year) for loss of offsite power event initiated by severe weather	Cases 1,2,3: 7.0E-03	NUREG/CR-5496
IE-LO-POOL-COOL	Initiating event frequency (per year) for loss of pool cooling events	Cases 1,2,3: 3.0E-03	NUREG-1275 Vol. 12
IE-LO-POOL-INV	Initiating event frequency (per year) for loss of pool inventory events	Cases 1,2,3: 1.0E-02	NUREG-1275 Vol. 12

EVENT NAME	DESCRIPTION	EVENT PROBABILITY	SOURCE/REFERENCE
IE-SEISMIC	Frequency (per year) for a 0.4 to 0.5 g earthquake	Cases 1,2,3: 2.0E-05	Estimate based on information obtained from NUREG-1488
IE-TORNADO-MIS	Frequency (per year) of a tornado generated missile causing damage to SFP integrity - this event is assumed to lead directly to fuel uncovery	Cases 1,2,3: 5.6E-07	Estimate based on data from the National Climatic Data Center for F4 and F5 tornadoes. The potential loss of support systems from F3 tornadoes (approx. 1E-5 per year) is subsumed into the LP2 initiating event.
REC-FIRE-EVT	Probability that a fire event is sufficiently large to fail OSP cables or components of the SFP cooling pumps.	Case 1: 5.0E-02	Estimate. Manual suppression is assumed to be less likely since occupancy by plant personnel in the building is unlikely.
		Case 2: 1.0E-02	Estimate. Manual suppression is assumed to be possible since occupancy by plant personnel in the building is likely.
		Case 3: 1.0E-01	Estimate. Same as Case 1 except fire protection equipment and training is assumed to be less.
REC-INV-OFFSITE	Failure to recover inventory using offsite sources (e.g., fire engines) - time available in excess of 50 hours	5.0E-02	Estimate. Used in Cases 1,2&3 of LP1, LP2, and Seismic events where there is no pool failure. Also used in Cases 1&3 of small LOI
REC-INV-OFFSITE1	Failure to recover inventory using offsite sources (e.g., fire engines) -events where pool heatup is very slow	1.0E-02	Estimate. Used in Cases 1,2&3 of LOC and Fire.
REC-INV-OFFSITE2	Failure to recover inventory using offsite sources (e.g., fire engines) - time available is less than 36 hours	1.0E-01	Estimate. Used in Case 3 of LOC (w/o CR alarms), and Cases 1&3 of large LOI (with CR alarms)
REC-INV-OFFSITE3	Failure to recover inventory using offsite sources (e.g., fire engines) - time available in excess of 50 hours	2.0E-01	Estimate. Used in Cases 1&3 of large LOI (w/o CR alarms)

EVENT NAME	DESCRIPTION	EVENT PROBABILITY	SOURCE/REFERENCE
REC-OSP-PC	Probability of recovery of offsite power (from plant centered or grid related events)	Cases 1,2,3: 1.0E-03	Conservative probability based on methodology in NUREG/CR-5032
REC-OSP-SW	Probability of recovery of offsite power (from severe weather events)	Case 1: 2.0E-02	Figure B-19 of NUREG/CR-5496
		Case 2: 1.0E-01	Figure B-19 of NUREG/CR-5496
		Case 3: 2.0E-02	Similar to Case 1
REC-WLKDWN-LOC	Operator fails to notice loss of cooling event during walkdowns. Indications include pool steaming and low pool level.	Case 1: 1.0E-02	Similar to REC-WLKDWN-LOI-S
		Case 2: 1.0E-02	same as Case 1
		Case 3: 5.0E-02	same as Case 1, except walkdown requirements are less and operators are less experienced.
REC-WLKDWN-LOI-L	Operator fails to notice a relatively fast decreasing level in the SFP during walkdowns. Similar to REC-WLKDWN-LOI-S except time available is less, but observable signs are more obvious.	Case 1: 1.0E-01	Estimate based on REC-WLKDWN-LOI-S
		Case 2: 1.0E-01	same as Case 1
		Case 3: 2.0E-01	same as Case 1, except walkdown requirements are less and operators are less experienced.
REC-WLKDWN-LOI-S	Operator fails to notice a relatively slow decreasing level in the SFP during walkdowns. Indications include low level in pool, and water in sump or in unexpected locations. Time available is in excess of 50 hours.	Case 1: 1.0E-02	From DOE Savannah River report WSRC-TR-93-581 event "failure of visual inspection to observe abnormal characteristics"
		Case 2: 1.0E-02	same as Case 1
		Case 3: 5.0E-02	same as Case 1, except walkdown requirements are less and operators are less experienced.
SFP-REGMKUP-F	Regular SFP Makeup system fails	Cases 1,2,3: 1.0E-01	based on event SFP-MKUP-REG-F in INEL-96/0334

EVENT NAME	DESCRIPTION	EVENT PROBABILITY	SOURCE/REFERENCE
SPC-CKV-CCF-H	Common cause failure of fuel pool cooling heat exchanger discharge check valves to open/remain open	Cases 1,2,3: 1.9E-05	based on event SPC1-CKV-CF-2F in INEL-96/0334
SPC-CKV-CCF-M	Common cause failure of fuel pool cooling pump discharge check valves to open/remain open	Cases 1,2,3: 3.2E-05	based on event SPC1-CKV-CF-MP2F in INEL-96/0334
SPC-HTX-CCF	Common cause failure of both fuel pool heat exchangers	Cases 1,2,3: 1.9E-05	based on event SPC1-HTX-CF-2F in INEL-96/0334
SPC-HTX-FTR	SPF heat exchanger cooling system fails to operate	Cases 1,2,3: 2.4E-04	based on event SPC1-HTX-FC-COOL in INEL-96/0334
SPC-HTX-PLG	Plugging failure of the SPF heat exchanger - includes the heat exchanger and 2 manual valves	Cases 1,2,3: 2.2E-05	based on event SPC1-HTX-FC-1A in INEL-96/0334
SPC-LVL-LOF	Level channel - loss of function during standby	Case 1: 1.0E-05	NUREG-1740
		Case 2: 1.0E-05	similar to Case 1
		Case 3: 1.0E-01	estimated based on the assumption that availability of instrumentation is not required
SPC-LVL-LOP	Level channel - local electrical faults	Cases 1,2,3: 2.0E-03	Estimate based on information in NUREG-1275 Vol. 12
SPC-PMP-CCF	Common cause failure of fuel pool cooling pumps	Cases 1,2,3: 5.9E-04	based on event SPC1-MDP-CF-2F in INEL-96/0334
SPC-PMP-FTF-1	Spent Fuel Pool cooling pump 1 fails to start and run	Cases 1,2,3: 3.9E-03	based on event SPC1-MDP-FC-1A in INEL-96/0334
SPC-PMP-FTF-2	Spent Fuel Pool cooling pump 2 fails to start and run	Cases 1,2,3: 3.9E-03	based on event SPC1-MDP-FC-1A in INEL-96/0334

APPENDIX B

Functional Assignments for the Event Trees

Table B-1 - Functional Assignments for the Seismic Event Tree

Event	Equation	Fault Tree	Comments
EQE	IE-EQE	FFT-IE	solve at gate GFFT1A0, single event IE-SEISMIC
FPI	SFP-INT	FFT-MISC	solve at gate GFFT140, single event SFP-INTEG-HCLPF
CSI	UNITY	FFT-MISC	solve at gate GFFT111, single event "TRUE" flag
CSF	n/a		
OCS	n/a		
OFB	REC-OSS	FFT-REC	solve at gate GFFT110, single event REC-INV-OFFSITE

Table B-2 - Functional Assignments for the Internal Fire Event Tree

Event	Equation	Fault Tree	Comments
FIR	IE-FIR	FFT-IE	solve at gate GFFT142, single event IE-INT-FIRE
OSP	OSP-FIR	FFT-REC	solve at gate GFFT150, single event REC-FIRE-EVT
OMK	OMK-DGFP	LOP-REC	solve at gate GLPR142 for Cases 1 & 2. For Case 3, use UNITY
OFD	REC-OSS1	FFT-REC	solve at gate GFFT111, single event REC-INV-OFFSITE1

Table B-3 - Functional Assignments for the Loss of Cooling Event Tree

Event	Equation	Fault Tree	Comments
LOC	IE-LOC	FFT-IE	solve at gate GFFT172, single event IE-LO-POOL-COOL
CRA	CR-ALARM	CR-ALARM	solve at gate GCRA112
IND	IND-LOC	FFT-REC	solve at gate GFFT130, single event REC-WLKDWN-LOC
OCS	OCSE-LOC	LOC-REC	solve at gate GLCR121
	OCSL-LOC	LOC-REC	solve at gate GLCR161
OFD	OFDE-LOC	LOC-REC	solve at gate GLCR123 for Cases 1 & 2. For Case 3, use UNITY
	OFDL-LOC	LOC-REC	solve at gate GLCR163 for Cases 1 & 2. For Case 3, use UNITY
OFB	REC-OSS1	FFT-REC	solve at gate GFFT111, single event REC-INV-OFFSITE1

Table B-4- Functional Assignments for the Loss of Inventory Event Tree

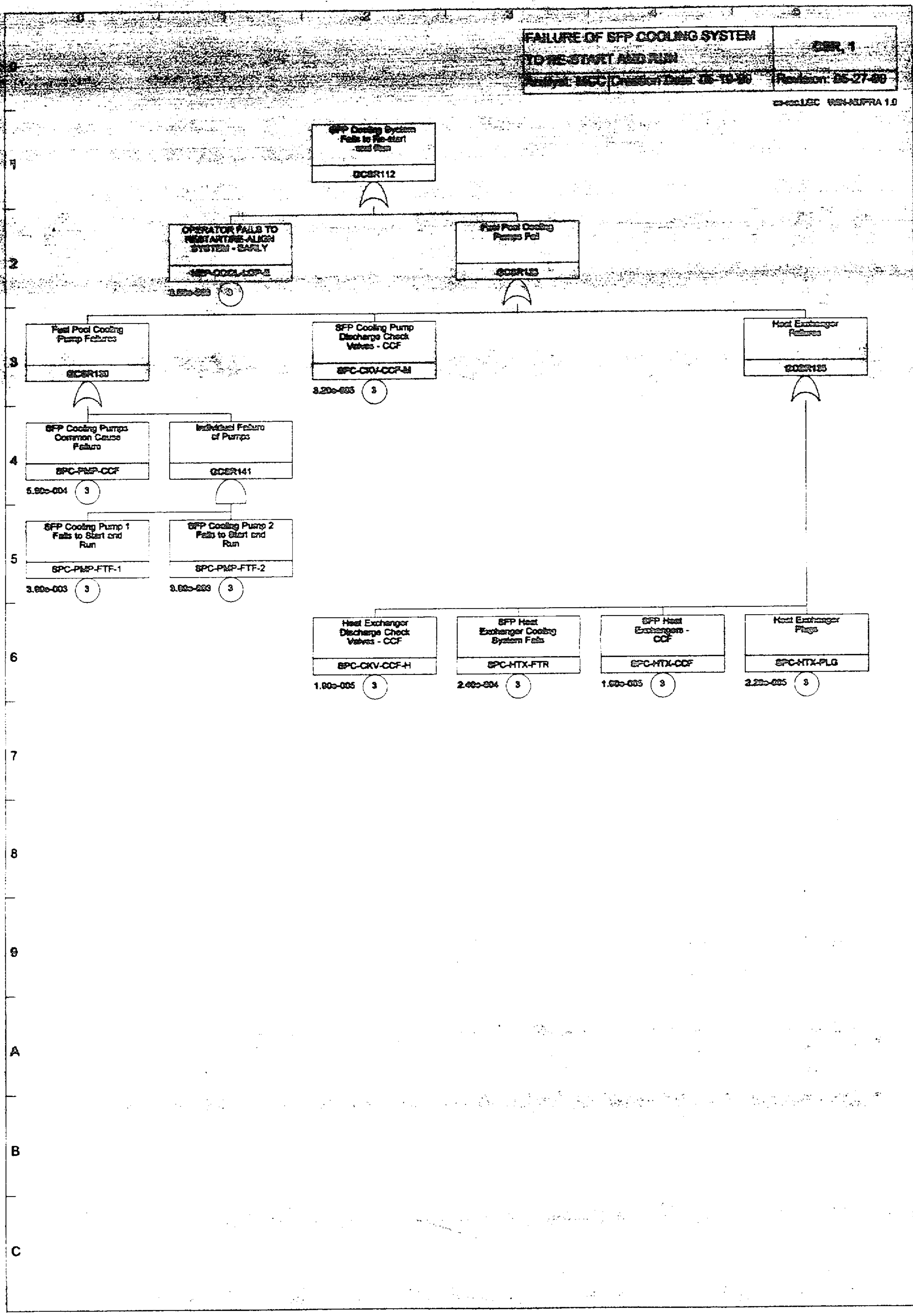
Event	Equation	Fault Tree	Comments
LOI	IE-LOI	FFT-IE	solve at gate GFFT174, single event IE-LO-POOL-INV
NLL	LOI-SML	FFT-MISC	solve at gate GFFT142, single event LOI-SMALL
CRA	CR-ALARM	CR-ALARM	solve at gate GCRA112
IND	IND-LOIL	FFT-REC	solve at gate GFFT132, single event REC-WLKDWN-LOI-L
	IND-LOIS	FFT-REC	solve at gate GFFT134, single event REC-WLKDWN-LOI-S
OIS	OIS-E	LOI-REC	solve at gate GLIR121
	OIS-L	LOI-REC	solve at gate GLIR151
OIL	OIMU	LOI-REC	solve at gate GLIR181
OMK	OMK-E	LOI-REC	solve at gate GLIR123 for Cases 1 & 2. For Case 3, use UNITY
	OMK-L	LOI-REC	solve at gate GLIR153 for Cases 1 & 2. For Case 3, use UNITY
	OMK-LOI	LOI-REC	solve at gate GLIR183 for Cases 1 & 2. For Case 3, use UNITY
OFD	REC-OSS	FFT-REC	solve at gate GFFT110, single event REC-INV-OFFSITE
	REC-OSS2	FFT-REC	solve at gate GFFT112, single event REC-INV-OFFSITE2
	REC-OSS3	FFT-REC	solve at gate GFFT114, single event REC-INV-OFFSITE3

Table B-5 - Functional Assignments for the Loss of Offsite Power (Plant Centered) Event Tree

Event	Equation	Fault Tree	Comments
LP1	IE-LP1	FFT-IE	solve at gate GFFT144, single event IE-LOOP-LP1
DG	DG-START	LOP-REC	solve at gate GLPR142 for Cases 1 & 2. For Case 3, use UNITY
OPR	REC-OSP1	FFT-REC	solve at gate GFFT170, single event REC-OSP-PC
OCS	OCSE-LOP	CS-REC	solve at gate GCSR112
OMK	OMK-FPS	LOP-REC	solve at gate GLPR112 for Cases 1 & 2. For Case 3, use UNITY
	OMK-DGFP	LOP-REC	solve at gate GLPR142 for Cases 1 & 2. For Case 3, use UNITY
	OMK-EPFP	LOP-REC	solve at gate GLPR172 for Cases 1 & 2. For Case 3, use UNITY
OFD	REC-OSS	FFT-REC	solve at gate GFFT110, single event REC-INV-OFFSITE

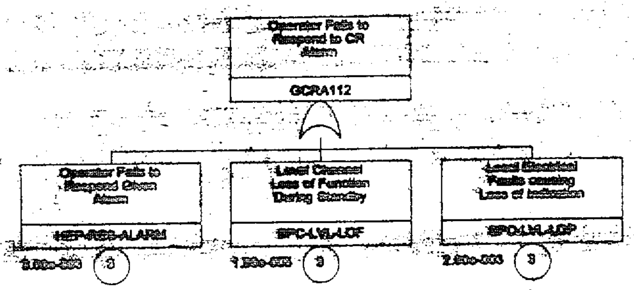
Table B-6 - Functional Assignments for the Loss of Offsite Power (Severe Weather) Event Tree

Event	Equation	Fault Tree	Comments
LP2	IE-LP2	FFT-IE	solve at gate GFFT170, single event IE-LOOP-LP2
DG	DG-START	LOP-REC	solve at gate GLPR142 for Cases 1 & 2. For Case 3, use UNITY
OPR	REC-OSP2	FFT-REC	solve at gate GFFT172, single event REC-OSP-SW
OCS	OCSE-LOP	CS-REC	solve at gate GCSR112
OMK	OMK-FPS	LOP-REC	solve at gate GLPR112 for Cases 1 & 2. For Case 3, use UNITY
	OMK-DGFP	LOP-REC	solve at gate GLPR142 for Cases 1 & 2. For Case 3, use UNITY
	OMK-EPFP	LOP-REC	solve at gate GLPR172 for Cases 1 & 2. For Case 3, use UNITY
OFD	REC-OSS	FFT-REC	solve at gate GFFT110, single event REC-INV-OFFSITE



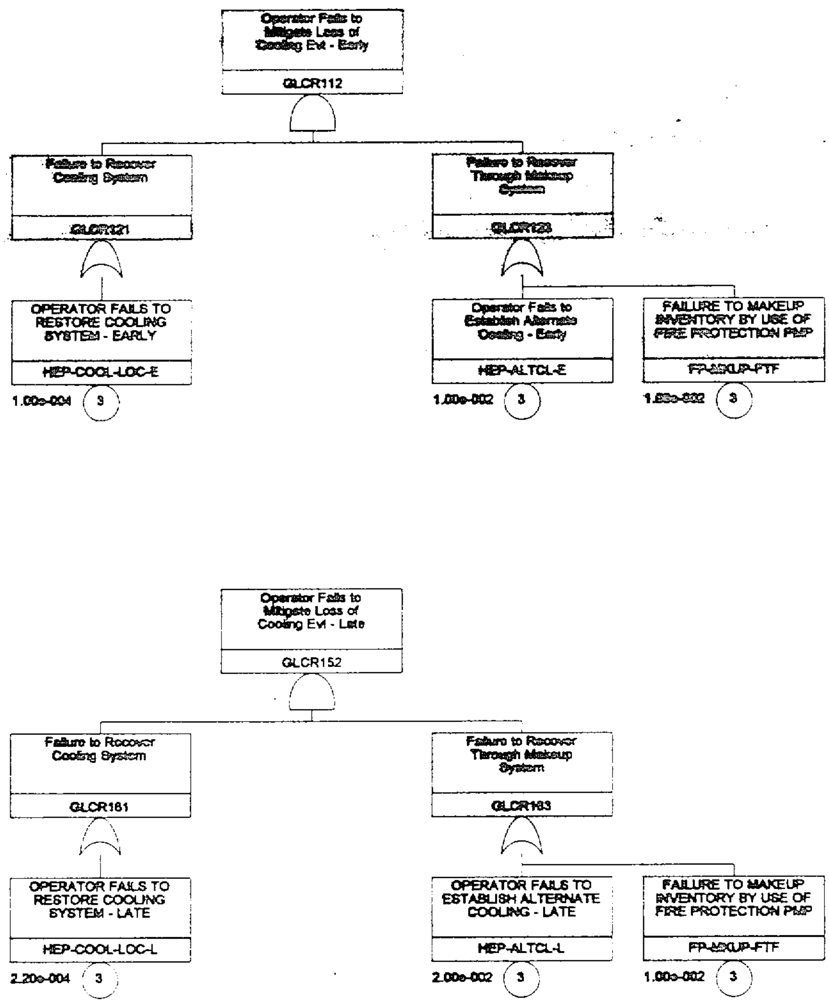
FAILURE OF SFP COOLING SYSTEM
TO RE-START AND RUN
SFP Cooling System Fails to Re-start and Run
GCSR112
OPERATOR FAILS TO RESTART/RE-ALIGN SYSTEM - EARLY
Fuel Pool Cooling Pumps Fail
Fuel Pool Cooling Pump Failures
GCSR130
SFP Cooling Pump Discharge Check Valves - CCF
SPC-CKV-CCF-M
3.20e-005
Heat Exchanger Failures
SFP Cooling Pumps Common Cause Failure
SPC-PMP-CCF
5.60e-004
Individual Failure of Pumps
GCSR141
SFP Cooling Pump 1 Fails to Start and Run
SPC-PMP-FTF-1
3.60e-003
SFP Cooling Pump 2 Fails to Start and Run
SPC-PMP-FTF-2
Heat Exchanger Discharge Check Valves - CCF
SPC-CKV-CCF-H
1.90e-005
SFP Heat Exchanger Cooling System Fails
SPC-HTX-FTR
2.40e-004
SFP Heat Exchangers - CCF
SPC-HTX-CCF
Heat Exchanger Plugs
SPC-HTX-PLG
3
1
2
4
5
6
7
8
9
A
B
C

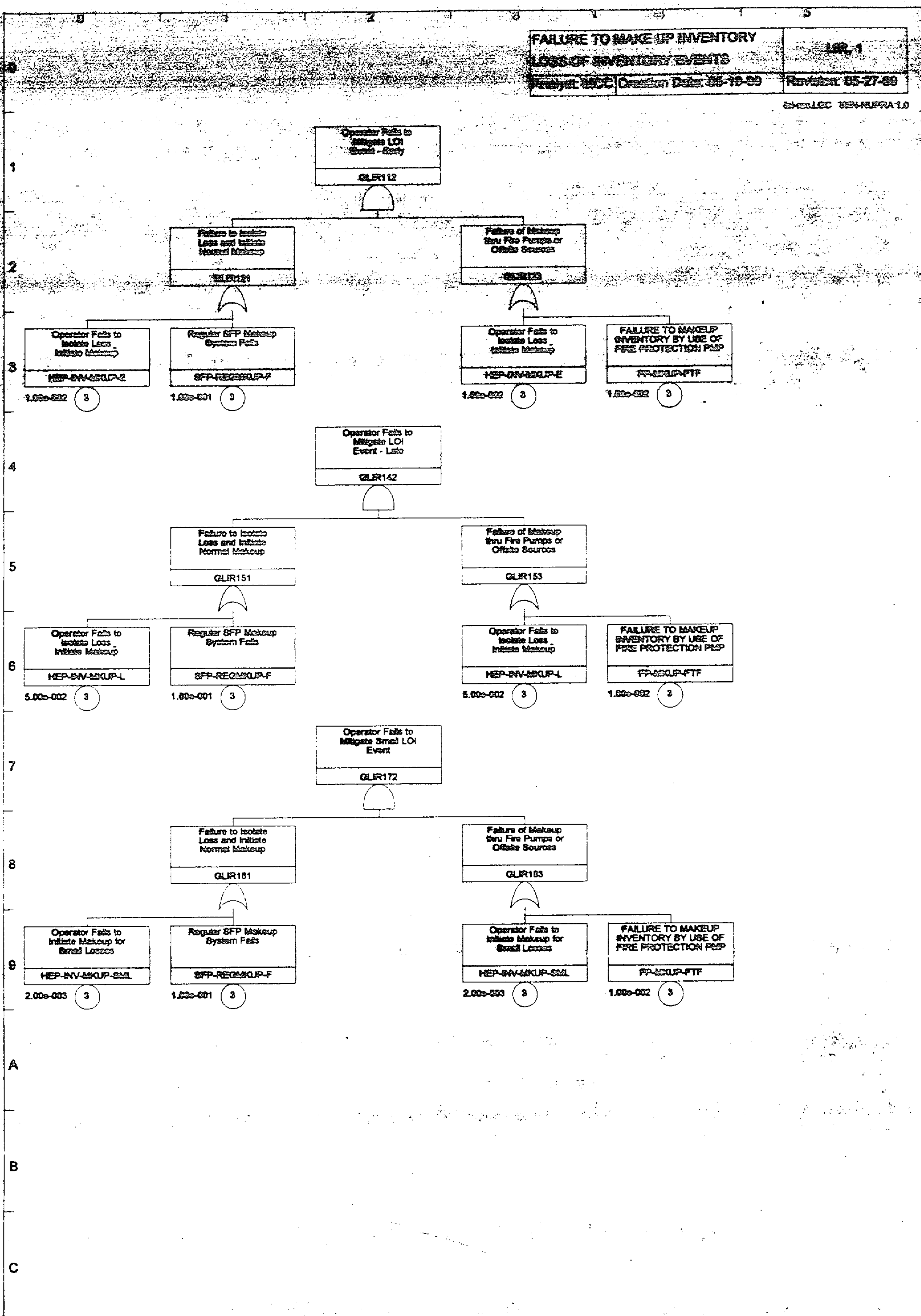
FAILURE TO RESPOND TO A CONTROL ROOM ALARM	CRA, 1
Creation Date: 05-18-99	Revision: 05-18-99



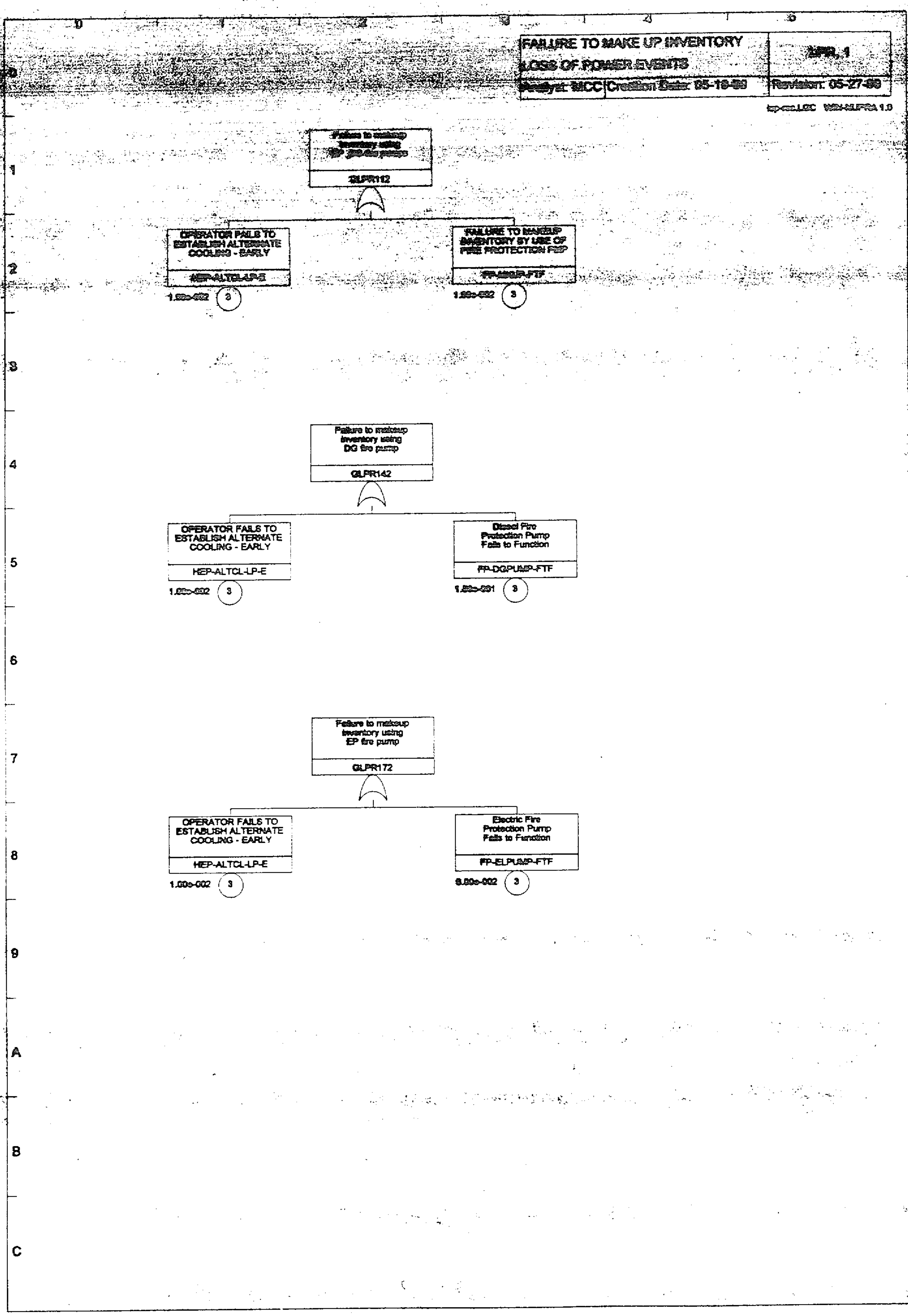
0
1
2
3
4
5
6
7
8
9
A
B
C

FAILURE TO MITIGATE LOSS OF COOLING EVENT		LCR, 1
Analyst: MCC	Creation Date: 05-18-99	Revision: 05-27-99





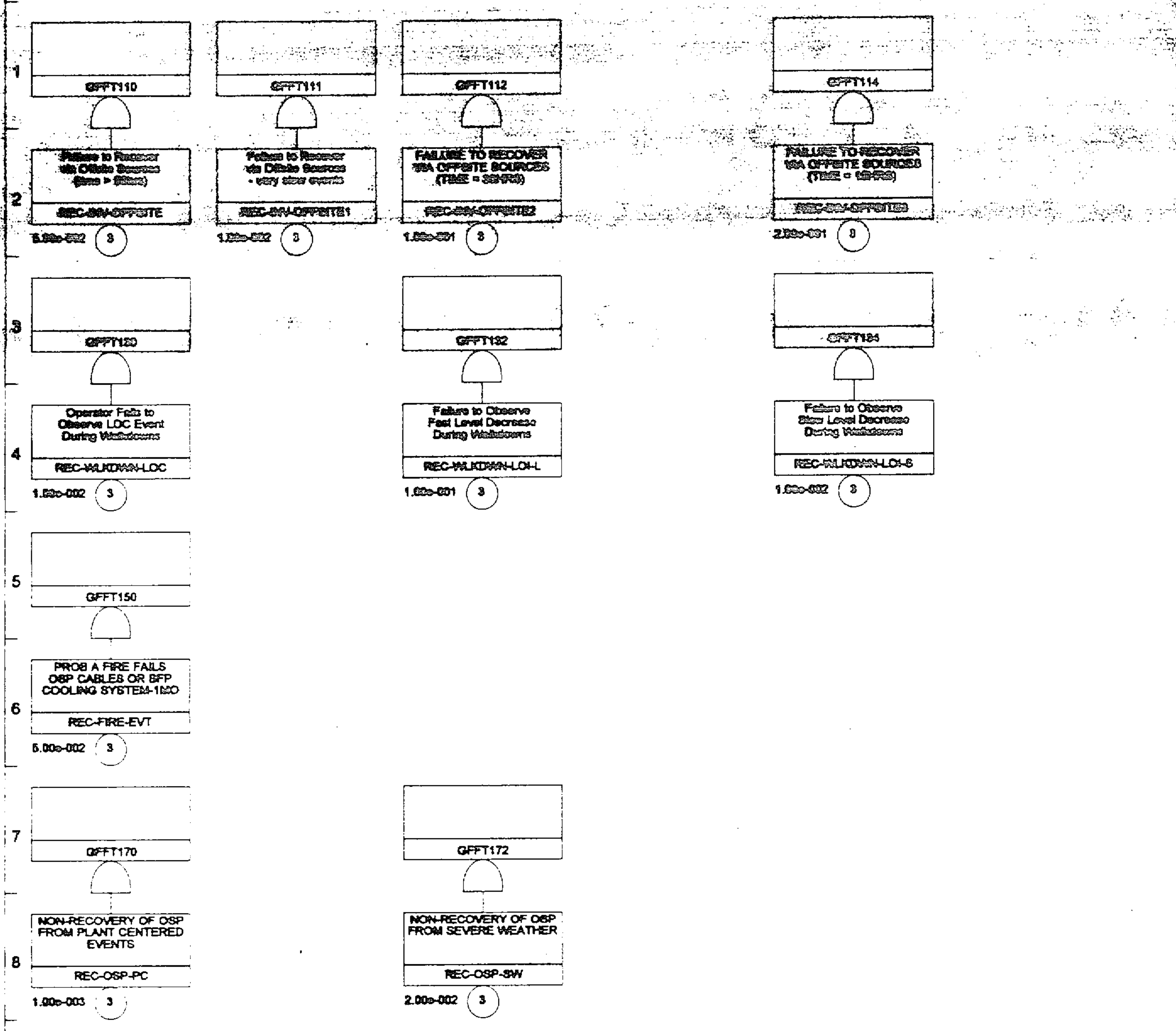
FAILURE TO MAKE UP INVENTORY
LOSS OF INVENTORY EVENTS
Analyst: MCC
Operator Fails to Mitigate LOI Event - Early
GLIR112
Failure to Isolate Loss and Initiate Normal Makeup
GLIR121
Failure of Makeup thru Fire Pumps or Offsite Sources
Operator Fails to Isolate Loss - Initiate Makeup
HEP-INV-MKUP-E
1.00e-002
Regular SFP Makeup System Fails
SFP-REGMKUP-F
1.60e-001
FAILURE TO MAKEUP INVENTORY BY USE OF FIRE PROTECTION PMP
FP-MKUP-FTF
1.00e-002
Operator Fails to Mitigate LOI Event - Late
GLIR142
Failure to Isolate Loss and Initiate Normal Makeup
GLIR151
Failure of Makeup thru Fire Pumps or Offsite Sources
GLIR153
Operator Fails to Isolate Loss - Initiate Makeup
HEP-INV-MKUP-L
5.00e-002
Regular SFP Makeup System Fails
SFP-REGMKUP-F
1.60e-001
Operator Fails to Isolate Loss - Initiate Makeup
HEP-INV-MKUP-L
5.00e-002
FAILURE TO MAKEUP INVENTORY BY USE OF FIRE PROTECTION PMP
FP-MKUP-FTF
1.00e-002
Operator Fails to Mitigate Small LOI Event
GLIR172
Failure to Isolate Loss and Initiate Normal Makeup
GLIR181
Failure of Makeup thru Fire Pumps or Offsite Sources
GLIR183
Operator Fails to Initiate Makeup for Small Losses
HEP-INV-MKUP-SML
2.00e-003
Regular SFP Makeup System Fails
SFP-REGMKUP-F
1.60e-001
Operator Fails to Initiate Makeup for Small Losses
HEP-INV-MKUP-SML
2.00e-003
FAILURE TO MAKEUP INVENTORY BY USE OF FIRE PROTECTION PMP
FP-MKUP-FTF
1.00e-002

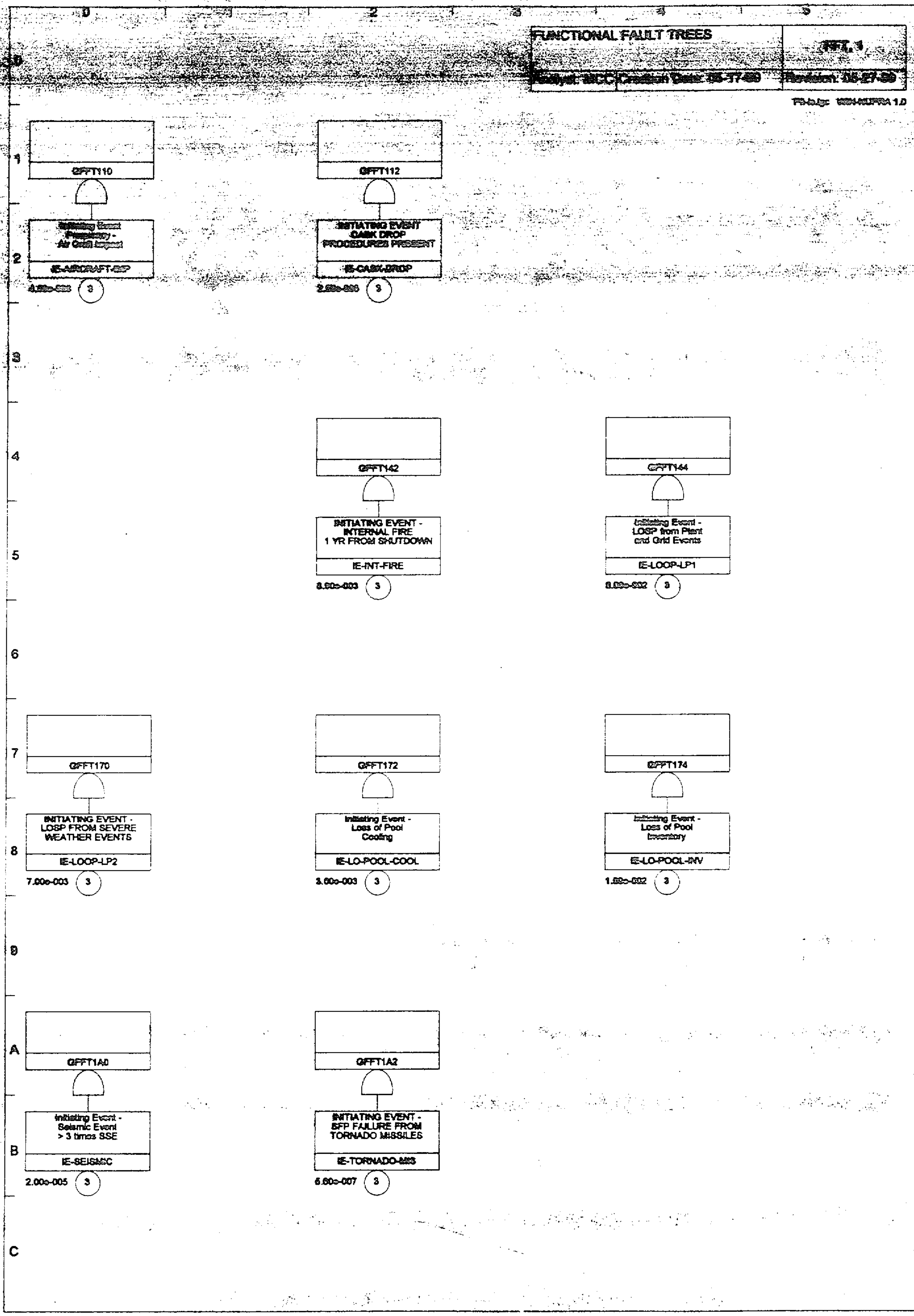

FAILURE TO MAKE UP INVENTORY
LOSS OF POWER EVENTS
Analyst: MCC
Creation Date: 05-19-99
Revision: 05-27-99
Failure to makeup
inventory using
GLPR112
OPERATOR FAILS TO ESTABLISH ALTERNATE COOLING - EARLY
FAILURE TO MAKEUP INVENTORY BY USE OF FIRE PROTECTION FSP
Failure to makeup inventory using DG fire pump
GLPR142
OPERATOR FAILS TO ESTABLISH ALTERNATE COOLING - EARLY
HEP-ALTCL-LP-E
Diesel Fire Protection Pump Fails to Function
FP-DGPUMP-FTF
Failure to makeup inventory using EP fire pump
GLPR172
OPERATOR FAILS TO ESTABLISH ALTERNATE COOLING - EARLY
HEP-ALTCL-LP-E
1.00e-002
Electric Fire Protection Pump Fails to Function
FP-ELPUMP-FTF
8.80e-002

FUNCTIONAL FAULT TREE

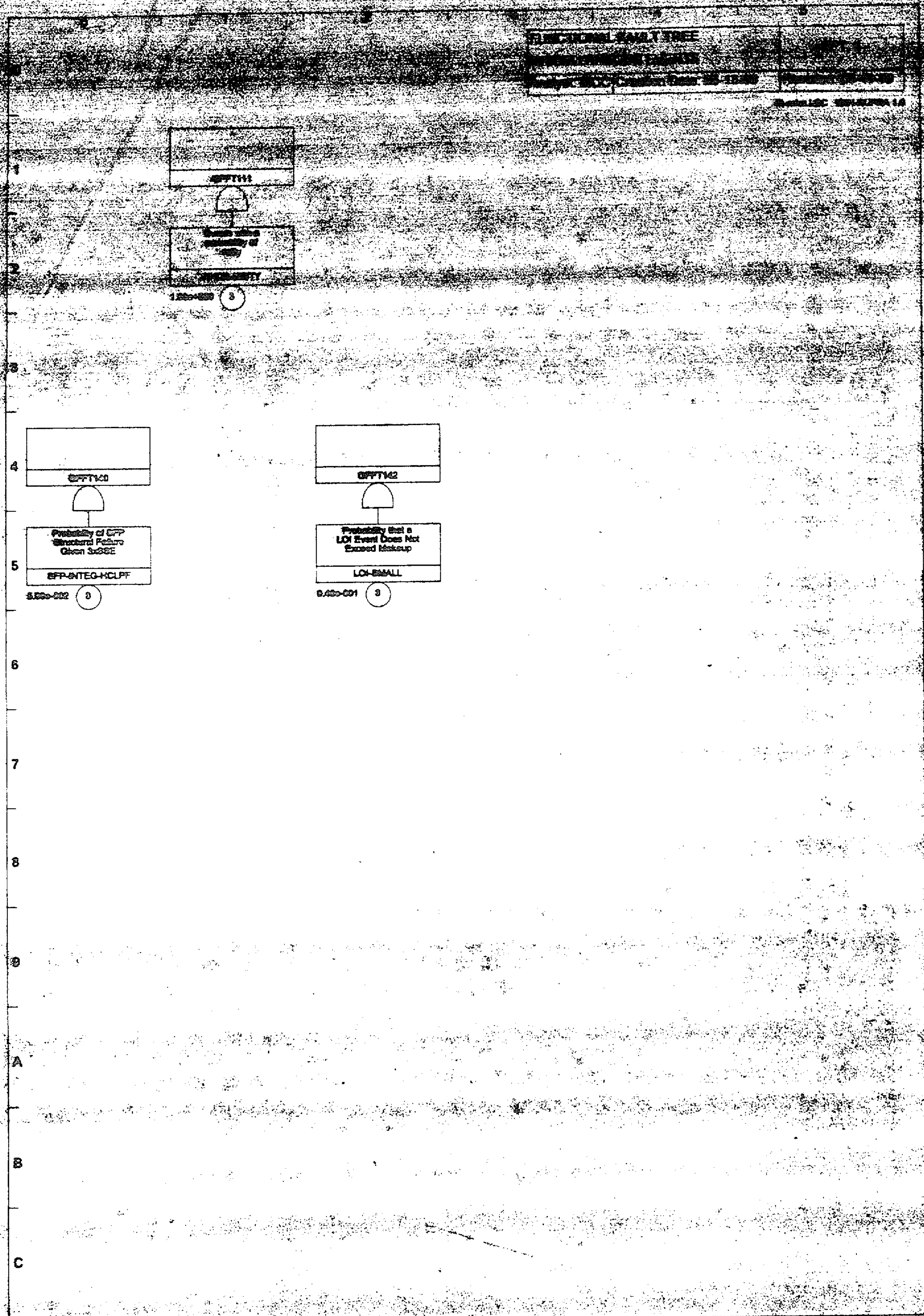
RECOVERY EVENTS

FFT_1





FUNCTIONAL FAULT TREES
Creation Date: 05-17-99
GFFT110
Air Craft Impact
IE-AIRCRAFT-SSP
3
GFFT112
INITIATING EVENT
CASK DROP
PROCEDURES PRESENT
IE-CASK-DROP
3
GFFT142
INITIATING EVENT -
INTERNAL FIRE
1 YR FROM SHUTDOWN
IE-INT-FIRE
3
GFFT144
Initiating Event -
LOSP from Plant
and Grid Events
IE-LOOP-LP1
3
GFFT170
INITIATING EVENT -
LOSP FROM SEVERE
WEATHER EVENTS
IE-LOOP-LP2
7.00e-003
3
GFFT172
Initiating Event -
Loss of Pool
Cooling
IE-LO-POOL-COOL
3.00e-003
3
GFFT174
Initiating Event -
Loss of Pool
Inventory
IE-LO-POOL-INV
3
GFFT1A0
Initiating Event -
Seismic Event
> 3 times SSE
IE-SEISMIC
2.00e-005
3
GFFT1A2
INITIATING EVENT -
SFP FAILURE FROM
TORNADO MISSILES
IE-TORNADO-MIS
3



GFFT140
Given 3xSSE
GFFT142
Probability that a
LOI Event Does Not
Exceed Makeup
LOI-SMALL