Discussed w/ Soli 11/15/99

1. Loss of Cooling Event Tree

1.1. Initiating Event LOC – Loss of Cooling

1.1.1. Event Description and Timing

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

1.1.2. Relevant Assumptions

None.

1.1.3. Quantification

The NRC draft report uses an initiation frequency of 3.0E-3/yr taken from NUREG-1275, "Operating Experience Feedback Report - Assessment of Spent Fuel Cooling." This represents loss of cooling events in which temperatures rose more than 20°F, and which resulted from failures of pumps, valves, piping, or from loss of heat sink (heat exchangers), or from local losses of power (e.g., electrical connections).

1.1.4. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
IE-LO-POOL-COOL	—	3.0E-3

Need to define basic events

1.2. Top Event CRA – Control Room Alarms

1.2.1. Event Description and Timing

This event represents the probability that control room instrumentation will fail to alarm given that SFP cooling has been lost, or that the operator fails to respond to that alarm. The proper conditions for an alarm are assumed to exist within the first 8 to 12 hours of the loss of cooling (i.e., one shift). Failure could be due to operator error (failure to respond), failure of the signal channel, or loss of indication due to electrical faults.

1.2.2. Relevant Assumptions

- The SFP has at least one temperature monitor, with either direct indication or a trouble light in the control room (there could also be indications or alarms associated with pump flow and pressure)
- Within 8 to 12 hours of the loss of cooling, one or more of these alarms or indications will reflect an out-of-tolerance condition to the operators in the control room (there may be level indication available locally or remotely, but any change in level is not likely to be significant until later in the sequence of events)

2.0.1. Quantification

Human Error Probabilities

One operator failure is modeled under this top event. The operator may fail to respond to a signal or indication in the control room. Such a signal would likely be the first indication of trouble, so the operator would not be under any heightened state of alertness. On the other hand, it is not likely that any other signals or alarms for any other conditions would be present to distract the operator. The probability of operator failure was taken from WSRC-TR-93-581 (3.0E-3).

Probability from Harold...

483

Non-HEP Probabilities

Failure of the alarm channel was taken from NUREG-1740 (1.0E-5). The value used for local electrical faults leading to alarm channel failure was estimated based on information in NUREG-1275, Volume 12 (2.0E-3).

Conclusion

The draft report modeled this event with fault tree GCRA112. The result of the fault tree quantification is 5.0E-3.

2.0.2. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
HEP-RES-ALARM	—	3.0E-3
SPC-LVL-LOF	—	1.0E-5
SPC-LVL-LOP	—	2.0E-3

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

2.1.1. Event Description and Timing

This top event models the probability that the operators fail to recognize the loss of cooling during walkdowns over multiple shifts. Indications available to the operator during a walkdown include high area temperature and humidity, low water level from boil-off, and local alarms. After pool heatup begins, the operator has more than 10 shifts (about 128 hours) to discover the loss of SFP cooling.

2.1.2. Relevant Assumptions

- Operators perform walkdowns once per shift (every 8 to 12 hours)
- The loss of cooling may not be noticeable during the first two shifts (this is conservative because conditions are assumed to be sufficient to trigger local and control room alarms)
- After bulk boiling begins, level changes in the SFP will be indicated on a large, graduated level indicator in the pool
- About 128 hours are available to recover from the initiating event before water level reaches 3 ft above the fuel

4.0.1. Quantification

Human Error Probabilities

This top event is modeled by a single HEP. At this point in the event tree, the control room alarms have failed, or the operator has failed to recognize their importance. The operator then fails to observe the loss of cooling during subsequent walkdowns. Note that during the first two or three shifts, water level may not drop significantly. After two shifts, however, the environment in the pool area would be hot and humid. After pool heatup begins, operator has more than 10 shifts (about 128 hours) to discover the loss of SFP cooling.

In the NRC Draft report, the top event probability was based on a failure rate taken from WSRC-TR-93-581 (Table 4, number 31), which represents a failure to observe something very small (e.g., looking through a camera or periscope). In reality, however, this event represents an observation that is easy to perform for characteristics that are readily observable. Based on the detailed definition of the events provided in Table 1 of the reference, a more appropriate human error event would be "Incorrect reading or recording data" (Table 4, number 11).

Probability from Harold...

Let us assume that that loss of cooling occurs just before the first operator makes his visit toward the end of his shift. Also assume that the next shift operator makes a round immediately after his shift starts. In this scenario, there is a chance that the operators may not notice the pool level dropping for the first two to three shifts. Therefore, the operators' failure to notice the loss of cooling would be 5.0E-1 (Table 4, number 11, "poor display"). However, this probability is for only one observation, not multiple observations by different people. By the time the fourth shift operator made his round there would be bulk boiling, which would create high temperatures and humidity, providing good indication of pool heatup. Therefore, the fourth operator's failure to notice the loss of cooling would be 3.0E-3 (Table 4, number 11, "excellent display"). Again, this is for only one observation, not multiple observations by different people. Also note that no credit is taken for the closed circuit monitor located in the control room.

The possibility of the operators missing their assigned shift walkdown was considered. A simple event tree was built wherein five shifts were modeled by asking whether each shift performed its round, and if so, whether the observation was successful (i.e., discovered the loss of cooling condition). The probability of missing a round was assigned a value of 0.1. In the first three rounds, the probability of failing to observe the pool's condition was assigned a value of 0.5, while the last two rounds received a probability of 3.0E-3. The resulting probability of failure was 2.29E-3.

That simple analysis assumed that the probability of failing to carry out a walkdown was truly independent. It could be argued, however, that the operating cultural environment of the facility might be such that it has become a habit to miss walkdowns. If we assume that the probability is 1.0E-3 that conditions could deteriorate to that point, then the overall probability would be slightly less than 3.29E-3.

Therefore, we have used a value of 3.0E-3 to represent the probability of multiple failures over multiple shifts.

4.0.2. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
REC-WLKDWN-LOC	3.0E-3	1.0E-2

4.1. Top Event OCS – Operator Recovery of Cooling System

4.1.1. Event Description and Timing

Once the loss of cooling has been recognized, either by control room alarms or by walkdowns, the operators will likely focus their attention on repair of the cooling system. It is only after bulk boiling begins and the water level drops below the cooling system suction that the operator will consider injection of water from other makeup systems (e.g., firewater). Therefore, the time available to recover the SFP cooling system could be as long as 43 hours (see Section 2.5.1). However, to be conservative, we have assumed that the operator has only until bulk boiling begins (33 hours) to restore the SFP cooling system. This assumption eliminates the requirement to model the SFP makeup system for this event tree, and it also eliminates any concerns about inventory swell or whether the makeup system capacity is sufficient to overcome the boil-off rate.

If the loss of cooling was detected via the control room alarms, the operator has the full 33 hours in which to repair the system. If discovered during walkdowns, we've assumed he has only 9 hours available (33 hours less 24 hours before loss of cooling was noticed).

4.1.2. Relevant Assumptions

- We assume that the operator will not use alternate systems (e.g., firewater) until after bulk boiling begins and the level drops to below the suction of the cooling system
- Time to bulk boiling is 33 hours from the time cooling is lost
- The boil-off rate is 0.2 ft/hr

- If the loss of cooling was detected through shift walkdowns, then we assume 24 hours has passed before discovery
- Mean time to repair for the SFP cooling system was assumed to be 10 hours basis —

5.0.1. Quantification

Human Error Probabilities

In the case when the operator action is initiated by control room alarms, the time available is 33 hours. Therefore, the probability of failure, given a 10-hour mean time to repair, is as follows:

?

In the case when discovery was due to operator walkdown, the probability is as follows:

5.0.2. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
HEP-COOL-LOC-E	3.7E-2	1.0E-4
HEP-COOL-LOC-L	4.1E-1	2.2E-4

5.1. Top Event OFD - Operator Recovery Using Onsite Sources

5.1.1. Event Description and Timing

At this point in the event tree, the operator has discovered the loss of cooling, but has been unable to restore the SFP cooling system to operation. After 43 hours, the level of the pool has dropped below the suction of the SFP cooling system (see below), so that repair of that system will not have any effect until pool level is restored. The operator now has 85 hours to provide some form of external makeup to the pool to prevent fuel uncovery (128 hours less 43 hours). This event represents failure of the operator to start a firewater pump and provide makeup to the SFP. He has both electric- and diesel-driven firewater pumps available to perform this function. Furthermore, given failure of both pumps, the operator has time to attempt repair of one of the pumps.

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

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

5.1.2. Relevant Assumptions

- The operator has 128 hours from the onset of the initiator to provide makeup and inventory cooling
- The operator will not attempt to use firewater until after bulk boiling begins and the level drops to below the suction of the cooling system, which occurs at about 43 hours because
- The suction of the cooling system is 2 ft below the nominal pool level

- The operator must travel to the firewater pumps to start them locally
- Firewater pumps are maintained on a regular schedule
- There is a means of fixing a fire hose in place, so that the operator is not required to stand in a hot, humid, and possibly radiologically hazardous area for the period of time required to refill the SFP

6.0.1. Quantification

Human Error Probabilities

The operator was unable to fix the SFPC system within the first 43 hours. He must diagnose the need for alternate makeup, and then successfully start a firewater pump and provide alignment to the SFP. The fault tree used to quantify this top event includes both the following operator actions:

> The operator fails to recognize the need to start a firewater pump within 85 hours after the onset of bulk boiling
>
> The operator fails to start the electric or diesel firewater pump within 85 hours after the onset of bulk boiling, given that the decision to start a firewater pump was made. No difficult valve alignment is required, but the operator may have to position a hose in the pool area.

Probability from Harold...

Non-HEP Probabilities

The failure probability used for electric pump failure to start and run in the NRC Draft report seemed low (its unavailability was 6.0E-2). The pump may be required to run 8 to 10 hours at the most, given that the water inventory drops by 20 ft (i.e., 3 ft from the top of the fuel). We recommend 3.7E-3 for failure to start and run for 24 hours (from INEL-96/0334).

Further, the possibility of repair of one pump has been added to the model. If the operator starts the electric firewater pump after 43 hours but the pump fails to start and run (with a probability of 1.1E-3), then the operator would try to start the diesel-driven firewater pump. If it also failed (with a probability of 0.18), then the operator would try to get one of the pumps repaired. We conservatively assume that the operator will focus his recovery efforts on only one pump. Assuming that it takes another two shifts (16 hours) before parts and technical help arrive, then the operator has 69 hours (85 hours less 16 hours) to repair the pump. Assuming a 10-hour mean time to repair, the probability of failure to repair the pump would be $\text{Exp}\,[-(1/10) \times 69] = 1.0\text{E-}3$. Therefore, the unavailability of both firewater pumps would be $3.7\text{E-}3 \times 0.18 \times 1.0\text{E-}3 = 6.7\text{E-}7$.

Conclusion

Fault tree GLPR112 was used to quantify this top event. The hardware failure probability is dominated by the operator's failure to diagnose or successfully start and align a firewater pump. The total...

6.0.2. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
HEP-COOL-LOC-E		1.0E-4
HEP-ALTCL-E		1.0E-2
FP-MKUP-FTF	6.7E-7	1.0E-2

6.1. Top Event OFB – Operator Recovery Using Offsite Sources

6.1.1. Event Description and Timing

Given the failure of recovery actions using onsite sources, this event accounts for recovery of coolant makeup using offsite sources such as procurement of a fire engine. Adequate time is available for this action, provided that the operator recognizes that recovery of cooling using onsite sources will not be successful, and that offsite sources are the only viable alternatives.

6.1.2. Relevant Assumptions

- The operator has 128 hours from the onset of the initiator to provide makeup and inventory cooling
- He has failed to restore the SFP cooling system, and has attempted to start both firewater pumps
- He has sufficient time to recognize the need for external sources of makeup.

3.0.1. Quantification

Human Error Probabilities

The operator must recognize that extreme measures must be taken to provide makeup to the SFP. He has had ample time up to this point to attempt recovery of both the SFP cooling system and both firewater pumps. Due to the complexity of this diagnosis, and the uncertainty involved in estimating the remaining time and offsite resources available, this operator action has been given a screening value of 0.01. A sensitivity study will be performed to determine the need for further refinement of this quantification.

3.0.2. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
REC-INV-OFFSITE1	—	1.0E-2

4. Internal Fire Event Tree

4.1. Initiating Event FIR - Internal Fire

4.1.1. Event Description and Timing

The fire initiator includes those fires of sufficient magnitude or location to cause a loss of cooling to the SFP. It is similar to the Loss of Cooling event tree, except for some differences listed in the following section.

4.1.2. Relevant Assumptions

- The operator has discovered the fire in time to attempt suppression and prevent loss of cooling to the SFP
- recovery of the SFP cooling system is not possible if fire suppression efforts fail
- the motor-driven firewater pump is assumed to be unavailable due to the fire

2.0.1. Quantification

The NRC draft report estimates the fire initiating event frequency using EPRI's Fire-Induced Vulnerability Evaluation (FIVE) document (EPRI TR-100370 dated April 1992). The NRC draft report uses 9.0E-3/yr, which is the result derived for two areas analyzed in the EPRI report: intake structures and radwaste areas.

Activities in radwaste areas during normal operation are not expected to be similar to the activities in a fuel handling building of decommissioned plant. During normal operation, a large amount of transient combustibles (i.e., oil, flammable chemicals, etc.) would be present in a radwaste area. Note that fuel for a diesel ~~fire pump in~~ a fuel handling building would not be considered as a transient combustible because it is stored ~~in an~~ appropriate fuel tank.

outside

Fire initiators in intake structures are divided into fires initiated by pumps, electrical cabinets, and "other." This analysis will derive an overall fire initiation frequency from the contribution of pumps and electrical cabinets.

Frequencies for the different buildings listed in the EPRI report are based on the average loading in each building. For example, the pump fire frequency for an intake building is based on factors such as the total number of operating pumps in the building, and on a severity factor, which is a measure of the potential of a fire to spread. The severity factor depends on the surroundings, housekeeping, and presence of other combustible loads. Both of these factors could be significantly different for a SFP facility.

The EPRI report gives a frequency of 4.0E-3/yr for pump fires in an intake structure. That estimate is based on pumps that require lubrication (lubrication fluid is the source of most pump fires). Further, the EPRI report assumes that four pumps are running in the intake building. The EPRI report also uses a severity factor of 0.2. Using this information, we can estimate a single pump fire frequency by dividing the given pump fire frequency by the number of pumps and the severity factor; i.e., 4.0E-3/(4 × 0.2) = 5E-3/yr.

For this analysis, we assume that the cooling system includes one SFP pump and one heat exchanger pump, both rated 480 volts. (In normal operating plants, SFP cooling pumps are 480 volts.) For 480-volt pumps with no significant combustibles (no oil reservoir or large amount of lubricant), the severity factor would be smaller than 0.2. The EPRI analysis assumed the severity factor for smaller pumps was small enough to be negligible. However, in the case of the SFP facility, the existence of a diesel pump in a close proximity and the potential for poor housekeeping could result in a potential for fire to spread. Therefore, assuming a severity factor of 0.01, the contribution of pumps to the facility fire frequency is 2 × 5E-3/yr × 0.01 = 1.0E-4/yr.

Note that the pump failure to run probability includes a contribution from localized pump fire and is included in of the loss of SFP cooling initiating event.

Similarly, the contribution of electrical cabinets to the facility fire frequency is based on the total number of cabinets. The EPRI ignition frequency of 2.4E-3/yr for electrical cabinets in the intake structure is based on 480-volt and higher cabinets. Note that probability of the SFP cooling system being an ignition source is less likely because it does not draw much load. Also, most intake structures have a minimum of ten cabinets (based on discussions with a former operator and an NRC examiner). Assuming there are two 480-volt cabinets supplying power to the SFP cooling components, and that the severity factor does not change, the contribution of electrical cabinets to the facility fire initiation frequency would be 2 × (2.4E-3/yr)/10 = 4.8E-4/yr.

Therefore, the total frequency for fires from both pumps and electrical cabinets is 5.8E-4/yr.

2.0.2. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
IE-INT-FIRE	5.8E-4	9.0E-3

2.1. Top Event OSP - Fire Suppression

2.1.1. Event Description and Timing

This top event represents failure to suppress the fire before the SFP cooling system is damaged. There is an underlying assumption that if the fire is not suppressed then the SFP cooling and makeup system pumps and their power supplies are damaged to a point that they can not be repaired in time to prevent fuel uncovery. If the fire is suppressed in time then SFP cooling system will be restored in time.

2.1.2. Relevant Assumptions

- The operator has discovered the fire in time to prevent loss of cooling to the SFP

- If suppression efforts fail, recovery of the SFP cooling system is not possible
- A damage time of 20 minutes is assumed; that is, it is assumed that it will take at least 20 minutes before a fire will either fail both of the cooling pumps or fail power to the pumps

3.0.1. Quantification

The probability of fire suppression is obtained from EPRI report NSAC-181, "Fire Requantification Studies," dated March 1993. That report gives the probabilities of failing to suppress a fire for three damage times as follows:

Probability of Failure of Fire Suppression (from NSAC-181)

Damage Time	Automatic Actuation	Manual Recovery	Manual Suppression	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, "Fire Protection Program for Nuclear Power Plants During Decommissioning and Permanent Shutdown," dated July 1998). 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 the presence of openings in the room. Because 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 because typical SFP facilities are relatively large and because equipment within such facilities is usually spread out. That is, it is assumed that it will take at least 20 minutes before a fire will either fail both of the cooling pumps or fail offsite power feed to the pumps. Therefore, from the table, 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, so 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.

3.0.2. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
REC-FIRE-EVT	—	5.0E-2

3.1. Top Event OMK - Operator Recovery Using Onsite Sources

3.1.1. Event Description and Timing

At this point in the event tree, the SFP has lost cooling because of the fire, and the operator is unable to restore the SFP cooling system. Also, the fire has damaged the electrical system such that the motor-driven firewater pump is unavailable. The operator now has 128 hours to provide some form of external makeup to the pool to prevent fuel uncovery. This event represents failure of the operator to start the diesel-driven firewater pump and provide makeup to the SFP. If the diesel firewater pump fails, the operator has time to attempt repair.

Refilling time is estimated to be more than 2 ft/hr for a 250-gpm capacity pump (1 ft/hr for a 100-gpm capacity pump).

NACOLA12

3.1.2. Relevant Assumptions

- The operator has 128 hours from the failure of the SFP cooling system to provide makeup and inventory cooling
- The fire damage time is assumed to be about 20 minutes
- The operator must travel to the firewater pump to start it locally
- Firewater pumps are maintained on a regular schedule
- There is a means of fixing a fire hose in place, so that the operator is not required to stand in a hot, humid, and possibly radiologically hazardous area for the period of time required to refill the SFP

5.0.1. Quantification

Human Error Probabilities

In the NRC draft report, this top event is quantified using basic event HEP-ALTCL-LP-E, which represents a human error probability. The draft report used a value of 0.01based on basic event ALT-XHE-XM-SFP in INEEL-96/0334. However, the HEPs in INEEL-96/0334 represent very different conditions than those in this analysis. First, INEEL-96/0334 only considered the time available until the initiation of bulk boiling. In the case of ALT-XHE-XM-SFP, less than 8 hours were assumed to be available for operator action. Also, the operator was required to restore the cooling using alternate methods or sources that were not identified in procedures. Finally, the events described in INEEL-96/0334 involved conditions at an operating plant, where there may be additional demands on an operator's attention. For these reasons, the use of data from INEEL-96/0334 is not warranted.

Given that the fire disables the SFPC system early in the sequence, the operator must diagnose the need for alternate makeup, and then successfully start the diesel firewater pump and provide alignment to the SFP. The fault tree used to quantify this top event includes both the following operator actions:

> The operator fails to recognize the need to start a firewater pump within 85 hours after the onset of bulk boiling
>
> The operator fails to start the electric or diesel firewater pump within 85 hours after the onset of bulk boiling, given that the decision to start a firewater pump was made. No difficult valve alignment is required, but the operator may have to position a hose in the pool area.

Note that in the case of a fire, the operator would likely have more than 85 hours available; however, These HEPs were quantified for the Loss of Cooling event tree, where initial recovery of the SFP cooling system was assumed to be possible, and thus the time available to the operator for supplying firewater to the pool is shortened. It is slightly conservative to use the same HEPs in this event tree, but not excessively so. This quantification can be reviewed if sequence results prove to be higher than reasonable.

Probability from Harold...

Non-HEP Probabilities

The possibility of repair of the diesel pump has been added to the model. If the diesel firewater pump fails to start and run (with a probability of 0.18), then the operator would try to repair it. Assuming that it takes another two shifts (16 hours) before parts and technical help arrive, then the operator has 112 hours (128 hours less 16 hours) to repair the pump. Assuming a 10-hour mean time to repair, the probability of failure to repair the pump would be Exp [-(1/10) × 112] = 1.4E-5. Therefore, the unavailability of the diesel firewater pump would be 0.18 × 1.4E-5 = 2.5E-6.

Conclusion

Fault tree GLPR142 was used to quantify this top event. The hardware failure probability is dominated by the operator's failure to diagnose or successfully start and align the diesel-driven firewater pump. The total...

5.0.2. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
HEP-ALTCL-LP-E		1.0E-2
FP-DGPUMP-FTF	2.5E-6	1.8E-1

5.1. Top Event OFD - Operator Recovery Using Offsite Sources

5.1.1. Event Description and Timing

Given the failure of recovery actions using onsite sources, this event accounts for recovery of coolant makeup using offsite sources such as procurement of a fire engine. Adequate time is available for this action, provided that the operator recognizes that recovery of cooling using onsite sources will not be successful, and that offsite sources are the only viable alternatives.

5.1.2. Relevant Assumptions

- The operator has 128 hours from the onset of the initiator to provide makeup and inventory cooling
- The SFP cooling system and the electric firewater pump were damaged in the fire, and the operator has attempted to start the diesel firewater pump
- He has sufficient time to recognize the need for external sources of makeup

3.0.1. Quantification

Human Error Probabilities

The operator must recognize that extreme measures must be taken to provide makeup to the SFP. He has had ample time up to this point to attempt recovery of the diesel firewater pump. Due to the complexity of this diagnosis, and the uncertainty involved in estimating the remaining time and offsite resources available, this operator action has been given a screening value of 0.01. A sensitivity study will be performed to determine the need for further refinement of this quantification.

3.0.2. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
REC-INV-OFFSITE1	—	1.0E-2

4. Plant-centered and Grid-related Loss of Offsite Power Event Tree

This event tree represents the loss of SFP cooling resulting from a loss of offsite power from plant-centered and grid-related events. Until offsite power is recovered, the electrical pumps would be unavailable, and only the diesel fire pump would be available to provide makeup. The order of the top events has been modified when compared to the NRC draft report to represent the expected sequence of events (i.e., given a LOSP event, the first thing operator would do is to attempt to recover power), and to evaluate properly the dependency between operator errors.

4.1. Initiating Event LP1 - Plant-centered and Grid-related Loss of Offsite Power

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. The NRC draft report uses a LOSP frequency of 0.08/yr for plant-centered events (taken from

INEL-96/0334), and 1.9E-3/yr for grid-related events (taken from NUREG/CR-5496). For the purpose of this analysis, the LOSP IE frequency from plant-centered and grid-related events is assigned a value of 0.08/yr.

4.2. Top Event OPR – Offsite Power Recovery

4.2.1. Event Description and Timing

This top event is a single basic event that represents the non-recovery probability of offsite power. The draft report assumes that if the power is not recovered in first 50 hours, the probability of recovering offsite power in 128 hours is negligible.

Baranowsky (1988) classified LOSP events into plant-centered, grid-related, and severe-weather-related categories, because these categories involved different mechanisms and also seemed to have different recovery times. Similarly, NUREG/CE-5496 divides LOSPs into three categories and estimates different values of non-recovery as functions of time. For the purpose of this analysis, a weighted non-recovery probability is used.

4.2.2. Relevant Assumptions

If power is not recovered within the first 33 hours, it is assumed that problem is significant and the probability of recovering power within 128 hours is very small.

4.2.3. Quantification

<u>Non-HEP Probabilities</u>

Based on the ORNL/NRC/LTR-89/11 ASP analysis for plant-centered LOSP events, the non-recovery probability within 24 hours is less than 1.0E-5. In the case of grid-related LOSP events, the non-recovery probability within 24 hours is 1.0E-3. Therefore, the weighted non-recovery probability of offsite power, from both plant-centered and grid-related events is as follows:

The draft report provides only one estimate (1.0E-3) for non-recovery of power for more than 50 hours (derived from NUREG/CR-5032).

4.2.4. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
REC-OSP-PC	3.3E-5	1.0E-3

4.3. Top Event OCS - Cooling System Restart and Run

4.3.1. Event Description and Timing

This top event represents restarting the SFP cooling system, given that offsite power has been recovered within 24 hours. There are two electrically operated pumps and the operator can start either one. If the operator starts the pump that was in operation, no valve alignment would be required. However, if operator starts the standby pump, some valve alignment may be required.

The top event has several basic events: one operator error to establish SFP cooling, and several hardware failures of the system. This top event is dominated by the operator error to restart/realign the SFP cooling system. If power is recovered within 24 hours, the operator has 9 hours to start the system before boil-off starts. If he fails to initiate SFP cooling before boil-off begins, the operator must start a firewater pump to provide makeup.

4.3.2. Relevant Assumptions

- Operator has 9 hours to start the SFP cooling system (this is equivalent to the conservative assumption that offsite power is recovered at exactly 24 hours).
- Task completion time 1 hour
- Well-written procedures exist
- Operator has received the necessary training
- Potential harsh environment (hot and humid)

5.0.1. Quantification

Human Error Probability

One operator error is modeled under this top event. In the Draft report, a probability of 3.5E-3 was assigned to the operator error to restart/realign the SFP cooling system, based on event SFP-XHE-XE-LP from INEL-96/0334. This event represents operator failure to restart/realign the SFP cooling system in 9 hours given that power is recovered.

Human error probability: from Harold

Operator can restart the previously running pump and may not have to make any valve alignment. If he decides to restart standby pump he may have to make some valve alignment.

Non-HEP Probabilities

In the NRC draft report, a probability of 9.4E-4 was estimated for the hardware failures of the system. If the system fails to start and run for a few hours then the operator would try to get the system repaired. Assuming that it takes another two shifts (16 hours) to contact maintenance personnel, make a diagnosis, and get new parts, and assuming an average repair time of 10 hours, there is not sufficient time to fix the system. Therefore, no credit was given to repair the SFP cooling system.

5.0.2. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
HEP-COOL-LOP-E		3.5E-3
Gate GCSR123	—	9.4E-4

5.1. Top Event OMK - Operator Recovery Using Onsite Sources

5.1.1. Event Description and Timing

This top event represents the unavailability of the firewater pumps. If offsite power is recovered then the fault tree GLPR112 represents this top event. In this case, the operator has both electric and diesel firewater pumps available. The top event has two basic events: an operator error to start any firewater pump, and failure of electric and diesel firewater pumps to start and run.

If offsite power is not recovered then fault tree GLPR142 represents this top event. In this case, operator has only diesel firewater pump available. The top event has two basic events: an operator error to start the diesel firewater pump and failure of the diesel firewater pump to start and run. (Note that if power is recovered later in the event, operator has an option of starting the electrical firewater pump.)

It is assumed that the operator will first try to reestablish the SFP cooling system, and will wait some time for offsite power to be restored before resorting to the firewater system as a source of makeup. Failure to restore power or failure to restart/realign the SFP cooling system would eventually result in pool boiling and loss of inventory. Once the pool level drops below the SFP cooling system suction level (assumed to occur at about 43 hours - see Section 2.5.1), the operator would have to provide makeup using the firewater system. Therefore, the operator would have about 85 hours to provide firewater makeup (128 hours less 43 hours). If one or both pumps fail to start or run, we assume that it takes another two shifts (16 hours) to contact maintenance personnel, to perform the diagnosis, and to get new parts; therefore, the operator would have 69 hours (85 hours less 16 hours) to perform repairs.

5.1.2. Relevant Assumptions

- Maintenance is performed per schedule on diesel and electric firewater pumps to maintain operable status
- Operator has 85 hours to start a firewater pump
- On average, it takes 10 hours to repair a pump if it fails to start and run
- It takes two shifts (16 hours) to contact maintenance personnel, make a diagnosis, and get new parts
- The hose in the SFP area can be secured in less than 30 minutes
- Both firewater pumps are located in a separate structure or protected from the potential harsh environment in case of pool bulk boiling

6.0.1. Quantification

Human Error Probabilities

This top event includes two operator actions. One represents the operator's failure to establish firewater makeup given that power was recovered and the operator failed to restart/realign the SFP cooling system before boil-off began. Success is defined as the operator starting one of two firewater pumps and securing a firewater hose in the spent fuel pool area. There are multiple shifts available to start the pump. In the Draft report, a probability of 0.01 was assigned to the operator error to start and run electric and diesel FW pump. The failure probability for the operator action used in the fault tree was based on event ALT-XHE-XM-SFP from INEL-96/0334.

Human error probability: from Harold. This event may have dependency on the previous event.

The second event represents the operator's failure to establish makeup given that power was not recovered. Success is defined as the operator starting the diesel firewater pump and securing a firewater hose in the spent fuel pool area. There are multiple shifts available to start the pump. It is assumed the task requires 30 minutes.

Human error probability: from Harold. It could be more than couple of days offsite power is not recovered.

Non-HEP Probabilities

In the NRC draft report, the failure probabilities (including both failure to start and failure to run) for electric and diesel firewater pumps are 6.0E-2 and 0.18, respectively. Either pump may be required to run at the most 8 hours, given that the water inventory drops by 20 feet (i.e., 3 feet from the top of the fuel). For the electric firewater pump, we recommend 3.7E-3 failure probability for the pump to start and run for 10 hours (from INEL-96/0334).

Operator would first try to start all available pumps. If he fails to do so, he would try to fix only one pump. Therefore, credit for repairing a pump is given to only one pump. Given that the operator will not initiate firewater until the water level in the pool drops below the SFP cooling system suction level, he would have about 85 hours to provide makeup (128 hours less 43 hours). Assuming that it takes another two shifts (16 hours) to contact maintenance personnel, make a diagnosis, and get new parts, then the operator has 69 hours (85 hours less 16 hours) to repair the pump. Assuming a 10-hour mean time to repair, the probability of failure to repair the pump would be 1.0E-3 (Exp [-(1/10) × 69]). Therefore, the probability of the diesel and electric firewater pumps failing to start and run would be 0.18 × 3.7E-3 × 1.0E-3 = 6.7E-7.

Similarly, given that offsite power is not recovered, the probability of the diesel firewater pump failing to start and run would be 0.18 × 1.0E-3 = 1.8E-4.

6.0.2. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
HEP-ALTCL-LP-E Power recovered Power not recovered		1.0E-2
FP-MKUP-FTF	6.7E-7	2.E-2
FP-DGPUMP-FTF	1.8E-4	0.19

6.1. Top Event OFD - Operator Recovery Using Offsite Sources

6.1.1. Event Description and Timing

Given the failure of recovery actions using onsite sources, this event accounts for recovery of coolant makeup using offsite sources such as procurement of a fire engine. Adequate time is available for this action, provided that the operator recognizes that recovery of cooling using onsite sources will not be successful, and that offsite sources are the only viable alternatives.

6.1.2. Relevant Assumptions

- The operator has 128 hours from the onset of the initiator to provide makeup and inventory cooling
- He has sufficient time to recognize the need for external sources of makeup

8.0.1. Quantification

<u>Human Error Probabilities</u>

The operator must recognize that extreme measures must be taken to provide makeup to the SFP. He has had ample time up to this point to attempt recovery of the diesel firewater pump. Due to the complexity of this diagnosis, and the uncertainty involved in estimating the remaining time and offsite resources available, this operator action has been given a screening value of 0.01. A sensitivity study will be performed to determine the need for further refinement of this quantification.

8.0.2. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
REC-INV-OFFSITE1	—	1.0E-2

9. Severe Weather Loss of Offsite Power Event Tree

This event tree represents the loss of SFP cooling resulting from a loss of offsite power from severe-weather-related events. Until offsite power is recovered, the electrical pumps would be unavailable, and only the diesel fire pump would be available to provide makeup. The order of the top events has been modified when compared to the NRC draft report to represent the expected sequence of events (i.e., given a LOSP event, the first thing operator would do is to attempt to recover power), and to evaluate properly the dependency between operator errors.

9.1. Initiating Event LP2 - Severe Weather Loss of Offsite Power

The LOSP frequency from severe weather events is 7.0E-3/yr, taken from NUREG/CR-5496.

9.2. Top Event OPR – Offsite Power Recovery

9.2.1. Event Description and Timing

This top event includes a single basic event, which represents the non-recovery probability of offsite power. The NRC draft report estimated non-recovery probability based on 128 hours. However, if power is recovered after 33 hours (the onset of pool bulk boiling), the operator may not be able to use the SFP cooling system because the pool water level may drop below the SFP cooling system suction level by the time SFP cooling is established; therefore, the operator must start a firewater pump to makeup inventory. It is assumed that if power is recovered before boil-off starts (33 hours), the operator has a chance to reestablish cooling using SFP cooling system.

9.2.2. Relevant Assumptions

If power is not recovered within the first 33 hours, it is assumed that problem is significant and the probability of recovering power within 128 hours is very small.

9.2.3. Quantification

Non-HEP Probabilities

The NRC draft report estimated a non-recovery probability of 0.02 based on 128 hours. In this analysis, the non-recovery probability of offsite power in 33 hours is estimated to be 0.1 (both results derived from NUREG/CR-5496).

9.2.4. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
REC-INV-OFFSITE1	0.1	0.02

9.3. Top Event OCS – Cooling System Restart and Run

9.3.1. Event Description and Timing

This top event represents restarting the SFP cooling system, given that offsite power has been recovered within 24 hours. There are two electrically operated pumps and the operator can start either one. If the operator starts the pump that was in operation, no valve alignment would be required. However, if operator starts the standby pump, some valve alignment may be required.

The top event has several basic events: one operator error to establish SFP cooling, and several hardware failures of the system. This top event is dominated by the operator error to restart/realign the SFP cooling system. If power is recovered within 24 hours, the operator has 9 hours to start the system before boil-off starts. If he fails to initiate SFP cooling before boil-off begins, the operator must start a firewater pump to provide makeup.

9.3.2. Relevant Assumptions

- Operator has 9 hours to start the SFP cooling system (this is equivalent to the conservative assumption that offsite power is recovered at exactly 24 hours).
- Task completion time 1 hour
- Well-written procedures exist
- Operator has received the necessary training
- Potential harsh environment (hot and humid)

14.0.1. Quantification

Human Error Probability

One operator error is modeled under this top event. In the Draft report, a probability of 3.5E-3 was assigned to the operator error to restart/realign the SFP cooling system, based on event SFP-XHE-XE-LP from INEL-96/0334. This event represents operator failure to restart/realign the SFP cooling system in 9 hours given that power is recovered.

Human error probability: from Harold

Operator can restart the previously running pump and may not have to make any valve alignment. If he decides to restart standby pump he may have to make some valve alignment.

Non-HEP Probabilities

In the NRC draft report, a probability of 9.4E-4 was estimated for the hardware failures of the system. If the system fails to start and run for a few hours then the operator would try to get the system repaired. Assuming that it takes another two shifts (16 hours) to contact maintenance personnel, make a diagnosis, and get new parts, and assuming an average repair time of 10 hours, there is not sufficient time to fix the system. Therefore, no credit was given to repair the SFP cooling system.

14.0.2. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
HEP-COOL-LOP-E		3.5E-3
Gate GCSR123	—	9.4E-4

14.1. Top Event OMK - Operator Recovery Using Onsite Sources

14.1.1. Event Description and Timing

This top event represents the unavailability of the firewater pumps. If offsite power is recovered then the fault tree GLPR112 represents this top event. In this case, the operator has both electric and diesel firewater pumps available. The top event has two basic events: an operator error to start any firewater pump, and failure of electric and diesel firewater pumps to start and run.

If offsite power is not recovered then fault tree GLPR142 represents this top event. In this case, operator has only diesel firewater pump available. The top event has two basic events: an operator error to start the diesel firewater pump and failure of the diesel firewater pump to start and run. (Note that if power is recovered later in the event, operator has an option of starting the electrical firewater pump.)

It is assumed that the operator will first try to reestablish the SFP cooling system, and will wait some time for offsite power to be restored before resorting to the firewater system as a source of makeup. Failure to restore power or failure to restart/realign the SFP cooling system would eventually result in pool boiling and loss of inventory. Once the pool level drops below the SFP cooling system suction level (assumed to occur at about 43 hours - see Section 2.5.1), the operator would have to provide makeup using the firewater system. Therefore, the operator would have about 85 hours to provide firewater makeup (128 hours less 43 hours). If one or both pumps fail to start or run, we assume that it takes another two shifts (16 hours) to contact maintenance personnel, to perform the diagnosis, and to get new parts; therefore, the operator would have 69 hours (85 hours less 16 hours) to perform repairs.

14.1.2. Relevant Assumptions

- Maintenance is performed per schedule on diesel and electric firewater pumps to maintain operable status

- Operator has 85 hours to start a firewater pump
- On average, it takes 10 hours to repair a pump if it fails to start and run
- It takes two shifts (16 hours) to contact maintenance personnel, make a diagnosis, and get new parts
- The hose in the SFP area can be secured in less than 30 minutes
- Both firewater pumps are located in a separate structure or protected from the potential harsh environment in case of pool bulk boiling

20.0.1. Quantification

Human Error Probabilities

This top event includes two operator actions. One represents the operator's failure to establish firewater makeup given that power was recovered and the operator failed to restart/realign the SFP cooling system before boil-off began. Success is defined as the operator starting one of two firewater pumps and securing a firewater hose in the spent fuel pool area. There are multiple shifts available to start the pump. In the Draft report, a probability of 0.01 was assigned to the operator error to start and run electric and diesel FW pump. The failure probability for the operator action used in the fault tree was based on event ALT-XHE-XM-SFP from INEL-96/0334.

Human error probability: from Harold. This event may have dependency on the previous event.

The second event represents the operator's failure to establish makeup given that power was not recovered. Success is defined as the operator starting the diesel firewater pump and securing a firewater hose in the spent fuel pool area. There are multiple shifts available to start the pump. It is assumed the task requires 30 minutes.

Human error probability: from Harold. It could be more than couple of days offsite power is not recovered.

Non-HEP Probabilities

In the NRC draft report, the failure probabilities (including both failure to start and failure to run) for electric and diesel firewater pumps are 6.0E-2 and 0.18, respectively. Either pump may be required to run at the most 8 hours, given that the water inventory drops by 20 feet (i.e., 3 feet from the top of the fuel). For the electric firewater pump, we recommend 3.7E-3 failure probability for the pump to start and run for 10 hours (from INEL-96/0334).

Operator would first try to start all available pumps. If he fails to do so, he would try to fix only one pump. Therefore, credit for repairing a pump is given to only one pump. Given that the operator will not initiate firewater until the water level in the pool drops below the SFP cooling system suction level, he would have about 85 hours to provide makeup (128 hours less 43 hours). Assuming that it takes another two shifts (16 hours) to contact maintenance personnel, make a diagnosis, and get new parts, then the operator has 69 hours (85 hours less 16 hours) to repair the pump. Assuming a 10-hour mean time to repair, the probability of failure to repair the pump would be 1.0E-3 (Exp [-(1/10) × 69]). Therefore, the probability of the diesel and electric firewater pumps failing to start and run would be 0.18 × 3.7E-3 × 1.0E-3 = 6.7E-7.

Similarly, given that offsite power is not recovered, the probability of the diesel firewater pump failing to start and run would be 0.18 × 1.0E-3 = 1.8E-4.

20.0.2. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
HEP-ALTCL-LP-E Power recovered		1.0E-2

Power not recovered		
FP-MKUP-FTF	6.7E-7	2.E-2
FP-DGPUMP-FTF	1.8E-4	0.19

20.1. Top Event OFD – Operator Recovery Using Offsite Sources

20.1.1. Event Description and Timing

Given the failure of recovery actions using onsite sources, this event accounts for recovery of coolant makeup using offsite sources such as procurement of a fire engine. Adequate time is available for this action, provided that the operator recognizes that recovery of cooling using onsite sources will not be successful, and that offsite sources are the only viable alternatives.

20.1.2. Relevant Assumptions

- The operator has 128 hours from the onset of the initiator to provide makeup and inventory cooling
- He has sufficient time to recognize the need for external sources of makeup

22.0.1. Quantification

Human Error Probabilities

The operator must recognize that extreme measures must be taken to provide makeup to the SFP. He has had ample time up to this point to attempt recovery of the diesel firewater pump. Due to the complexity of this diagnosis, and the uncertainty involved in estimating the remaining time and offsite resources available, this operator action has been given a screening value of 0.05. A sensitivity study will be performed to determine the need for further refinement of this quantification.

22.0.2. Changes from NRC Draft Report

Basic Event	INEEL	NRC Draft Report
REC-INV-OFFSITE1		5.0E-2
Power recovered	—	
Power not recovered	0.1	