The fourth component described above dominates probabilistically and its calculation is described below. The sum of the other three is more than 2 orders of magnitude lower.

The likelihood of an extended LOSP has been estimated by using the probability of a LOSP exceeding 24 hours, which is the longest non-recovery period identified in NUREG/CR-6890 (Ref. 2.2.45). The 720 hour period for which a brake holding failure has been modeled should provide ample time to either recover offsite power or for operators to implement an alternative means to safely lower any load. Provision for manual lowering of loads is provided in NOG-1 cranes (Ref. 2.2.9).

The probability of the fourth component described above – the combination of LOSP and load drop (brakes set but fail to hold over a 720 hour mission time) is:

LOSP-IE × Holding brake fails × Emergency brake fails =
= 3.2E-02 × (8.4E-06 × 720) × (4.4E-06 × 720)
= 6.1E-07

Thus, the LOSP load drop probability over the preclosure period is estimated to be 6E-07. This number of occurrences of the compound initiating event is much less than 1 chance in 10,000 (1E-4) during the preclosure period. Therefore, event sequences with LOSP and a coincident drop load as the initiating event are Beyond Category 2.

The possibility of inadvertent direct exposure of workers due to a loss of electrical power is considered next. Canisters are always shielded during facility operations by a transportation cask, a canister preparation platform, concrete floors and walls, the CTM shield bell and shield skirt, the WPTT, facility shield doors, and the TEV shield compartment. Loss of electrical power to any of these simply stops operations while maintaining shielding. For example, inadvertent shield bell and shield door motion can not occur in the absence of electrical power. Therefore, direct exposure to workers owing to loss of electrical power is considered to be Beyond Category 2.

It has been shown that loss of electrical power in conjunction with other failures is screened out as an initiating event. Nevertheless, this compound failure mode is included in the initiating and pivotal event fault trees as appropriate. For example, the hoist brake on the CTM requires electrical power to remain unengaged. A loss of power would cut power to the brake, leading to its automatic engagement. If the brake fails in conjunction with a loss of power in this scenario, a drop of the load could occur, initiating an event sequence. This failure scenario is included in the CTM fault tree. For the overhead cranes, the initiating event frequencies are based on industry-wide empirical data for cranes. The ITS HVAC system depends on continued electrical power and it is explicitly modeled in the fault tree for this pivotal event.

6.0.3 Screening of Internal Initiating Events

All facility safety analyses, whether risk-informed or not, takes into account the physical conditions, dimensions, materials, human-machine interface, and other attributes such as operating conditions and environments, to assess potential failure modes and event sequences. Such accounting guides the assessment of what can happen, the likelihood, and the potential consequences. In many situations, it is obvious that the probability of a particular exposure scenario is very low. In many cases, it is impractical or unnecessary to actually quantify the probability when a non-probabilistic engineering analysis provides sufficient assurance and insights that permit the scenario to be either screened out or demonstrated to be bounded by another scenario.

Potential initiating events were qualitatively identified in *Wet Handling Facility Event Sequence Development Analysis* (Ref. 2.2.37) for quantitative treatment in the present analysis. For completeness, some events that were identified in the event sequence development analysis are extremely unlikely or physically unrealizable and can reasonably be qualitatively screened from further consideration. A qualitative screening argument for certain internal initiating events is developed in the present analysis as documented in Table 6.0-2. The first column of Table 6.0-2 indicates the branch of the initiator event tree, where applicable, that pertains to the screened initiating event. Each branch of an initiator event tree represents an initiating event or an initiating event group that includes other similar initiating events and corresponds to a little bubble on an ESD (Ref. 2.2.37, Attachments F and G). Some of the initiating events that are addressed in Table 6.0-2 were implicitly screened out in the event sequence development analysis and for that reason there is no applicable event tree. The screening argument for internal flooding is presented in Section 6.0.4. The screened initiating events are assigned frequencies of zero in the quantification of the model.

Table 6.0-2. Bases for Screening Internal Initiating Events

Initiator Event Tree (Branch No.)	Initiating Event Description	Screening Basis
WHF-ESD01-CSNF (#2) (Figure A5-2)	Rollover of a truck trailer carrying a transportation cask in the Cask Preparation Area or Transportation Cask Vestibule	For a truck trailer to roll over, its center of mass has to move laterally beyond the wheel base of the trailer. This could occur upon traversing a significantly uneven surface, running over a very large object, or turning sharply at high speed. There are no uneven surfaces in the Cask Preparation Area or the Transportation Cask Vestibule. The area in question has a flat concrete surface. There are no objects that could be run over that could significantly shift the trailer's center of mass. Turning sharply at high speed is not possible inside the building because the rooms are is too narrow and the truck comes to a complete stop outside the closed entrance door prior to the door opening and the truck entering. Therefore, event sequences associated with this failure mode are considered to be physically unrealizable.
WHF-ESD07-DPC (#4) (Figure A5-14) WHF-ESD08-CSNF (#3) (Figure A5-15) WHF-ESD09-DPC (#4) (Figure A5-16)	Operator drops cask during cask preparation activities	The 20-ton auxiliary crane, rather than the 200-ton crane, is used in the lid-removal operation. Because the cask is not intentionally lifted in this step, dropping the cask would require a series of extraordinary human failures. For DPCs, a cask drop would require a series of human failures as follows: During lid removal, the crew must fail to remove some fraction of the lid bolts, fail to properly use the check list to verify bolt removal, and use the wrong crane (the 20-ton crane would be incapable of lifting the cask). The crane operator and at least two other crew members will be standing on the platform in direct view of the cask during lid removal and they all would fail to notice that the entire cask is being lifted before the bolts break. Therefore, event sequences associated with this initiating event are judged to contribute insignificantly to the frequency of the grouped event sequences of which they would be a part. For casks other than DPC casks, the lid is not removed from the cask at this point. Therefore, no configuration that could result in a crane lifting the cask occurs for such casks. This initiating event, as it relates to casks other than DPC casks, is considered to be unrealizable.

Table 6.0-2. Bases for Screening Internal Initiating Events (Continued)

Initiator Event Tree (Branch No.)	Initiating Event Description	Screening Basis
WHF-ESD10-DPC (#2) (Figure A5-17) WHF-ESD14-DPC (#3) (Figure A5-24)	Structural damage to transportation cask due to impact from the crane hook or rigging while under the cask preparation platform	In this operation, the lid is unbolted and the lid lift fixture is attached. The cask is flush or recessed with respect to the cask preparation station, and therefore cannot be impacted. Therefore, event sequences associated with these initiating events are considered to be physically unrealizable.
WHF-ESD13-TAD (#8) (Figure A5-23)	Canister dropped inside shield bell	Drops within the shield bell have been included within event sequences for drops from the operational lift height, and not separately addressed. This is conservative because the drop height within the shield bell is less than the operational lift height.
No applicable event trees	Internal flooding	Internal flooding as an initiating event is screened out from further analysis in Section 6.0.4.
No applicable event trees	Canister dropped into the Cask Unloading Room or Loading Room with no STC or aging overpack present	Lowering a canister by the CTM through a port without a STC or aging overpack present is prevented by interlocking the port slide gate opening with a sensor that shows there is a receptacle (STC or aging overpack) located beneath. The design incorporates an interlock to prevent the opening of the port slide gate when an STC or an aging overpack is not present (Ref. 2.2.31). The combination of (a) failure to stage the receptacle, (b) failure of more than one operator to notice that it is not staged, (c) failure of the hardwired interlock, and (d) drop of the canister are required for such an initiating event to occur. Considering the combination of unlikely events that must occur to cause this initiating event, event sequences involving this combination of failures are judged to contribute insignificantly to the frequency of the grouped event sequences of which they would be a part.
WHF-ESD10-DPC (#2) (Figure A5-17)	Tipover of CTT	The CTT is designed to prevent tipover (Ref. 2.2.22, Section 3.2). The CTT is normally set on the floor inside a preparation platform. The size, weight, low center of gravity, and low speed of the CTT ensure that no tipover can occur. As such, tipover is not physically realizable during preparation activities. During transit, the CTT glides slowly on a cushion of air, an inch or less above the floor. If air pressure is lost, air to the CTT is cut and the CTT, with its load, settles to the floor. While the CTT is in transit, or after settling to the floor, any applied force from facility operations in incapable of tipping over the CTT. Due the slow travel of the CTT, a loss of air pressure or a collision with other equipment or a facility structure will not result in tipover. Therefore, tipover of the CTT is considered physically unrealizable for internal events. CTT tipover, however, is analyzed in the seismic event sequence and categorization analysis.

Table 6.0-2. Bases for Screening Internal Initiating Events (Continued)

Initiator Event Tree (Branch No.)	Initiating Event Description	Screening Basis
WHF-ESD23-POOL (#5) (Figure A5-38)	Improper decontamination of DPC/STC	This event is not considered an event sequence. It is considered as part of the normal or off-normal operations, and mishaps during the normal operations are evaluated elsewhere.
WHF-ESD23-POOL (#4) (Figure A5-38)	Operator exposed during pool filter change-out	This event is not considered an event sequence. It is considered as part of the normal or off-normal operations, and mishaps during the normal operations are evaluated elsewhere.
WHF-ESD26-TAD (#2) (Figure A5-42)	Failure to fully dry TAD canisters	As described in NUREG-1567 (Ref. 2.2.91, Section 6.0.7) discusses a process to evacuate water from SNF canisters. If the process is followed, the NRC has concluded in their various safety evaluation reports that there is reasonable assurance that less than 1 gram mole of water will be left in the canister. The YMP process will conform to this process. Hence, failure to fully dry TAD canisters is screened out.
WHF-ESD27-TAD (#2) (Figure A5-44)	Operator fails to detect bad weld during inspection	As discussed in Section 6.0.6, bad welds are detected during the welding and drying process. The design of the welding machine incorporates weld testing device that test the weld as it is laid. In addition, the structural integrity of the weld is also confirmed during the TAD canister drying and inerting–if there is a crack on weld, the inerting pressure will not hold. Additional ultrasonic testing can be performed (if needed) to confirm the weld integrity after the TAD canister drying and inerting process. Based on these steps, the chance of having a bad weld is negligible, and the associated event sequence is screened from further consideration.
WHF-ESD30-DPC (#2) (Figure A5-48)	Operator exposed during decontamination operations	This event is not considered an event sequence. It is considered as part of the normal or off-normal operations, and mishaps during the normal operations are evaluated elsewhere.
ESD12-DPC-DOOR (Figure A5-20)	Conveyance carrying a cask, STC, or aging overpack collides with a shield door, causing the door to dislodge from its supports and fall onto the waste form	The shield doors are designed to withstand collision of the conveyance into the door without dislodging from their supports such that the stress of all support mechanisms of the door stay below yield. Therefore, this initiating event is considered physically unrealizable.

Table 6.0-2. Bases for Screening Internal Initiating Events (Continued)

Initiator Event Tree (Branch No.)	Initiating Event Description	Screening Basis
No applicable event tree	Water dilution event in WHF pool results in criticality	For normal operations, it is not physically possible to dilute the boron concentration in the WHF pool sufficiently to cause criticality and hence this event is screened out by the following argument. The only water source in Room 1016 is the de-ionized water system and this system does not have enough water to dilute the boron concentration to levels to cause criticality. According to *Utilities Facility Deionized Water System Supply Piping & Instrument. Diagram* (Ref. 2.2.25), the maximum amount of water that can be drained from de-ionized water system due to a pipe rupture is 19,600 gallons. The WHF pool contains 1.4 million gallons of water. *Pool Water Treatment and Cooling System* (Ref. 2.2.32). The addition of 19,600 gallons reduces the boron concentration by 1.4%. According to *Preclosure Criticality Safety Analysis* (Ref. 2.2.35) the minimum required concentration of soluble boron in the pool is 2500 mg/L of boron enriched to 90 atom % ^{10}B. For all normal WHF pool operations, subcriticality is maintained crediting no more than 15% of this minimum required soluble boron concentration. Hence, there is a factor of safety of 85%/1.4% = 60.7 and water dilution is not a credible scenario leading to criticality in the WHF pool for normal operations.
No applicable event trees	Fuel tank explosion involving site transporter, cask tractor, cask transfer trailer, or site prime mover	Fuel tank design for equipment used to move casks or aging overpacks containing high-level waste shall include a requirement for the tank construction to use a low-temperature melt material. The low-temperature melt material precludes tank explosion as an initiating event; therefore, fuel tank explosions for these movers are not analyzed further for categorization.
WHF-ESD13-DPC (#3) (Figure A5-22) WHF-ESD13-TAD (#3) (Figure A5-17)	Side impact from a slide gate	Slide gate impacts during CTM transfer are included in the CTM fault tree as a cause of canister drop, rather than as an independent initiating event.
WHF-ESD13-DPC (#8) (Figure A5-22) WHF-ESD13-TAD (#8) (Figure A5-17)	Canister dropped inside shield bell (with CTM slide gate closed)	Drops within the shield bell are subsumed within the initiating event for drops from the operational lift height, and are not separately addressed. This is conservative because the drop height within the shield bell is less than the operational lift height.

Table 6.0-2. Bases for Screening Internal Initiating Events (Continued)

Initiator Event Tree (Branch No.)	Initiating Event Description	Screening Basis
No applicable event trees	Moderator introduced during sampling event	During sampling of the DPC or transportation cask with uncanistered fuel assemblies, there are no credible source of water intrusion. Connections of the sampling lines are designed to prevent wrong hook ups. Thus, the associated event sequence is considered to be not realizable.
No applicable event trees	Cask transfer trailer punctures HTC, HSTC, or HDPC	The ram unit on the cask transfer trailer is designed such that the ram is positioned to preclude puncture of the HTC or HSTC during a collision or seismic event. In addition, the ram is designed to have insufficient force to deform a DPC (Ref. 2.2.93); therefore, further consideration of this initiating event is not required.

NOTE: Initiator event trees are provided in Attachment A in the figures cited. The branch numbers are shown in each figure under the column labeled "#."

AO = aging overpack; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; HDPC = horizontal dual-purpose canister; HSTC = horizontal shielded transfer cask; HTC = horizontal transportation cask; ST = site transporter; STC = shielded transfer cask; TAD = transportation, aging, and disposal canister.

Source: Original

6.0.4 Screening of Internal Flooding as an Initiating Event

By the definition of an event sequence, a flood inside a facility would be an initiating event if it led to a sequence of events that would either breach waste containers, causing a release, or caused elevated radiological exposure without a release (i.e., direct exposure of personnel). Internal floods, whether caused by random failure or earthquakes, emerge from two sources. The first is inadvertent actuation of the fire-suppression system. The second is failure of water-carrying pipes or valves associated with chilled water, hot water, potable water, or other water systems. Drains, channels and curbs are situated to remove water from these sources. However, the following discussion does not rely on these.

Transportation casks, canisters, and waste packages are not physically susceptible to breach associated with water in the short-term. With extremely long exposure to water, corrosion may be a factor but intervention to drain water from the buildings would prevent such exposure. Short-term breaches do not occur owing to exposure to water. Canisters are surrounded by transportation casks, and waste packages. Casks are elevated as all times at least five feet above the floor by railcar or truck and canister transfer trolley. Waste packages are similarly elevated on the waste package transfer trolley. Inside the TEV, the waste package is elevated approximately one foot above the floor. A lifted canister or/and cask is higher than these minimum elevations. Therefore, water from fire suppression and other water systems is unlikely to attain a depth that would contact transportation casks, waste packages, or canisters. Of greater significance, however, is that the fuel is contained in canisters within an overpack nearly all the time and these containers do not fail from short-term exposure to flood water. In this context, short-term is a time period that is at least 30 days but less than the length of time that significant corrosion may occur.

Water impingement on electrical equipment (e.g., motor control centers, motors, and switchgear cabinets) would ordinarily trigger circuit protection features that would open the circuit and cause a loss of electrical power (which is covered in Section 6.0.2.2). If a short circuit occurred as a result of water impingement, normal circuit protection features or overheating of the wires would subsequently open the affected circuit. In an extreme situation, an electrical fire might be started. Fires from all causes are covered in Section 6.5.

The possibility of inadvertent direct exposure of workers due to internal flooding is considered next. Direct exposure to workers during a flood would occur if shielding were disabled as a result of the flooding. Canisters are always shielded during facility operations by transportation casks, canister preparation platforms, CTT, concrete floors and walls, the CTM shield bell or shield skirt, or shield doors. Loss of electrical power to any of these simply stops operation without affecting the shielding. Flooding might also cause hot shorts in control boxes. However, hardwired interlocks between the CTM slide gate, shield bell skirt, and shield doors prevent such inadvertent motion. Therefore, internal flooding cannot initiate an event sequence that causes increased levels of radiological exposure.

Moderator intrusion into canisters resulting from event sequences that might breach a waste container are treated quantitatively as described in the pivotal event descriptions of Section 6.2.

6.0.5 Screening Argument for Release Due to Rupture of Bare Fuel in Transportation Cask Exposed to Fire

If a transportation cask containing bare fuel rods is exposed to fire, the fuel rods could be heated to the point of degradation, allowing release of radionuclides within the sealed transportation cask. If in addition, the fire reaches the top of the transportation cask and causes failure of the lid seals, the radionuclides could be released to the surroundings.

An assessment of the temperature at which spent fuel rods would fail is summarized in NUREG/CR-6672 (Ref. 2.2.83, Section 7.2.5.2). A critical review of accident conditions indicates that rod rupture is expected to occur at temperatures near 725°C to 750°C. After correcting for differences in burnup and internal pressure, data in the Cask Designers Guide suggest that spent fuel rods may fail due to creep rupture at temperatures as low as 700°C or require temperatures as high as 850°C. Because the release of cesium vapors will be greater when rods fail at higher temperatures than lower temperatures, the middle of the range, about 750°C, is taken as the temperature at which rods fail by thermal rupture.

The probability of fuel rod failure at 750°C is 2.7×10^{-4} given exposure to fire (Table D2.1-11). The probability of exposure of a transportation cask containing bare fuel to fire in the WHF is 1×10^{-5} (Attachment F, Table F5.7-2). The overall probability that a transportation cask is exposed to a fire sufficient to cause rupture of the fuel rods contained within and release of radionuclides to the surroundings is 3×10^{-9} for the WHF.

The analysis includes some extreme conservatisms:

- A view factor of 1 was used for determining the probability that the fuel rods would heat up to the failure temperature given exposure of the transportation cask to fire. Not all fires to which a transportation cask is exposed would be positioned such that a complete radiation exposure would be possible.

- The lid seals are at the top of the transportation cask which is approximately 15 feet tall. Only a limited fraction of the fires to which a transportation cask would be exposed would be large enough to cause failure of the lid seals even if the lower portion of the cask got hot enough to allow rupture of the fuel rods.

Thus it is concluded that this event is beyond Category 2 and can be screened from further analysis.

6.0.6 Screening of Operator Failing to Detect Bad Welds During Inspection

TAD canister closure is the process that closes the loaded TAD canister by welding the shield plug and fully draining and drying the TAD canister interior, followed by backfilling the TAD canister with helium and fully welding the TAD canister lid around its circumference onto the body of the TAD canister.

The process control program for the closure welds produced by the TAD canister closure system is controlled as a special process by the Quality Assurance Program (Ref. 2.2.44).

TAD canister closure is done at the TAD canister closure station in the cask preparation area. The shielded transfer cask (STC) containing a loaded TAD canister is transferred from the pool to the TAD canister closure station using the cask handling crane. The STC lid is unbolted and then removed using the TAD canister closure jib crane. The TAD canister is then partially drained via the siphon port in order to lower the water level below the shield plug in preparation for welding. The TAD canister welding machine is positioned onto the TAD canister shield plug using the TAD canister closure jib crane, and the shield plug is welded in place. After a weld is completed, visual examination of the weld is performed in addition to the eddy current testing and ultrasonic testing that are performed by the TAD canister welding machine.

A draining, drying, and inerting system is connected to the siphon and vent ports in the shield plug and used to dry the interior of the TAD canister, followed by backfilling it with helium gas. Port covers are then placed over the siphon and vent ports and welded in place using the TAD canister welding machine. The TAD canister welding machine is removed, and the outer lid is placed onto the TAD canister using the TAD canister closure jib crane. The TAD canister welding machine is positioned onto the TAD canister outer lid, and the lid is welded in place. The TAD canister welding machine is removed, and the shielded transfer cask lid is placed onto the shielded transfer cask using the TAD canister closure jib crane and installed. Hoses are connected to the fill and drain ports on the shielded transfer cask, and the water is sampled for contamination. If the water is clean, the ports are opened to drain the annulus between the TAD canister and the shielded transfer cask. If the water is contaminated, then the annulus is flushed with treated borated water as needed. A drying system is then used to dry the annulus. The potential for contamination is kept to a minimum by the use of the inflatable seal.

The qualification of the TAD canister final closure welds is in accordance with SFPO-ISG-18 (Ref. 2.2.89). Adherence to this guidance is deemed to provide reasonable assurance that weld defects occur at a low rate.

6.0.7 Water in Transportation, Aging, and Disposal Canister

NUREG-1567 (Ref. 2.2.91) discusses a process to evacuate water from SNF canisters. If the process is followed, the NRC has concluded in their various safety evaluation reports that there is reasonable assurance that less than 1 gram mole of water will be left in the canister. The YMP process will conform to this process.

Potential initiating events, should water be left in the canister, during the preclosure period, include saturated vapor pressurization or development of hydrogen and subsequent recombination reactions. Facility operating processes are similar to those covered by 10 CFR Part 71 (Ref. 2.3.3) and 10 CFR Part 72 (Ref. 2.3.4) (e.g., in the use of cranes), and there are no processes or conditions that would exacerbate adverse effects associated with abnormal amounts of water retention. These processes are highly reliable as indicated by no overpressure ruptures of canisters on utility sites to date.

Hydrogen generation by radiolysis is a very slow process requiring decades to generate flammable or explosive mixtures in TAD sized canisters. However, if sufficient water is left in the canister, overpressurization owing to hydrogen recombination is extremely unlikely to occur because of several reasons.

1. Hydrogen and oxygen must be well mixed for an efficient burn or explosion– because of density differences; gaseous hydrogen would tend to separate and stay separate from oxygen.

2. Detonation from a rapidly moving flammable wave front is physically unrealizable for closed containers.

3. An ignition source must be present and water vapor tends to inhibit hydrogen combustion by raising the lower flammability limit.

4. Typically, burning of hydrogen and oxygen in close proximity when not well mixed would generate heat intermittently allowing time for heat removal through the canister walls.

5. Any such burning would tend to drive apart the hydrogen and oxygen components.

It is judged that the joint probability of water remaining in the canister and the confluence of all factors that might lead to an overpressurization during the preclosure period is Beyond Category 2.

Vapor pressurization would occur soon after TAD canister welding as the water vapor at saturation equilibrates with the internal canister temperature. Internal canister temperatures will normally exceed 212°F causing boiling and vaporization. If sufficient water is left, then the vapor and water would come to its saturation pressure. Saturated vapor pressures would not exceed canister internal pressure capability during normal conditions. During off-normal conditions of abnormal heat removal (e.g., loss of building air flow), saturated vapor temperatures may challenge the integrity of the canister. Overpressurization would occur within a couple of hours after the TAD canister is closed while it is still in the WHF. Rupture of the canister under these conditions are not expected to be worse than rupture as a result of a fire in which hoop stress limits are exceeded. The coincidence of release owing to water left in a canister is expected to be Beyond Category 2 because of the low frequency of water left in the canister, low conditional probability of large amounts of water that would lead to saturated vapor conditions, and low frequency of loss of cooling.

6.0.8 Screening of Loss of Pool Borated Water Due to a Drop of Cask as Initiating Event

An evaluation was performed to investigate whether the drop of a cask loaded with fuel into the pool could lead to structural damage to the pool such that borated water would rapidly drain from the pool through the rupture.

The pool characteristics are:

Pool floor – 8 ft-thick reinforced concrete
Pool water depth – 52 ft
Pool water – borated water (considered to have the same physical properties as water)
Pool water density (ρ_L) – 62.4 lb_m/ft^3 (water @ 70°F).

The cask containing fuel assemblies is conservatively selected as a shielded transfer cask containing a DPC with the following characteristics:

Cask length (L) (maximum) – 264 in. or 22 ft (Ref. 2.2.92)
Cask diameter (D) – 9 ft or 108 in. (Ref. 2.2.92)
Cask cross section area (A) ($\pi.D^2/4$) – $3.14 \times (9)^2/4 = 63.6$ ft^2
Cask volume (vol) (A × L) – $63.6 \times 22 = 1399$ ft^3
Cask weight (W) – 400,000 lb_f (Ref. 2.2.92)
Nominal cask density (ρ_s) – 400,000 lb_m/ 1399 ft^3 = 285.9 lb_m/ft^3
Mass of cask (M) (W/g) – 400,000 (lb_f)/32.17 (ft/sec^2) = 12,435 $lb_f\text{-}sec^2/ft$
Mass of cask (M) – 400,000 lb_m

The event starts when the cask is dropped from normal operating lift height of the cask handling crane, with the bottom of the cask at 6 ft above the water level, to the bottom of the pool. Higher drop heights have lower probability of occurrence. The drop would have perforated the 1/4 inch steel pool liner and continued to penetrate the pool floor for x inches. The following calculation neglects the energy absorption capability of the reinforcing (rebar) material. To estimate the penetration distance x, the following steps are used:

6.0.8.1 Estimation of Cask Drop Velocity at the Pool Water Surface

Considering that there is no air resistance, the free fall velocity of the cask dropping 6 ft in the air is given in Equation 17:

$$V = (2.g.h)^{0.5} \quad \text{(Eq. 17)}$$

where:

V = velocity after dropping h feet
g = gravitational acceleration – 32.17 ft/sec^2
h = dropped height – 6 ft

$$V = (2 \times 32.17 \times 6)^{0.5} = 19.6 \text{ ft/sec}$$

If the dropped height is 30 ft above the pool water surface, the cask drop velocity at the water surface is:

$$V = (2 \times 32.17 \times 30)^{0.5} = 43.9 \text{ ft/sec}$$

6.0.8.2 Estimation of Cask Velocity at the Pool Liner

The cask drops through 52 ft of water and arrives at the bottom of the pool. The initial velocity (V_0) at the pool water surface (0 ft) is the velocity calculated above (e.g., 19.6 ft/sec). As the cask drops through the water medium, it is subjected to buoyant force and drag force that opposes the gravitation force, which results in a decreasing acceleration. The equation summarizing these forces is given below in Equation 18:

$$F_W - F_b - F_d = M \times a \quad \text{(Eq. 18)}$$

where:

F_W is the gravitational force pulling the cask down (M × g) (lb_m-ft/sec^2)

F_b is the buoyant force created by the displacement of a volume of water equal to the volume of object dropping through water (vol × ρ_L × g) (lb_m-ft/sec^2)

F_d is the drag force exerted on the cross sectional area of the object as it speeds through water (0.5 × C_d × ρ_L × V^2 ×A) (lb_m-ft/sec^2)

M×a is the resulting force that moves the cask down into the water at acceleration *a* (lb_m.ft/sec^2)

Acceleration *a* is a function of time *t* and is defined in Equation 19:

$$a = dV/dt \text{ or } dV = a.dt \quad \text{(Eq. 19)}$$

Integrating both sides is defined in Equation 20,

$$V-V_0 = a.t \text{ or } V = at + V_0 \quad \text{(Eq. 20)}$$

Velocity *V* is also a function of time t, and is defined as in Equation 21:

$$V = dx/dt \text{ or } dx = V.dt \text{ or } dx = (a.t + V_0)\, dt \quad \text{(Eq. 21)}$$

Integrating both sides of Equation 21,

$$x - x_0 = ½ .a.t^2 + V_0.t \text{ or } 0 = ½ .a.t^2 + V_0.t - (x - x_0) \quad \text{(Eq. 22)}$$

Given a known $(x - x_0)$, let say 1 ft, and the acceleration *a* calculated as

$a = (F_w - F_b - F_d)/ M$, then the time it takes to travel $(x - x_0)$ ft at acceleration a is estimated by solving Equation 22 for t. Using Equation 20, solve for velocity V by substituting a, t and V_0. Continue this iteration for the next travel increment of 1 ft until reaching 52 ft, the impact velocity at the pool liner is the velocity at the 52 ft. A copy of the iteration is provided in Table 6.0-3 below.

The information required for this iteration includes:

x	distance traveled (ft)
Vo	initial velocity (ft/sec)
V	velocity at depth *x* (ft/sec)
Fb	buoyancy force exerted on the cask; (vol × ρ_L × g) (lb_m-ft/sec^2)
Fw	gravitational force exerted on the cask; (M × g) (lb_m-ft/sec^2)
Fd	drag force exerted on the cask; (0.5 × C_d × ρ_L × V^2 ×A) (lb_m-ft/sec^2)
C_d	drag coefficient; typical 0.25
acc	acceleration *a* of the cask through water (ft/sec^2)
Qa	$0.5 \times a$; the first term of the quadratic equation Eq. 22
Qb	*Vo*; the second term of the quadratic equation Eq. 22
Qc	$x - xo$; the third term of the quadratic equation Eq. 22
t	time it takes the cask to travel *x* ft in water by solving the quadratic equation, Eq. 22

The buoyancy force exerted on the cask increases as the cask plunges into the water until it is fully submerged. From that point on, the buoyancy force remains constant until the cask reaches the bottom of the pool. Therefore, Fb is calculated based on the submerged volume (e.g., volume = A × x) up to 22 ft (the maximum length of the cask), and becomes constant from 23 ft to 52 ft.

Table 6.0-3. Estimation of Cask Drop Velocity Through Water

x	Vo	Fb	Fw	Fd	Fw-Fb-Fd	acc	Qa	Qb	Qc	t	V
0	19.64	0	12868000	0	12868000	32.17	0	0	0	0	19.64
1	19.64	127641	12868000	191308	12549051	31.37263	15.68631	19.64	1	0.048999	21.17722
2	21.17722	255282	12868000	222427	12390291	30.97573	15.48786	21.17722	1	0.045694	22.59262
3	22.59262	382923	12868000	253153	12231924	30.57981	15.28991	22.59262	1	0.04301	23.90786
4	23.90786	510564	12868000	283485	12073950	30.18488	15.09244	23.90786	1	0.040778	25.13873
5	25.13873	638205	12868000	313427	11916368	29.79092	14.89546	25.13873	1	0.038883	26.2971
6	26.2971	765846	12868000	342977	11759177	29.39794	14.69897	26.2971	1	0.037251	27.39221
7	27.39221	893487	12868000	372138	11602375	29.00594	14.50297	27.39221	1	0.035827	28.43141
8	28.43141	1021128	12868000	400909	11445962	28.61491	14.30745	28.43141	1	0.034571	29.42066
9	29.42066	1148769	12868000	429293	11289937	28.22484	14.11242	29.42066	1	0.033453	30.36486
10	30.36486	1276410	12868000	457290	11134299	27.83575	13.91787	30.36486	1	0.03245	31.26814
11	31.26814	1404051	12868000	484901	10979047	27.44762	13.72381	31.26814	1	0.031545	32.13396
12	32.13396	1531692	12868000	512127	10824180	27.06045	13.53023	32.13396	1	0.030722	32.96532
13	32.96532	1659333	12868000	538969	10669697	26.67424	13.33712	32.96532	1	0.029971	33.76479
14	33.76479	1786975	12868000	565428	10515597	26.28899	13.1445	33.76479	1	0.029283	34.5346
15	34.5346	1914616	12868000	591505	10361880	25.9047	12.95235	34.5346	1	0.028649	35.27674
16	35.27674	2042257	12868000	617200	10208543	25.52136	12.76068	35.27674	1	0.028062	35.99293
17	35.99293	2169898	12868000	642516	10055587	25.13897	12.56948	35.99293	1	0.027519	36.68472
18	36.68472	2297539	12868000	667452	9903010	24.75752	12.37876	36.68472	1	0.027013	37.3535
19	37.3535	2425180	12868000	692009	9750811	24.37703	12.18851	37.3535	1	0.026541	38.0005
20	38.0005	2552821	12868000	716189	9598990	23.99747	11.99874	38.0005	1	0.0261	38.62684
21	38.62684	2680462	12868000	739993	9447545	23.61886	11.80943	38.62684	1	0.025687	39.23354
22	39.23354	2808103	12868000	763421	9296476	23.24119	11.62059	39.23354	1	0.025299	39.82152
23	39.82152	2808103	12868000	786475	9273422	23.18356	11.59178	39.82152	1	0.024931	40.39951
24	40.39951	2808103	12868000	809471	9250426	23.12606	11.56303	40.39951	1	0.02458	40.96794
25	40.96794	2808103	12868000	832411	9227486	23.06872	11.53436	40.96794	1	0.024244	41.52722
26	41.52722	2808103	12868000	855293	9204604	23.01151	11.50575	41.52722	1	0.023922	42.0777
27	42.0777	2808103	12868000	878119	9181778	22.95445	11.47722	42.0777	1	0.023613	42.61973
28	42.61973	2808103	12868000	900888	9159009	22.89752	11.44876	42.61973	1	0.023317	43.15364
29	43.15364	2808103	12868000	923601	9136296	22.84074	11.42037	43.15364	1	0.023033	43.67972

Table 6.0-3. Estimation of Cask Drop Velocity Through Water (Continued)

x	Vo	Fb	Fw	Fd	Fw-Fb-Fd	acc	Qa	Qb	Qc	t	V
30	43.67972	2808103	12868000	946257	9113640	22.7841	11.39205	43.67972	1	0.022759	44.19826
31	44.19826	2808103	12868000	968857	9091040	22.7276	11.3638	44.19826	1	0.022495	44.70952
32	44.70952	2808103	12868000	991401	9068496	22.67124	11.33562	44.70952	1	0.022241	45.21376
33	45.21376	2808103	12868000	1013889	9046008	22.61502	11.30751	45.21376	1	0.021996	45.7112
34	45.7112	2808103	12868000	1036322	9023575	22.55894	11.27947	45.7112	1	0.02176	46.20208
35	46.20208	2808103	12868000	1058698	9001199	22.503	11.2515	46.20208	1	0.021531	46.68659
36	46.68659	2808103	12868000	1081020	8978877	22.44719	11.2236	46.68659	1	0.02131	47.16495
37	47.16495	2808103	12868000	1103286	8956611	22.39153	11.19576	47.16495	1	0.021097	47.63733
38	47.63733	2808103	12868000	1125496	8934401	22.336	11.168	47.63733	1	0.02089	48.10392
39	48.10392	2808103	12868000	1147652	8912245	22.28061	11.14031	48.10392	1	0.020689	48.56489
40	48.56489	2808103	12868000	1169753	8890144	22.22536	11.11268	48.56489	1	0.020495	49.0204
41	49.0204	2808103	12868000	1191799	8868098	22.17025	11.08512	49.0204	1	0.020306	49.4706
42	49.4706	2808103	12868000	1213790	8846107	22.11527	11.05763	49.4706	1	0.020124	49.91563
43	49.91563	2808103	12868000	1235727	8824170	22.06043	11.03021	49.91563	1	0.019946	50.35565
44	50.35565	2808103	12868000	1257609	8802288	22.00572	11.00286	50.35565	1	0.019773	50.79077
45	50.79077	2808103	12868000	1279437	8780460	21.95115	10.97557	50.79077	1	0.019606	51.22114
46	51.22114	2808103	12868000	1301211	8758686	21.89671	10.94836	51.22114	1	0.019442	51.64686
47	51.64686	2808103	12868000	1322931	8736966	21.84242	10.92121	51.64686	1	0.019284	52.06806
48	52.06806	2808103	12868000	1344597	8715300	21.78825	10.89413	52.06806	1	0.019129	52.48485
49	52.48485	2808103	12868000	1366209	8693688	21.73422	10.86711	52.48485	1	0.018979	52.89734
50	52.89734	2808103	12868000	1387768	8672129	21.68032	10.84016	52.89734	1	0.018832	53.30562
51	53.30562	2808103	12868000	1409273	8650624	21.62656	10.81328	53.30562	1	0.018689	53.70979
52	53.70979	2808103	12868000	1430725	8629172	21.57293	10.78646	53.70979	1	0.018549	54.10996

Source: Original

As shown in Table 6.0-3, the drop velocity of the cask at the bottom of the pool (52 ft) is 54.1 ft/sec. Using the same technique, given a V_0 of 43.9 ft/sec (for a 30-ft drop above the pool water surface), the velocity of the cask hitting the pool bottom is 65.5 ft/sec.

6.0.8.3 Estimation of Perforation Velocity Through Steel Pool Liner

The velocity required for just-perforation of the pool liner is modeled as a missile striking a steel plate. The estimation is given in *External Events Hazards Screening Analysis* (Ref. 2.2.29), Equation A18e:

$$T^{1.5} = (0.5 \times M \times V^2)/(17400 \times K_s \times D^{1.5}) \qquad \text{(Eq. 23)}$$

where:

- T = predicted thickness to just perforate a steel plate (in.)
- M = mass of missile; W/g (lb_f-sec^2/ft)
- g = 32.2 ft/sec^2
- V = missile impact velocity (ft/sec)
- K_s = constant depending on the grade of steel (usually ~ 1)
- D = effective missile diameter (in.)

Equation 23 is rewritten as follows in Equation 24:

$$V = ((T^{1.5} \times 17400 \times K_s \times D^{1.5})/ (0.5 \times M))^{0.5} \qquad \text{(Eq. 24)}$$

Given T = 0.25 in., D = 108 in., K_s = 1, M = W/g = 400,000 lb_f/32.2 ft/sec^2 = 12,422 lb_f-sec^2/ft, the velocity needed to just perforate the pool liner is estimated below.

$$V = ((0.25^{1.5} \times 17400 \times 1 \times 108^{1.5})/ (0.5 \times 12{,}422))^{0.5} = 19.8 \text{ ft/sec}$$

If the pool liner thickness is 1 in. or T = 1 in., then the just perforation velocity is:

$$V = ((1^{1.5} \times 17400 \times 1 \times 108^{1.5})/ (0.5 \times 12{,}422))^{0.5} = 56.1 \text{ ft/sec}$$

6.0.8.4 Estimation of Impact Velocity on Concrete Pool Floor

The impact velocity on the concrete pool floor is estimated based on the difference in the kinetic energies of the cask dropping through the water and that used to perforate the steel liner. Kinetic energy is estimated using the Equation 25:

$$KE = \tfrac{1}{2} \times M \times V^2/g_c \qquad \text{(Eq. 25)}$$

where:

- KE = kinetic energy (lb_f-ft)
- M = mass of cask (400,000 lb_m)
- V = velocity (ft/sec)
- g_c = gravitational constant, 32.2 lb_m-ft/lb_f-sec^2

Using Equation 25, the kinetic energy of the cask impacting the pool floor at velocity V_1 of 54.1 ft/sec and the kinetic energy associated with the perforation of the pool liner that requires a velocity V_2 of 19.8 ft/sec is estimated as follows:

$KE_1 = ½ \times 400{,}000 \times 54.1^2/32.2 = 18{,}178{,}944$ (lb_f-ft) for $V_1 = 54.1$ ft/sec
and $KE_2 = ½ \times 400{,}000 \times 19.8^2/32.2 = 2{,}435{,}031$ (lb_f-ft) for $V_2 = 19.8$ ft/sec

The difference between KE_1 and KE_2 is the kinetic energy available to strike the concrete floor of the pool.

$$KE_c = KE_1 - KE_2 = 18{,}178{,}944 - 2{,}435{,}031 = 15{,}743{,}912 \ (lb_f\text{-ft})$$

From KE_c, the velocity impacting the concrete floor is calculated as follows:

$$V_c = (KE_c \times 2 \times g_c/M)^{0.5} = (15{,}743{,}912 \times 2 \times 32.2/400{,}000)^{0.5} = 50.3 \text{ ft/sec}$$

For a 30-ft drop above the pool water surface, with $V_1 = 65.5$ ft/sec, the velocity impacting the pool concrete floor would be:

$KE_1 = ½ \times 400{,}000 \times 65.5^2/32.2 = 26{,}647{,}515$ (lb_f-ft) for $V_1 = 65.5$ ft/sec
$KE_2 = ½ \times 400{,}000 \times 19.8^2/32.2 = 2{,}435{,}031$ (lb_f-ft) for $V_2 = 19.8$ ft/sec
$KE_c = KE_1 - KE_2 = 26{,}647{,}5154 - 2{,}435{,}031 = 24{,}212{,}484$ (lb_f-ft)
and $V_c = (KE_c \times 2 \times g_c/M)^{0.5} = (24{,}212{,}484 \times 2 \times 32.2/400{,}000)^{0.5} = 62.4$ ft/sec

For a 1 in. thick steel pool liner, the just perforation velocity, V_2, is 56.1 ft/sec. The impact velocities for the dropped heights, 6 ft and 30 ft above the pool water surface, are given below:

For 6-ft drop above the pool:
$KE_1 = ½ \times 400{,}000 \times 54.1^2/32.2 = 18{,}178{,}944$ (lb_f-ft) for $V_1 = 54.1$ ft/sec
$KE_2 = ½ \times 400{,}000 \times 56.1^2/32.2 = 19{,}547{,}888$ (lb_f-ft) for $V_2 = 56.1$ ft/sec
$KE_c = KE_1 - KE_2 = 18{,}178{,}944 - 19{,}547{,}888 = -1{,}368{,}944$ (lb_f-ft)

This shows that there is not enough kinetic energy to perforate the pool liner.

For 30-ft drop above the pool:
$KE_1 = ½ \times 400{,}000 \times 65.5^2/32.2 = 26{,}647{,}515$ (lb_f-ft) for $V_1 = 65.5$ ft/sec
$KE_2 = ½ \times 400{,}000 \times 56.1^2/32.2 = 19{,}547{,}888$ (lb_f-ft) for $V_2 = 56.1$ ft/sec
$KEc = KE_1 - KE_2 = 26{,}647{,}515 - 19{,}547{,}888 = 7{,}099{,}627$ (lb_f-ft)
and $V_c = (KE_c \times 2 \times g_c/M)^{0.5} = (7{,}099{,}627 \times 2 \times 32.2/400{,}000)^{0.5} = 33.8$ ft/sec

6.0.8.5 Estimation of the Pool Floor Penetration Thickness

The penetration of concrete pool floor is modeled as a missile striking a concrete wall without consideration of rebar. The methodology for evaluating the thickness for penetration is outlined in *External Events Hazards Screening Analysis* (Ref. 2.2.29). Penetration is the displacement of the missile into the target. As described in *External Events Hazards Screening Analysis* (Ref. 2.2.29), the penetration depth of the missile is given as Equation 26:

$$x = (4 \times K \times N \times W \times D \times (V/(1000 \times D))^{1.8})^{0.5} \text{ for } x/D \leq 2.0 \qquad \text{(Eq. 26)}$$

where:

x = penetration depth of the missile (in.)
K = concrete penetrability factor = $(180/(f'_c)^{0.5}) = (180/(5000)^{0.5}) = 2.55$
f'_c = ultimate compressive strength of concrete = 5,000 $lb_f/in.^2$
N = missile shape factor = 0.72 for flat-nosed bodies
W = missile weight = 400,000 lb_f
D = effective missile diameter = 108 in.
V = missile impact velocity = 50.3 ft/sec

Substituting these values into Equation 26, a penetration depth into the pool floor is estimated below:

$$x = (4 \times 2.55 \times 0.72 \times 400{,}000 \times 108 \times (50.3/(1000 \times 108))^{1.8})^{0.5}$$

$$x = 17.9 \text{ in.}$$

For a 30-ft drop above the pool water surface with an impact velocity of 62.4 ft/sec, the penetration depth is:

$$x = (4 \times 2.55 \times 0.72 \times 400{,}000 \times 108 \times (62.4/(1000 \times 108))^{1.8})^{0.5} = 21.7 \text{ in.}$$

Similarly, for a 1 in. thick steel pool liner, the penetration depth at the impact velocity of 33.8 ft/sec is:

$$x = (4 \times 2.55 \times 0.72 \times 400{,}000 \times 108 \times (33.8/(1000 \times 108))^{1.8})^{0.5} = 12.4 \text{ in.}$$

The penetration depth into the concrete pool floor is a function of drop height and the pool liner thickness, which is summarized below:

Table 6.0.4 Results of Cask Drop Penetration Depths

Drop height above pool water	Pool liner thickness 0.25 in.	1 in.
	Penetration depth into Pool Floor	
6 ft	17.9 in.	No penetration
30 ft	21.7 in.	12.4 in.

Source: Original

Given the pool floor thickness of 8 ft or 96 in., a cask drop penetrating 22 in. would not perforate the floor. This represents the local effects of the drop; since the pool is continuously supported by the underlying soil structure, structural response of the impacted concrete slab is not required. If the steel pool liner is 1 in. thick, there would be no perforation of the liner for a cask drop from normal operating height (6 ft); from a 30-ft drop, the concrete pool floor would be penetrated by a foot. In addition, the rebar, by bending, would hold the concrete together, thus preventing large cracks in the impacted concrete slab. In conclusion, a cask drop into the pool would not perforate the concrete pool floor and would not create cracks that could lead to significant loss of water. Therefore, further analysis of this initiating event is not required.

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6.1 EVENT TREE ANALYSIS

The event trees that are quantified in this analysis were developed from ESDs in the *Wet Handling Facility Event Sequence Development Analysis* (Ref. 2.2.37, Attachments F and G). This section describes the use of SAPHIRE (Section 4.2) to model event sequences. The event trees are discussed and presented in Attachment A.

6.1.1 Event Tree Analysis Methods

6.1.1.1 Linked Event Trees and Fault Trees

As described in Section 4, the PCSA uses linked event trees with linked fault trees to calculate the frequency of occurrence of event sequences. The SAPHIRE computer program (Section 4.2) is used for this purpose. The event tree quantification is supported by FTA (Section 6.2 and Attachment B), PEFA (Section 6.3.2 and Attachment D), and HRA (Section 6.4 and Attachment E). The YMP preclosure handling is performed using four kinds of buildings as summarized below:

1. The RF accepts DPC and TAD canisters and places them into aging overpacks, either destined for the aging pads or the CRCF.
2. The CRCF accepts all waste containers except those supplied by the Naval Nuclear Propulsion Program for placement in waste packages destined for emplacement in the repository emplacement drifts.
3. The WHF accepts DPCs and transportation casks containing uncanistered commercial SNF and transfers the SNF to TAD canisters which are destined for the CRCF or the aging pads.
4. The IHF accepts SNF canisters from the Naval Nuclear Propulsion Program and some canisters containing high-level radioactive waste for placement in waste packages destined for emplacement in the repository emplacement drifts.

Preclosure waste handling as modeled in the PCSA also includes TEV and Subsurface Operations. The TEV accepts waste packages from the CRCF and IHF and, by means of rail, transports and deposits it into its designated location in the emplacement drifts. All other extra-building transportation, low-level waste handling, and balance of plant is called Intra-Site Operations.

Event sequences are developed for each of the four building types, TEV and Subsurface Operations, and Intra-Site Operations. Because each type of waste container in the WHF has different characteristics that manifest during event sequences, separate event sequences are developed for each type of waste container. As described in the *Wet Handling Facility Event Sequence Development Analysis* (Ref. 2.2.37), event sequences are also developed separately for each major group of waste handling processes by location within the building. Therefore, event sequences also distinguish among the various steps in waste handling.

As described in Section 4.3, event sequences result in one of the following end states:

1. "OK"
2. Direct Exposure, Degraded Shielding
3. Direct Exposure, Loss of Shielding
4. Radionuclide Release, Filtered (HVAC)
5. Radionuclide Release, Unfiltered (HVAC system is not operating)
6. Radionuclide Release, Filtered, Also Important to Criticality
7. Radionuclide Release, Unfiltered, Also Important to Criticality
8. Important to Criticality.

Radionuclide release describes a condition where radioactive material has been released from the container creating a potential inhalation or ingestion hazard, accompanied by the potential for immersion in a radioactive plume and direct exposure.

The WHF has several unique release scenarios due to the operations that take place in the spent fuel handling pool. Several event sequences that end in release occur in the borated water of the pool. These releases are given an additional unique identifier to indicate that the release occurs in the pool water. The borated pool water prevents a release of particulate, but a gaseous release can still occur. The end states for a radionuclide releases from the pool have the word "gaseous" added to the end state description and are abbreviated as GRRF, GRRU, or GRRC. These end states are the same as those associated with radionuclide releases abbreviated RRF, RRU, and RRC.

The SAPHIRE computer program has advanced features that permit the analyst to control the inputs and conditions for quantifying linked event trees and fault trees. One feature is the use of "basic rules" by which the analyst tells the program how and when to link certain variations of fault trees and basic event data that describe a given initiating and pivotal event. This allows path dependent development of sequence minimal cut sets and probabilities.

The primary inputs to the program are the following:

- Event tree logic models
- Fault tree logic models for initiating and pivotal events
- Initiating event frequencies derived from waste-form throughputs and numbers of opportunities for initiating an event sequence
- Basic event data that provides failure rates for active and passive equipment and for HFEs. The basic event data also includes a probability distribution of uncertainty associated with each basic event. The event tree and fault tree logic models are linked to the basic event library.

Each basic event is characterized by a probability distribution. SAPHIRE's Monte Carlo sampling method is employed to propagate the uncertainties to obtain event sequence mean values and parameters of the underlying probability distribution such as variance. As described in Section 4.3.6, categorization is done on aggregated event sequences, whose resultant probability distributions are also obtained by Monte Carlo simulation. SAPHIRE accounts for the correlation between analogous basic events sharing the same reliability information, which ensures the spread of the probability distribution of the event sequences in which these basic events intervene is not underestimated.

6.1.1.2 Initiator, System-Response, and Self-Contained Event Trees

Event sequences are described and graphically depicted using one or two event trees depending on whether the ESD considered has one or more initiating events:

1. **Self-contained event trees.** Self-contained event trees are used when only one initiating event appears in the corresponding ESD (Ref. 2.2.37, Attachment F). An example is WHF-ESD12-DPC, which is shown in Figure A5-20 in Attachment A. The feed on the left side of the event tree is an event that represents the frequency of challenge to the successful operation of the process step represented in the event tree. In the example, the frequency of challenge is equal to the number of transportation casks containing DPCs that are handled over the preclosure period in the WHF. The initiating event is presented next, followed by the pivotal events. By convention, the description of each branching event is stated as a success. The branching under each event heading represents success by an upward branch and failure by a downward branch. If a given pivotal event cannot occur in a given sequence due to a prior pivotal event or is irrelevant to the sequence, it does not appear in the event sequence as illustrated in the corresponding ESD and no branching occurs in the event tree. Each pathway through a self-contained event tree terminates in an end state. End states that are labeled "OK" mean that the sequence of events does not result in one of the specifically identified undesired outcomes. "OK" often means that normal operation can continue. The undesired end states represent a release of airborne radioactivity, a direct exposure to radiation, or a potential criticality condition.

2. **Separate initiator and system-response event trees**. Separate event trees for initiating events and the system response are used when more than one initiating event appears in the corresponding ESD (Ref. 2.2.37, Attachment F). The initiator event tree decomposes a group of initiating events into the specific failure events that comprise the group. For example, an initiator event tree, WHF-ESD01-CSNF, is shown in Figure A5-2 in Attachment A, and the corresponding system response event tree, RESPONSE-TCASK-CSNF, is shown in Figure A5-3. The feed to the left side of the initiator event tree is an event that represents the frequency of challenge to the successful operation of the process step represented in the event tree. In the example, the frequency of challenge is equal to the number of transportation casks containing uncanistered spent nuclear fuel that are received during the preclosure period. Initiator event trees do not end at end states but transfer to a system response event tree. System response event trees contain only pivotal events. The user specifies the models to be used for the initiating events associated with each initiator event tree and the pivotal events associated with the corresponding system response event tree by writing "basic rules," which are attached to the initiator event tree in SAPHIRE. In accordance with the user-specified basic rules, the SAPHIRE program links a specific fault tree model or basic event to a given initiating event or pivotal event. Because the

conditional probability of each pivotal event may be specific to the initiating event for each event sequence, the same system response event tree is quantified by SAPHIRE as many times as there are initiating events in the initiator event tree.

6.1.1.3 Summary of the Major Pivotal Events

A self-contained event tree or a system response event tree may include pivotal events concerning the success or failure of the waste package, transportation cask, canister, shielding properties, HEPA filtration availability, and moderator intrusion susceptibility. The pivotal events are summarized in Attachment A, Section A3.

Each of the specific failure events included in a self-contained or system-response event tree may be linked to a basic event or to the top event of a fault tree. Two kinds of fault trees are developed and represented in Attachment B. The first type represents equipment fault trees including HFEs that contribute directly to the specific pivotal or initiating event. The second type links initiating and pivotal events to these equipment fault trees (via transfer gates) and miscellaneous events. This second type is called a linking or connector fault tree. The equipment fault tree models are, in turn, linked to basic event reliability information separately entered into SAPHIRE. Some of the pivotal events do not have associated fault trees because they are linked directly to basic events in the reliability database entered into SAPHIRE. Section 6.2 provides more information about the reliability information developed for this analysis.

6.1.2 Waste Form Throughputs

Each initiator event tree and self-contained event tree begins with the container throughputs, that is, the numbers of waste form units (such as casks, canisters, or fuel assemblies) to be handled over the life of the WHF. The throughputs are identified in Table 6.1-1 and are drawn into the descriptions of specific event trees as needed. With the number of waste form units as a multiplier in the event tree and the initiating events specified as a probability per waste form unit, the value passed to the system response is the number of occurrences of the initiating event expected over the life of the facility.

Table 6.1-1. Waste Form Throughputs for the WHF Over the Preclosure Period

Waste Form Unit	WHF Throughput Over the Preclosure Period	Comment
Transportation casks containing bare SNF assemblies (9 BWR or 4 PWR SNF assemblies per cask)	3,775	Total number of transfers
Transportation casks or horizontal shielded transfer casks containing a DPC	346	One canister per cask
Aging overpack containing a DPC	346	One canister per aging overpack
Aging overpack containing a TAD canister	1,165	One canister per aging overpack
DPCs (64 BWR or 25 PWR SNF assemblies per canister)	346	Same as number of DPC casks, number of transfers by a CTM inside the WHF
TAD canisters produced at the repository	1,165	Same as number of TAD canister casks (44 BWR or 21 PWR SNF assemblies per canister)
SNF assemblies transferred in the pool of the WHF (from a bare-fuel transportation cask or DPC to a staging rack, and from a staging rack to a TAD canister)	66,208	Total number of transfers

NOTE: BWR = boiling water reactor; CTM = canister transfer machine; DPC = dual-purpose canister; PWR =pressurized water reactor; SNF = spent nuclear fuel; TAD = transportation, aging, and disposal; WHF = Wet Handling Facility.

Source: Ref. 2.2.26, Table 4

6.1.3 Guide to Event Trees

Event trees are located in Attachment A. Table 6.1-2 contains the crosswalk from the ESD (Ref. 2.2.37, Attachment F) to the initiating event tree and response tree figure location in Attachment A.

Table 6.1-2. Figure Locations for Initiating Event Trees and Response Trees

ESD#	ESD Title	IE Event Tree Name	IE Event Tree Location	Response Tree Name	Response Tree Location
WHF-ESD01	Event Sequences for Activities Associated with Receipt of Transportation Cask with Spent Nuclear Fuel in the Transportation Cask Vestibule and Movement into Cask Preparation Area	WHF-ESD01-CSNF	Figure A5-2	RESPONSE-TCASK-CSNF	Figure A5-3
WHF-ESD02	Event Sequences for Activities Associated with Receipt of Transportation Cask with DPC in the Transportation Cask Vestibule and Movement into Cask Preparation Area	WHF-ESD02-DPC	Figure A5-4	RESPONSE-TCASK-DPC	Figure A5-5
WHF-ESD03	Event Sequences for Activities Associated with Receipt of Aging Overpack in the Site Transporter Vestibule	WHF-ESD03-AODPC	Figure A5-6	RESPONSE-CANISTER1	Figure A5-7
WHF-ESD04	Event Sequences for Activities Associated with Receipt of Horizontal STC/DPC in the Transportation Cask Vestibule and Movement into the Cask Preparation Area	WHF-ESD04-DPC	Figure A5-8	RESPONSE-STC1	Figure A5-9
WHF-ESD05	Event Sequences for Activities Associated with TC/CSNF Removal of Impact Limiters, Upending, and Removal from Conveyance and Transfer to Preparation Station	WHF-ESD05-CSNF	Figure A5-10	RESPONSE-TCASK-CSNF	Figure A5-3
WHF-ESD06	Event Sequences for Activities Associated with Removal of Impact Limiters, Upending, and Removal of Transportation Cask from Conveyance and Transfer to CTT	WHF-ESD06-VTC WHF-ESD06-TTC	Figure A5-11 Figure A5-13	RESPONSE-TCASK	Figure A5-12

Table 6.1-2. Figure Locations for Initiating Event Trees and Response Trees (Continued)

ESD#	ESD Title	IE Event Tree Name	IE Event Tree Location	Response Tree Name	Response Tree Location
WHF-ESD07	Event Sequences for Associated Cask Preparation Activities (i.e., Installation of Lid Lift Fixture on Transportation Cask/DPC)	WHF-ESD07-DPC	Figure A5-14	RESPONSE-TCASK	Figure A5-12
WHF-ESD08	Event Sequences for Associated Cask Preparation Activities (i.e., Installation of Cask Lid Lift Fixture on Transportation Cask/CSNF)	WHF-ESD08-CSNF	Figure A5-15	RESPONSE-TCASK-CSNF	Figure A5-3
WHF-ESD09	Event Sequences for Associated Cask Preparation Activities (i.e., Lid Removal, or Installation of DPC Lid Lift Fixture, STC/DPC or Transportation Cask/DPC)	WHF-ESD09-DPC	Figure A5-16	RESPONSE-CANISTER1	Figure A5-7
WHF-ESD10	Event Sequences Associated with Transfer of Cask on CTT from Preparation Area to Cask Unloading Room	WHF-ESD10-DPC	Figure A5-17	RESPONSE-CANISTER1	Figure A5-7
WHF-ESD11	Event Sequences Associated with Transfer of an Aging Overpack/DPC or Aging Overpack/TAD on Site Transporter, through Site Transporter Vestibule, Aging Overpack Access Platform, and Loading Room (Receipt or Export)	WHF-ESD11-AODPC WHF-ESD11-AOTAD	Figure A5-18 Figure A5-19	RESPONSE-CANISTER1	Figure A5-7
WHF-ESD12	Event Sequences Associated with Aging Overpack (DPC or TAD) on Site Transporter or STC/TAD on CTT Colliding with Cask Loading Shield Door	WHF-ESD12-DPC WHF-ESD12-TAD	Figure A5-20 Figure A5-21	N/A	N/A

Table 6.1-2. Figure Locations for Initiating Event Trees and Response Trees (Continued)

ESD#	ESD Title	IE Event Tree Name	IE Event Tree Location	Response Tree Name	Response Tree Location
WHF-ESD13	Event Sequences for Activities Associated with the Transfer of a Canister to or from an Aging Overpack, STC, or Transportation Cask with the CTM	WHF-ESD13-DPC WHF-ESD13-TAD	Figure A5-22 Figure A5-23	RESPONSE-CANISTER1	Figure A5-7
WHF-ESD14	Event Sequences for Activities Associated with the Transfer of STC/DPC from the Cask Unloading Room to the Preparation Station	WHF-ESD14-DPC	Figure A5-24	RESPONSE-STC1	Figure A5-9
WHF-ESD15	Event Sequences for Activities Associated with the Transfer of STC/DPC from the Preparation Station to the DPC Cutting Station	WHF-ESD15-DPC	Figure A5-25	RESPONSE-STC1	Figure A5-9
WHF-ESD16	Event Sequences for Activities Associated with the STC/DPC Preparation at the Preparation Station	WHF-ESD16-CSNF	Figure A5-26	RESPONSE-PREPSTATION	Figure A5-27
WHF-ESD17	Event Sequences for Activities Assoicated with the STC/DPC Preparation Activities at the DPC Cutting Station	WHF-ESD17-DPC	Figure A5-28	RESPONSE-PREPSTATION	Figure A5-27
WHF-ESD18	Event Sequences for Activities Associated with the STC/DPC Preparation Activities – DPC Cutting at DPC Cutting Station	WHF-ESD18-DPC	Figure A5-29	RESPONSE-PREPSTATION	Figure A5-27
WHF-ESD19	Event Sequences Associated with Transfer of STC/DPC from DPC Cutting Station to Pool Ledge	WHF-ESD19-DPC	Figure A5-30	RESPONSE-POOLMOVE RESPONSE-STC1	Figure A5-31 Figure A5-9
WHF-ESD20	Event Sequences Associated with Transfer of Transportation Cask/CSNF from Preparation Station to Pool Ledge	WHF-ESD20-CSNF	Figure A5-32	RESPONSE-POOLMOVE RESPONSE-TCASK-CSNF	Figure A5-31 Figure A5-3

Table 6.1-2. Figure Locations for Initiating Event Trees and Response Trees (Continued)

ESD#	ESD Title	IE Event Tree Name	IE Event Tree Location	Response Tree Name	Response Tree Location
WHF-ESD21	Event Sequences for Activities Involving Lowering STC/DPC or Transportation Cask/CSNF to the Pool Floor	WHF-ESD21-CSNF WHF-ESD21-DPC WHF-ESD21-TAD	Figure A5-33 Figure A5-34 Figure A5-35	RESPONSE-POOLMOVE	Figure A5-31
WHF-ESD22	Event Sequences for Pool Activities Involving Transfer of Fuel Assembly to TAD Canister or Fuel Staging Rack	WHF-ESD22-FUEL	Figure A5-36	RESPONSE-POOLCONFINE	Figure A5-37
WHF-ESD23	Event Sequences for Activities Associated with Handling of Low-Level Liquid Waste	WHF-ESD23-POOL	Figure A5-38	N/A	N/A
WHF-ESD24	Event Sequences for Activities Associated with the Transfer of STC/TAD from the Pool Ledge to the TAD Canister Closure Station	WHF-ESD24-TAD	Figure A5-39	RESPONSE-POOLMOVE RESPONSE-STC1	Figure A5-31 Figure A5-9
WHF-ESD25	Event Sequences for Activities Associated with Preparation of STC/TAD and Closure of TAD Canister	WHF-ESD25-TAD	Figure A5-40	RESPONSE-TAD	Figure A5-41
WHF-ESD26	Event Sequences for Activities Associated with Closure of TAD Canister – TAD Drying and Inerting Process	WHF-ESD26-TAD	Figure A5-42	N/A	N/A
WHF-ESD27	Event Sequences for Activities Associated with TAD Closure – Welding, Drying, and Inerting Process	WHF-ESD27-TAD	Figure A5-43	RESPONSE-PREPSTATION	Figure A5-27
WHF-ESD28	Event Sequences for Activities Associated with Transfer of STC/TAD from TAD Closure Station to CTT in the Preparation Station	WHF-ESD28-TAD	Figure A5-44	RESPONSE-CANISTER1	Figure A5-7
WHF-ESD29	Direct Expsoure Event Sequences for Activities Associated with Cask Preparation or CTM Movement	WHF-ESD29-DPC WHF-ESD29-TAD	Figure A5-45 Figure A5-46	N/A	N/A

Table 6.1-2. Figure Locations for Initiating Event Trees and Response Trees (Continued)

ESD#	ESD Title	IE Event Tree Name	IE Event Tree Location	Response Tree Name	Response Tree Location
WHF-ESD30	Direct Exposure Event Sequences for Activities Associated with Pool Operations	WHF-ESD30-DPC WHF-ESD30-FUEL	Figure A5-47 Figure A5-48	N/A	N/A
WHF-ESD31	Event Sequences for Activities Associated with Fires Occurring in the WHF	WHF-ESD31-CSNF WHF-ESD31-DPC WHF-ESD31-TAD	Figure A5-49 Figure A5-51 Figure A5-52	RESPONSE-FIRE	Figure A5-50

NOTE: CSNF = commercial spent nuclear fuel; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; ESD = event sequence diagram; IE = initiating event; STC = shielded transportation cask; TAD = transportation, aging, and disposal canister; TC = transportation cask; VTC = a transportation cask that is upended on a railcar.

Source: Attachment A, Table A5-1

6.2 ANALYSIS OF INITIATING AND PIVOTAL EVENTS

6.2.1 Approach to Analysis of Initiating and Pivotal Events for Linking to Event Sequence Quantification

Section 4.3.2 provides a brief introduction to the application of FTA for initiating and pivotal events, including an example fault tree. Many of the initiating events involve faults in complex machinery for which no historical data exists at the system level, an exception being, historical data on load drops from cranes. Therefore, FTA is employed to map elements of equipment design and operational features to various failure modes of components down to a level of assembly, termed "basic events" for which historical data is available. Attachment B presents the fault tree logic and stand-alone quantifications.

Much of the equipment used in the WHF is also used in other surface facilities and the Intra-Site Operations. Furthermore, a given system, such as the site transporter, may affect the event sequences for several operational nodes of the same facility or several kinds of waste forms, as it does for the WHF. Therefore, the logic of the fault trees described in this section and Attachment B are linked to event trees where appropriate, via an intermediate top event name that is unique to the event sequence per the waste form involved and operational node. In this way, the logic structure of the system fault tree may be used over and over but, by virtue of the rules feature of SAPHIRE, the inputs to each fault tree can be tailored to fit the event sequence.

The fault trees are linked to the event trees via the initiating event tree rules file and the application of linking fault trees. The rules file specifies the names of the linking fault trees for initiating event and pivotal event fault trees to be substituted into the event tree top events during quantification. The rules files also specify the use of particular values for basic events and other probabilistic factors that affect the event sequence quantification. The linking fault trees have unique names for the facility and the operational nodes for each event tree. The linking fault trees are very simple, usually having a single top event that is an OR gate that connects to one of the system fault trees. This allows for application of unique top event probabilities to the different initiating events modeled in the initiating event tree.

Attachment B, Sections B1 through B9 presents all of the system fault trees. This section describes the bases for the system fault trees and the quantification of their top events.

Attachment B, Section B10 presents the linking fault trees used in the WHF analysis. The linking fault trees are self explanatory. No quantification is performed for the linking trees alone.

A top event occurs when one of the success criteria for a given SSC fails to be achieved. At least one success criteria is defined for each system. Multiple success criteria are defined for systems that perform multiple safety functions in the WHF.

Each of the top events for the initiating event fault trees represent the conditional probability that the top event will occur when the system is put into service. That is, the results of the FTA answer a question such as "what is the probability given each canister lift that the CTM drops the canister, given a lift?" The expected number of canister drop initiating events during the preclosure period is the product of the number of times a canister is lifted during the preclosure operations and the conditional probability of the top event. Such values for the expected number of canister drops are not developed directly, however. Instead, the initiating event tree in SAPHIRE links the various fault tree logic models to the canister, or other waste form, and the throughput values to generate the initial portions of event sequence cut sets that are subsequently processed as part of the solution of the complete event sequence that includes pivotal events.

By contrast, the top event for the confinement function of the HVAC represents the conditional probability that the confinement feature is not achieved for the required duration following an airborne release of radioactive material inside the WHF. The quantification of the top event, as summarized in Section 6.2.2.7 and detailed in Attachment B, Section B7, is expressed as unavailability. The results provide insight into the reliability of the HVAC and its contribution to event sequence quantification. Again, the quantified top event is not used directly in the event sequence quantification. Instead, the fault tree logic for the HVAC is linked to event sequence analysis via SAPHIRE.

In general, each FTA in Attachment B is developed to include both (1) HFEs, and (2) mechanical failures that result in the occurrence of the top event. The HFEs include postulated unintended operator actions that could potentially occur during the facility activity and, as applicable, hardware failures for those SSCs whose function are to prevent the top event from occurring given the unintended operator action occurs (e.g., interlock). Mechanical failures typically involve random component failures (electrical, mechanical, etc.) and failures from the loss of a supporting system (e.g., loss of power).

For quantification of the probability of the top event, failure probabilities are developed for each basic event (hardware or HFE) and are used to compute the probability of each cut set. For component failure data that is expressed as "failures per hour," a "mission time" must be defined. In many instances in the FTA quantification, a mission time of 1 hour is used if this value is conservative. Where mission time is critical, appropriate times are justified and incorporated into the event sequence quantification. Hardware failure probabilities are taken from the reliability analysis data discussed in Sections 6.3. HFE probabilities are taken from the HFE analysis discussed in Section 6.4.

Uncertainties in the probabilities of basic events are included in the inputs to the SAPHIRE analysis. The uncertainties are propagated through the FTA to yield the uncertainty distribution of the top event.

Issues that are addressed in the fault trees, in addition to the mapping of the descriptions of the physical system into a fault tree logic diagram based on explicit effects of mechanical and hardware failures, include the following:

- Basic event data
- Common-cause and common mode failures such as failures induced by common training, maintenance practices, fabrication, common electrical supplies
- Support systems and subsystems such as filtering (e.g., HVAC, HEPA filters) and electrical

- System interactions
- HFEs
- Control logic malfunctions.

The following subsections provide summaries of the analyses detailed in Attachment B. For each fault tree, the following information is provided:

- Physical description
- Operation
- Control system
- System/pivotal event success criteria
- Mission time
- Fault tree results.

6.2.2 Summary of Fault Tree Analysis

6.2.2.1 Site Prime Mover Fault Tree Analysis

The FTA is detailed in Attachment B, Section B1. The following is a summary of the design, operations, success criteria, and results of the fault tree quantification. See Attachment B, Section B1 for sources of information on the physical and operational characteristics of the site prime mover (SPM).

6.2.2.1.1 Physical Description

The SPM is a diesel/electric self-propelled vehicle that is designed to move railcars or truck trailers loaded with transportation casks. The transport occurs for both the Intra-Site Operations and within the WHF. Movement of the SPM with railcars (i.e., site prime mover railcars (SPMRC)) or truck trailers (i.e., site prime mover truck trailers (SPMTT)) within the WHF is limited to the entry vestibule and the Cask Preparation Room.

Retractable railroad wheels attached to the front and rear axles of the SPM are used for rail operations. The driving and braking power comes directly from the road tires, as they are in contact with the rails. A diesel engine provides the energy to operate the SPM outside the facilities. Inside the WHF, the SPM is electrically driven via an umbilical cord (or remote control) from electrical power obtained from the WHF main electrical supply.

6.2.2.1.2 Operations

In-facility SPM operations begin after the SPM has positioned the railcar or truck trailer outside the WHF. The site prime mover diesel engine is shut down and the outer is opened. Facility power is connected to the SPM for all operations inside the facility. The operator connects the pendant controller or uses a remote (i.e., wireless) controller to move the SPM to push the railcar or truck trailer into the vestibule.

In the event of loss of power, the SPM is designed to stop, retain control of the railcar or truck trailer, and enter a locked mode where it remains until operator action is taken, to return to normal operations.

6.2.2.1.3 Control System

A simplified schematic of the functional components on the SPMRC/truck trailer is shown in Attachment B1, Figure B1.2-1.

The control system provides features for preventing initiating events:

- The SPM is designed to stop whenever (1) commanded to stop, or (2) when there is a loss of power.
- The operator can stop the SPM by either commanding a stop from the start/stop button or by releasing the palm switch which initiates an emergency stop.
- At anytime there is a loss of power detected, the SPM will immediately stop all movement and enter into "lock mode" safe state. The SPM will remain in this locked mode until power is returned and the operator restarts the SPM.

6.2.2.1.4 System/Pivotal Event Success Criteria

Success criteria for the SPM are the following:

- Prevent SPMRC AND SPMTT collisions
- Prevent SPMRC derailment
- Prevent SPMTT rollover.

Various design features are provided to achieve each of the success criteria. The failure to achieve each success criterion defines the top event of a fault tree for the SPM.

6.2.2.1.5 Mission Time

A nominal 1 hour mission time is used to calculate the failure probability for components having a time-based failure rate. One hour is conservative because it does not require more than 1 hour to disconnect the SPM from the railcar and remove it from the facility. Otherwise, failure-on-demand probabilities are used.

For railcar derailment, the probability is based on the distance traveled inside the WHF (0.04 miles) and industry data derailment rate of 1.18E-5 per hour traveled (Attachment C, Table C4-1, DER-FOM).

6.2.2.1.6 Fault Tree Results

The detailed description in Attachment B, Section B1 documents the application of basic event data, CCFs, and HRA.

The SPMRC or SPMTT has three credible failure scenarios:

1. SPMRC collides with WHF structures
2. SPMTT collides with WHF structures
3. SPMRC Derailment
4. SPMTT Rollover.

Each failure mode may occur with various waste forms that are received in the transportation casks.

Results of the analysis are summarized in Table 6.2.-1.

Table 6.2-1.Summary of Top Event Quantification for the Site Prime Mover

Top Event	Mean Probability	Standard Deviation
SPMRC collides with WHF structures	4.3E-03	1.1E-02
SPMTT collides with WHF structures	4.3E-03	1.0E-02
SPMRC derailment	4.7E-07	7.4E-09
SPMTT rollover (operator error)	0.0E+00	0.0E+00

NOTE: SPMRC = site prime mover railcar; SPMTT = site prime mover truck trailer; WHF = Wet Handling Facility.

Source: Attachment B, Section B1, Figures B1.4-1, B1.4-6, B1.4-11 and Section B1.4.4.5

6.2.2.2 Cask Transfer Trolley Fault Tree Analysis

The FTA for the CTT is detailed in Attachment B, Section B2. The following is a summary of the design, operations, success criteria, and results of the fault tree quantification. See Attachment B, Section B2 for sources of information on the physical and operational characteristics of the CTT.

6.2.2.2.1 Physical Description

The CTT is an air powered machine that is used to transport various vertically oriented transportation casks from the Cask Preparation Area to the Cask Unloading Room. The trolley consists of a platform, a cask support assembly, a pedestal assembly, a seismic restraint system, and an air system.

The CTT will handle a number of different casks so several different pedestals are used to properly position the cask height. Each pedestal sub-component is designed for its respective cask to sit down in a "cavity." In addition, the cask is restrained in the longitudinal and transverse directions by the cavity walls and restrained in the vertical down direction by the pedestal itself. This design also ensures the cask is positioned correctly. The trolley is positioned within a set tolerance under the cask port in the Canister Transfer Room using bumpers and stops that are bolted to the floor of the Cask Unloading Room and which are designed with bolts that would break to allow the CTT to slide during a seismic event.

Further, the cask is also restrained by two electric powered linkage systems that prevent side motions during a seismic event. Different cask diameters are handled by bolting unique interface clamps on the seismic restraints. When the restraint system is properly positioned next to the cask, two locking pins are pneumatically actuated to secure the position of the system. If the locking pins are not secured, the CTT will not be able to power up and move/levitate.

The facility compressed air supply inflates air casters beneath the trolley platform, which allow the CTT to rise above the steel floor. The platform mounted hose reel has an air-powered return, a ball valve shut-off, quick disconnect fittings, and a safety air fuse. A main “off/on” control valve and separate flow control/monitoring valves for each air bearing allow adjustment and verification of pressure/flow for each individual bearing. Interlocks for the air are provided to verify the main incoming pressure is not too high, and to verify that all bearings have sufficient air pressure.

End-mounted turtle-style drive units that are 360° steerable are used to steer the CTT. Traction is produced by down-pressure on the wheels provided by a small air bag on each drive unit.

The CTT is evaluated for a collision with another object while carrying the cask. The speed of the drives, 10 ft/min, has been set so that the forces the cask experiences during a seismic event would envelope a collision. The speed is controlled in two ways. First, the electrical control system is designed to only give a proportional signal to the air valve that produces a speed of 0 to 10 ft/min. In the event this control system fails, a factory set mechanical throttle valve, in line with each motor drive, allows a maximum amount of air through at any time to prevent a “run-away” condition.

6.2.2.2.2 Operation

Initially, the CTT is located in the Cask Preparation Area with the battery fully charged, the seismic restraints retracted, and with no air or electrical power connected. Based on the next planned cask to be loaded onto the trolley, the corresponding pedestal components are installed into the base, and bumpers are bolted onto the seismic restraints and supports. The air hose is then connected to the CTT.

The overhead crane moves a cask onto the pedestal. With the cask still attached to the crane, the operator remotely operates the seismic restraints and secures the cask to the CTT. When the restraints are in place, the locking pins are pneumatically inserted remotely. With the cask secured to the CTT, the overhead crane is disengaged from the cask.

When the locking pins are inserted properly, an interlock allows the air bearings and drive motors to be operated. Once all preparations of the cask are complete, the CTT can be raised and moved to the Canister Transfer Room. Guides bolted to the floor insure that the CTT can only move forward and back, and will position the CTT so that the cask is directly below the transfer port. Once in position, the air pressure to the bearings is stopped and the CTT rests in position. The shield doors that separate the Cask Preparation Area from the Canister Transfer Room are then closed.

6.2.2.2.3 Control System

The control system is relay based and includes a pendant station as its operator interface.

No programmable logic controller (PLC) is used; all interlocks are hard wired. The pendant is a standard crane pendant that has all of the controls for the unit including:

- Deadman handle – operator must depress both handles to allow air to flow to the system so the CTT can levitate or move horizontally.
- E-stop (emergency stop) button on the pendant control and on the CTT.
- Clockwise/counterclockwise momentary switch to turn the drive units for horizontal movement. This rotational characteristic is used to move the CTT to storage or maintenance location after it leaves the Cask Preparation Area.
- Forward/reverse switch to determine direction of the drive units.
- Drive speed – variable speed control switch.
- Cask restraint – selector switch that actuates the motor to close the restraints and automatically engage the locking pin.

During normal operations, the controls operate off a battery system contained on the CTT. Only one operator is needed to drive the CTT since it only travels in one direction when it is carrying a cask.

The main air supply valve is a pilot operated solenoid valve that is fail safe (i.e., it is a spring valve that closes upon loss of electrical power or loss of air pressure). The air supply valve opens when the locking pins actuate the limit switches and the pendant deadman switches are actuated.

6.2.2.2.4 System/Pivotal Event Success Criteria

Success criteria for the CTT are the following:

- Ensure the CTT remains stationary with no spurious movement during transportation cask placement onto the CTT, transportation cask preparation, or during unloading.
- Prevent collisions while moving the CTT with cask from the Cask Preparation Area to the Cask Unloading Room.

Various design features are provided to achieve each of the success criteria. The failure to achieve each success criterion defines the top event of a fault tree for the CTT.

6.2.2.2.5 Mission Time

In all cases a conservative mission time of 1 hour per cask transfer is used for each fault tree.

6.2.2.2.6 Fault Tree Results

The detailed analysis is presented in Attachment B, Section B2.

There are four fault trees associated with the CTT:

1. Spurious movement in the Cask Preparation Room while loading a cask onto the CTT.
2. Spurious movement in the Cask Preparation Room during unbolting and lid adapter installation.
3. Spurious movement at the Cask Unloading Room while unloading canisters from the CTT.
4. Collision with an object or structure while moving a cask from the Cask Preparation Area to the Canister Transfer Room.

The results of the analysis are summarized in Table 6.2-2. Four fault trees were developed where the top events correspond to one of the scenarios listed above.

Table 6.2-2 Summary of Top Event Quantification for the Cask Transfer Trolley

Top Event	Mean Probability	Standard Deviation
Spurious movement of the CTT during cask loading	1.7E-9	7.5E-9
Spurious movement of the CTT during cask preparation	1.2E-4	2.0E-4
CTT collision into structure	1.0E-3	1.2E-3
Spurious movement during canister transfer	<1.0E-9[a]	<1.0E-9[a]

NOTE: [a]<1.0E-9 represents an insignificant contribution to the top event probability. The actual value is given in Figure B2.4-12.

CTT = cask transfer trolley.

Source: Attachment B, Section B2, Figures B2.4-1, B2.4-5, B2.4-8 and B2.4-12

6.2.2.3 Shield Door and Slide Gate Fault Tree Analysis

The WHF Cask Unloading Room and Loading Rooms have a slide gate providing access to the Canister Transfer Room and a shield door providing access to either the Cask Preparation Area or the Site Transport Vestibule. The shield doors and slide gates provide shielding during cask unloading and loading.

The FTA is detailed in Attachment B, Section B3. The following is a summary of the design, operations, success criteria, and results of the fault tree quantification. See Attachment B, Section B3 for sources of information on the physical and operational characteristics of the shield doors and slide gates.

6.2.2.3.1 Physical Description

The Cask Unloading Room's shield doors are opened to allow cask-carrying equipment, such as the site transporter, to enter the room. Once equipment is positioned properly in a Cask Unloading Room, shield doors may be shut in preparation for removing canisters from the cask. Once the shield doors are shut, the slide gate may be opened, to allow the CTM to perform cask unloading operations. Aging overpack loading operations in the Loading Room are analogous to cask unloading operations.

The shield doors consist of a pair of large heavy doors that close together. The doors are operated by individual motors that have over-torque sensors to prevent crushing of an object. Each door has two position sensors to indicate either a closed or open door and an obstruction sensor prevents the doors from closing on an object. The shield doors and slide gate are interlocked to prevent one another from opening if the other is open. The shield doors are opened and closed via a hand lever that must be enabled by an enable/disable switch. An emergency-open switch exists enabling the doors to be opened in case of an emergency situation.

Similar to the shield doors, the slide gate consists of two gates that close together between the Loading/Unloading Rooms and the Canister Transfer Room. The gates are operated by individual motors that also have over-torque sensors. Each gate has limit switches to indicate open or closed gates. A CTM skirt-in-place switch is interlocked to the slide gate to prevent the gates from opening without the CTM in place and a CTM in-place bypass hand switch exists for maintenance activities. Slide gate operation is controlled by a hand switch coupled with an enable/disable switch and shield door interlocks prevent the slide gate from opening when the shield door is open. Open/closed and CTM in-place indicators exist to assist operators in their activities.

6.2.2.3.2 Operation

The Cask Unloading Room shield doors are opened to allow cask-carrying equipment, such as the SPM, to enter the room. Once equipment is positioned properly in an Unloading Room, shield doors are shut in preparation for removing canisters from the cask. Once the shield doors are shut, the slide gate may be opened to allow the CTM to perform cask unloading operations.

6.2.2.3.3 Control System

The control systems have hard-wired interlocks for the following functions:

- Redundant hardwire interlocks prevent the shield door from opening while the slide gate is open.
- The shield door system will not have any test, maintenance or other modes/settings that will allow bypass of interlocks.
- A single interlock prevents the slide gate from opening when the CTM skirt is not in place.
- An obstruction sensor is provided to detect objects between the shield doors and prevent door closure initiation.
- Motor over-torque sensors are provided to prevent shield doors from causing damage to casks or waste packages in the event of closure on a conveyance.
- Shield doors and slide gates are equipped with redundant hardwire interlocks to prevent one another from opening when the other is open.

6.2.2.3.4 System/Pivotal Event Success Criteria

Success criteria for the shield door and slide gate are the following:

- Prevent inadvertent opening of shield door
- Prevent inadvertent opening of the slide gate
- Prevent concurrent opening of the shield door and slide gate when waste is present
- Prevent shield door closing on CTT carrying a transportation cask or site transporter carrying an aging overpack.

Various design features are provided to achieve each of the success criteria. The failure to achieve each success criterion defines the top event for a fault tree for the CTT.

6.2.2.3.5 Mission Time

Most of the basic events in the fault tree models are "failure on demand" for equipment failures and "failure per operation" for HFEs. A mission time of 1 hour is used to calculate the probability of a spurious signal being sent due to PLC failure.

6.2.2.3.6 Fault Tree Results

The detailed analysis is presented in Attachment B, Section B3.

The slide gate and shield door system has three credible failure scenarios:

1. Inadvertent opening of the shield door
2. Inadvertent opening of the slide gate
3. Shield door closes on conveyance.

The results of the analysis are summarized in Table 6.2-3. Three fault trees were developed where the top events correspond to one of the scenarios listed above.

Table 6.2-3.Summary of Top Event Quantification for the Shield Doors and Slide Gate

Top Event	Mean Probability	Standard Deviation
Inadvertent Opening of the Shield Door	1.3E-07	4.6E-07
Inadvertent Opening of the Slide Gate	3.5E-09	1.2E-08
Shield Door Closes on Conveyance	1.2E-06	2.5E-06

Source: Attachment B, Section B3, Figures B3.4-1, B3.4-4 and B3.4-7

6.2.2.4 Canister Transfer Machine Fault Tree Analysis

The FTA is detailed in Attachment B, Section B4. The following is a summary of the design, operations, success criteria, and results of the fault tree quantification. See Attachment B, Section B4 for sources of information on the physical and operational characteristics of the CTM.

6.2.2.4.1 Physical Description and Functions

The two types of canisters moved in the CTM for WHF operations are TAD canisters and DPCs.

The following three CTM operations specifically apply to the WHF:

1. Transfer of a DPC from a transportation cask to an STC (occurs solely in Cask Unloading Room).
2. Transfer of a TAD canister from an STC to an aging overpack (TAD canister is unloaded in the Cask Unloading Room and moved in the Transfer Room to the Cask Loading Room to be placed in an aging overpack).
3. Transfer of a DPC in an aging overpack to an STC (DPC is unloaded in Cask Loading Room and moved in the Canister Transfer Room to the Cask Unloading Room and placed into an STC).

The ports in the floor of the Canister Transfer Room provide access to the Cask Unloading Room and Loading Room.

The CTM is an overhead bridge crane with two trolleys. The first is a canister hoist trolley with a grapple attachment and hoisting capacity of 70 tons. The second is a shield bell trolley that supports the shield bell. The bottom end of the shield bell is attached to a larger chamber to accommodate cask lids. The CTM bottom plate assembly supports a thick motorized slide gate. The slide gate, when closed, provides bottom shielding of the canister once the canister is inside the shield bell. Around the perimeter of the bottom plate, a thick shield skirt is provided which can be raised and lowered to prevent lateral radiation shine during a canister transfer operation.

6.2.2.4.2 Operations

Typical operation for the WHF CTM includes the transfer of a TAD canister from an STC to an aging overpack.

The CTM is moved to a position over the center of the port above the loaded STC in the Unloading Room. The shield skirt is lowered to rest on the floor, and the port slide gate is opened. The CTM slide gate is opened and the canister grapple is lowered through the shield bell to engage and lift the cask lid. The port slide gate is closed and the shield skirt is raised so the CTM can be moved to a cask lid staging area to set down the lid.

The CTM is moved back over the port above the loaded cask to align the canister grapple. The shield skirt is lowered, the port slide gate is opened, and the grapple is lowered to engage the TAD canister lifting feature. The TAD canister is raised into the shield bell. The CTM slide gate and the port slide gate are closed and the shield skirt is raised so the CTM can be moved to the port above the empty aging overpack in the Cask Loading Room. Operation 1, transfer of a DPC from a transportation cask to an STC, occurs solely in the Unloading Room. Operation 1 of the CTM is somewhat similar to operation 2 except the CTM holds the DPC in the bell in the Canister Transfer Room above the port gate until the empty STC is moved in the unloading room. Operation 3, transfer of a DPC in an aging overpack to an STC, is essentially the reverse of that described for operation 2.

The CTM canister grapple is used for handling large diameter canisters such as TAD canisters and DPCs. These grapples are attached to the CTM canister grapple by positioning the CTM over a hatch located in the Canister Transfer Room floor and lowering the CTM hoist until the CTM grapple is accessible in the room below.

The CTM is normally controlled from the facility Operations Room, but a local control station is also provided.

Generally, under off normal conditions the CTM is not in operation. Following a loss of offsite AC power, all power to the CTM motors (e.g., hoist, bridge, trolley, and bell trolley) is lost. If a transfer is underway when power is lost, all of the CTM motors would stop and the hoist holding brake engages. Operations would be suspended until power is restored and the load can be safely moved. Under other off-normal conditions, transfer operations would be suspended and the CTM would remain idle.

6.2.2.4.3 Control System

Hard-wired interlocks are provided to:

- Prevent bridge and trolley movement when the shield bell skirt is lowered.
- Prevent raising the shield bell skirt when the slide gate is open.
- Prevent hoist movement unless the grapple is fully engaged or disengage.
- Stop the hoist and erase the lift command when a canister clears the shield bell slide gate.
- Stop a lift before upper lift heights are reached (two interlocks are provided for this function).
- Prevent opening of the port gate unless the shield bell skirt is lowered and in position.
- Prevent hoist movement unless the shield bell skirt is lowered.
- Prevent lifting of a load beyond the operational limit of the CTM (load cells).

Some of these interlocks can be bypassed during maintenance. The most significant of these interlocks that can be bypassed is the interlock between the shield skirt position and the position of the slide gate (the shield skirt cannot be raised unless the slide gate is closed or the maintenance bypass is engaged.) The design of the grapple interlock ensures that the bypass is voided when a canister is grappled.

Much of the operational controls are provided by non-ITS PLCs. Spurious or failed operation of the PLCs is in the FTA when such operation may contribute to a drop or collision event.

6.2.2.4.4 System/Pivotal Event Success Criteria

Success criteria for the CTM are the following:

- Prevent a canister drop from a height below the design basis height for canister damage from any cause during the lifting, lateral movement, and lowering portions of the canister transfer.
- Prevent a canister drop from above the canister design limit drop height from any cause during the lifting, lateral movement, and lowering portions of the canister transfer.
- Prevent a drop of any object onto the canister from any cause during the lift, lateral movement, and lowering portions of the canister transfer.
- Prevent CTM movement that could result in a shearing force being applied to the canister when the canister is being lifted and is between the first and second floors of the WHF.

The failure to achieve each success criterion defines the top event for a fault tree for the CTM.

6.2.2.4.5 Mission Time

The mission time for the ITS CTM is set to 1 hour.

6.2.2.4.6 Fault Tree Results

The analysis is detailed in Attachment B, Section B4.

There are five scenarios associated with the CTM that represent potential initiating events:

1. The CTM drops a canister from a height below the design basis height for canister damage (this includes canister drops within the shield bell once the bell slide gate has been closed and drops through the Canister Transfer Room ports to the loading/unloading areas that can occur before the bell slide gate is closed).
2. The CTM drops a canister from a height above the design basis height for canister damage.
3. The CTM drops an object onto a canister.
4. The CTM, while carrying a canister, moves in such a manner (spurious movements, exceeding bridge or trolley end of travel limits) as to cause an impact of the canister with the shield bell.

5. The CTM moves when the canister being transferred is being lifted and is between the WHF floors resulting in shear forces being applied to the canister.

The results of the analysis are summarized in Table 6.2-4. Five fault trees were developed. The top events correspond to the four potential initiating events defined above.

Table 6.2-4 Summary of Top Event Quantification for the CTM

Top Event	Mean Probability	Standard Deviation
CTM drop all heights	1.4E-5	1.0E-5
CTM high drops from two blocking events	2.8E-8	1.6E-7
Drop of object onto canister	1.4E-5	1.1E-5
CTM collision	3.9E-6	2.7E-7
Spurious movement of bridge/trolley breaches canister (shear)	6.7E-9	1.4E-8

NOTE: CTM = canister transfer machine.

Source: Attachment B, Section B4, Figures B4.4-1, B4.4-16, B4.4-21, B4.4-38, and B4.4-45

6.2.2.5 Cask Cooling Fault Tree Analysis

The FTA is detailed in Attachment B, Section B5. The FTA considered two kinds of leaks or ruptures in the cask cooling system leading to a radiological release:

1. Non-pressurized leaks or ruptures
2. Pressurized leaks or ruptures.

The following is a summary of the design, operations, success criteria, and results of the fault tree quantification. See Attachment B, Section B5 for sources of information on the physical and operational characteristics of the cask cooling system.

6.2.2.5.1 Physical Description

The cask cooling system is a pump driven system that will be used to cool casks by introducing borated water into the cask. The system consists of two motor-driven pumps, a pressure relief valve, two non-hardwired interlocks, water piping, four quick disconnects, two sections of flexible tubing, and a separator vessel.

The pumps serve to direct water from the pool, into the cask, and back to the pool. The positive displacement pump drives water out of the pool and into the cask, while the centrifugal pump directs water out of the cask and back into the pool for reuse. Borated water is injected via the drain pipe which is below the bottom of the spent fuel assemblies. Steam leaves the cask through the vent piping.

The water delivery and removal systems consist of a series of pipes, tubing, and quick disconnects. The flexible tubing connects the supply and return piping to the cask, with connections provided by quick disconnects. System piping runs from the pool to the flexible tubing which supplies the cask, and from the cask return to the separator vessel.

Two lines of piping flow out of the separator vessel: one provides water for treatment, the other routes air to off-gas treatment. The separator vessel serves the purpose of separating air and water delivered from the cask.

6.2.2.5.2 Operations

The cask handling crane places the cask into the preparation station. At the preparation station, the gas sampling port is opened and the drain valve and drain port cover plates are removed. The borated water line is connected to the drain port, and the vent line is connected to the gas sampling port. Borated water is then introduced into the cask as the steam is vented. Once the cask is satisfactorily cooled, the lines are disconnected and the cover plates are reinstalled.

6.2.2.5.3 Control System

The pump failures and blockages which can cause cask over pressurization may be controlled by two features which would negate the over pressurization. The first of these features are interlocks (not hardwired) which are designed to detect excess pressure/water at the filling and venting ends of the cooling system. Should an interlock detect such a scenario, the positive displacement pump is shut down. If this shut down does not occur, or the interlock does not detect the condition, a pressure relief valve is in place to be physically affected by the over-pressurization to open and relieve the pressure. Should both of these features fail, an over-pressurization of the cask will result in the release of contaminated steam or water. However, these interlocks depend upon PLCs and are not credited in the FTA. The pressure relief valve is the only credited safety feature.

6.2.2.5.4 System/Pivotal Event Success Criteria

A pressure relief valve shall remedy a cask overfilling or over-pressurization failure. This valve is physically activated by the presence of an exceeding pressure, causing the valve to open and relieve the excess pressure.

6.2.2.5.5 Mission Time

A nominal eight-hour mission time is used to calculate the failure probability for components having a time-based failure rate. Otherwise, failure-on-demand probabilities are used.

6.2.2.5.6 Fault Tree Results

The detailed description in Attachment B, Section B5 documents the application of basic event data, CCFs, and HRA.

There are two fault trees associated with the cask cooling system:

1. Break of non-pressurized sample line
2. Cask overpressurization.

Results of the quantitative FTA are summarized in Table 6.2-5.

Table 6.2-5. Summary of Top Event Quantification for Cask Cooling

Top Event	Mean Probability (per cask)	Standard Deviation
Sample line break non-pressurized	2.0E-05	6.1E-5
Cask/sample line overpressurized	7.8E-06	5.1E-5

Source: Attachment B, Section B5, Figures B5.4-1 and B5.4-6

6.2.2.6 Site Transporter Fault Tree Analysis

The FTA for the site transporter is detailed in Attachment B, Section B6. The following is a summary of the design, operations, success criteria, and results of the fault tree quantification. See Attachment B, Section B6 for sources of information on the physical and operational characteristics of the site transporter.

6.2.2.6.1 Physical Description

The site transporter is a diesel/electric self-propelled tracked vehicle that is designed to transport a concrete and steel ventilated aging overpack. The transport occurs both within the Intra-site and within the WHF. The analysis described herein is limited to movement of the site transporter within the WHF: the Site Transporter Vestibule, the Cask Preparation Area, and the Cask Unloading Room.

The site transporter is a track driven vehicle with four synchronized tracks (two on each side). The components of the drive system (i.e., tumblers, idlers, rollers) are not included in this analysis since these components are not ITS. An integrated diesel powered electric generator provides the energy to operate the site transporter outside the facility building. Inside the facility buildings the site transporter is electrically driven via an umbilical cord or remote control from the facility main electrical supply.

A rear fork assembly and a pair of support arms are used to lift and lower the cask. The rear forks are inserted in two rectangular slots near the base of the aging overpack. Casks are carried in a vertical orientation with the lid at the top. Access to the top of the casks is unobstructed.

A passive restraint system provides stabilization during cask movement. These restraints are brought into contact with the cask after it has been raised to the desire height. A pin is inserted into each of the three restraint arms to keep the restraint in place should there be a failure of the electromechanical assembly. The pins also serve as an interlock that prevents movement of a loaded site transporter without the restraints being properly installed.

6.2.2.6.2 Control System

There are two modes of control provided on the site transporter. Operators can control every operation on the site transporter with either a remote (wireless) controller or through a pendant connected to the site transporter. All safety interlocks and controls of the site transporter are hard wired between the specific relays, drives, circuit breakers, and other electrical equipment. No PLC or computer is used to control the machine.

6.2.2.6.3 Normal Operations

The site transporter operator lines up the front opening of the site transporter to envelop the aging overpack and positions the rear fork down and in-line with the rectangular lifting slots near the bottom of the aging overpack and moves the site transporter forward until the aging overpack is centered in the interior of the site transporter.

The rear forks are raised to contact the bottom of the lift slots but no attempt to lift the cask is made at this time. The operator and interlocks (torque and/or position) are incorporated to prevent lifting with the rear forks only.

The operator initiates the lift support arm's interface sequence with the rear forks and cask to prepare for lifting. After the operator and machine's switches have confirmed that the rear forks and lift support are properly aligned with one another, the lift sequence is initiated. The control system will sequence the lift motors so all screws operate together.

When the lift is completed, the operator performs the final positioning of the upper restraint arms and inserts a pin in each arm. When the pins are properly installed, the site transporter can move.

The operator trails behind the site transporter during movement using the remote control to drive the site transporter to the desired location. At the facility, the operator stops the site transporter outside the entrance vestibule and turns off the diesel generator and then an electric power cable is attached.

Once driven inside the building, the operator positions the site transporter in either the Cask Preparation Area or in the Cask Unloading Room. During the various movements inside the WHF, the operator disengages the restraint arms for lower and lift operations at the various stations. Each time, the operator removes or replaces the pins from the restraint arms, as appropriate. The movement interlock is engaged when the pins are removed.

6.2.2.6.4 System/Pivotal Event Success Criteria

Success criteria for the site transporter are the following:

- Prevent a collision of the site transporter with objects, structures, or shield doors
- Prevent runaway situations
- Prevent site transporter movements in the wrong direction
- Preventing a rollover of the site transporter
- Prevent spurious site transporter movements
- Prevent a load drop during lift/lower or transport operations.

Various design features are provided to achieve each of the success criteria. The failure to achieve each success criterion defines the top event for a fault tree for the site transporter.

6.2.2.6.5 Mission Time

For quantification of the site transporter fault trees in Attachment B, Section B6, a mission time of 1 hour per cask transfer is used.

6.2.2.6.6 Fault Tree Results

There are seven basic site transporter fault trees developed for the WHF. The scenarios represented and the variations by these fault trees are the following:

1. Site transporter collides with WHF structures:
   A. Importing aging overpack to Cask Preparation Room
   B. Transfer from Cask Preparation Room to Cask Unloading Room
   C. Transfer from Cask Unloading Room to Cask Preparation Room.
2. Collision of site transporter with Cask Unloading Room shield door
3. Site transporter load drop during lift/lower
4. Site transporter tip over
5. Site transporter impact
6. Site transporter rigging
7. Site transporter spurious movement.

The results of the analysis are summarized in Table 6.2-6 for the seven fault trees.

Table 6.2-6. Summary of Top Event Quantification for the Site Transporter

Top Event	Mean Probability	Standard Deviation
Collides with WHF structures	4.4E-3	1.3E-2
Site transporter rollover	2.3E-6	1.9E-6
Site transporter spurious movement	<1.0E-9[a]	<1.0E-9[a]

NOTE: [a]<1.0E-9 represents an insignificant contribution to the top event probability . The actual value is given in Figure B6.4-9.

WHF = Wet Handling Facility.

Source: Attachment B, Section B6, Figure B6.4-1, B6.4-6, B6.4-9

6.2.2.7 HVAC FAULT TREE ANALYSIS

The FTA is detailed in Attachment B, Section B7. The following is a summary of the design, operations, success criteria, and results of the fault tree quantification. See Attachment B, Section B7 for sources of information on the physical and operational characteristics of the HVAC system.

6.2.2.7.1 HVAC Description and Function

The ITS HVAC is a two train system of identical components. One train is always operational and one train is in standby mode. This system is not configured to run both trains at the same time without bypassing control circuitry. This off-normal situation is not addressed in this analysis.

In the WHF, the Train A HVAC equipment is located on the opposite end of the building from Train B HVAC equipment. Each HVAC train exhausts air through separate discharge ducts into the atmosphere. Although these trains are interconnected through interior duct work, the trains are independent. A back-draft damper is used on each train to ensure there is no airflow from the atmosphere back through the standby train.

Each HVAC system train is composed of four subsystems:

- A series of dampers are used to control pressure, flow, as well as flow direction in this system.
- Three HEPA filters, each consisting of one medium efficiency roughing filter (60 to 90% efficiency), two high efficiency filters for particulate removal in air (99.97% efficiency), and a mister/demister for maintaining proper humidity levels.
- One exhaust fan with a rated capacity of 40,500 ft/min^3 and an exhaust fan motor rated at 200 hp.
- Control circuitry with logic contained in an erasable programmable read-only memory located in the adjustable speed drive controller used for controlling the speed of the operating fan and on fault detection, and for off-nominal conditions, shutting down the operating train and transmitting signals to the standby system to start.

6.2.2.7.2 Success Criteria

One success criterion is defined for the each of independent Trains, A and B, for providing the HVAC confinement function–maintain negative differential pressure in the WHF for the specified mission time.

The respective trains of the ITS portions of the HVAC are identical. Various design features are provided to achieve each of the success criteria for the respective trains and for the combined system.

The HVAC FTA for the HVAC includes separate analyses for the respective trains. The failure to achieve the success criterion defines the top event for the fault tree for each train of the HVAC.

6.2.2.7.3 Mission Time

The mission time for the HVAC system is 720 hours for a canister breach event and radionuclide release. (Attachment B, Section B7.4.1.4). However, the mission time for the backup system has been taken as half of the active system (i.e., 360 hours). This is to account for the difference in failure rates between active and passive systems.

The SAPHIRE model was re-run, changing only the mission time. For a sample line break during cask cooling, a mission of time for the HVAC system is 24 hours. The 24 hours correspond to the time required to rectify the situation and seal the leak.

6.2.2.7.4 Fault Tree Results

The top event in this fault tree is "Delta pressure not maintained in WHF facility." This is defined as the inability of the ITS HVAC system to maintain proper delta pressure within the facility. The system failure probability and standard deviation, including failure of electrical power, are as follows:

For a 720 hour mission time:

- The mean HVAC system probability of failure, including loss of electrical power is 3.6E-2
- The standard deviation is 9.9E-2 (Reference Attachment B, Figure B7.4-1).

For a 24 hour mission time:

- The mean HVAC system probability of failure, including loss of electrical power is 1.0E-3
- The standard deviation is 1.1E-2 (Reference Attachment B, Figure B7.4-1A).

6.2.2.8 ITS AC Power Fault Tree Analysis

The FTA is detailed in Attachment B, Section B8. The following is a summary of the design, operations, success criteria, and results of the fault tree quantification. See Attachment B, Section B8, for sources of information on the physical and operational characteristics of the ITS AC power system.

6.2.2.8.1 System Description

The ITS AC power system supplies power to the ITS systems (the HVAC Systems). The ITS power system consists of two elements; those used during normal operations and those used during off-normal conditions. During normal operations, AC power is supplied from one of two offsite 138 kV offsite power lines through the 138 kV to 13.8 kV switchyard and then through the plant AC power distribution system to the various facilities throughout the site. Off-normal conditions for the distribution of AC power occur during a LOSP.

A LOSP may be the result of problems on the power grid, or may be the result of failures within the plant AC power systems. Under these conditions, the AC power source for the WHF ITS equipment is two onsite ITS diesel generators. Power is supplied to ITS loads via the same onsite AC power distribution system that is used during normal operation. Each ITS diesel