Table 6.3-2. Failure Probabilities Due to Drops and Other Impacts

	Drop Height (ft)	Failure Probability	Note
Representative transportation cask [a]	6	1.0E−05	3 degrees from horizontal, LLNL, adjusted, no impact limiters
Aging overpack	3	1.0E−05	LLNL, adjusted
Representative canister	32.5[b]	1.0E−05	Flat bottomed, LLNL, adjusted

NOTE: [a]Also applies to shielded transfer casks (used for waste forms only inside WHF) and horizontal shielded transfer casks.
[b]This drop height is greater than the maximum drop height associated with Intra-Site Operations.

ft = feet; LLNL = Lawrence Livermore National Laboratory.

Source: Attachment D, Section D1

Containment failure probabilities due to other physical impact conditions, equivalent to drops, are listed in Table 6.3-3. These probabilities were modeled by LLNL using FEA, resulting in prediction of failure probabilities of less than 1.0E-08. Again, additional conservatism was incorporated by using a failure probability of 1.0E-05 for most of these events. The side impact event was not adjusted from the LLNL result of < 1.0E-08 because of the very low velocities involved. A comparison of the strains induced by drops and slow speed side impacts indicates significantly lower strains for the low velocity impacts.

Table 6.3-3. Failure Probabilities Due to Miscellaneous Events

Event	Failure Probability	Note
Derail	1.0E-05	LLNL, adjusted, analogous to 6', 3° from horizontal
Rollover	1.0E-05	LLNL, adjusted, analogous to 6', 3° from horizontal
Drop on	1.0E-05	LLNL, adjusted 10-ton load onto container
Side impact from collision with rigid surface	1.0E-08	Or value for low-speed collision, whichever is greater (Table 6.3-4)

NOTE: LLNL = Lawrence Livermore National Laboratory.

Source: Attachment D, Section D1.6

Table 6.3-4 shows failure probabilities for various collision events for various containers as a function of impact speed. For each of the events, the collision speed, whether in miles per hour (mph) or feet per minute (fpm) is converted to feet per second (fps), then to an equivalent drop height in feet. The drop heights are very small compared with the drop heights for the modeled situations summarized in Table 6.3-2. The damage to a container, expressed in terms of strain, is roughly proportional to the impact energy, which is proportional to the drop height, as is readily seen from the following:

Energy from drop = $mgh \propto Fs$ and $F \propto mg$, therefore, $s \propto h$, where s = strain, F = local force on container from drop, m = mass of container, h = drop height, and g = acceleration due to gravity.

For drop heights other than those for the modeled situations presented in Table 6.3-2, failure probabilities can be estimated by shifting capacity curve to match the conservative failure probabilities listed in Table 6.3-2. The mean failure drop height, H_m, is found so that the probability of failure, P, (calculated using Equation 24), is the value listed in Table 6.3-2 for the drop height, H_d, listed in Table 6.3-2.

$$P = \int_{-\infty}^{x} N(t)\,dt \quad and \quad x = \frac{H_d / H_m - 1}{COV} \qquad \text{(Eq. 24)}$$

where

- P = Probability of failure for container dropped from height H_d
- $N(t)$ = Standard normal distribution with mean of zero and standard deviation of one
- t = Variable of integration
- H_d = Modeled drop height for which the failure probability has been determined
- H_m = Median failure drop height of the failure drop height distribution such that the failure probability at the modeled drop height, H_d, is P
- COV = Coefficient of variation, which is the ratio of standard deviation to mean for strain capacity distribution, applied here to stress capacity or true tensile strength

The probabilities of failure for the collision cases listed in Table 6.3-4 are then determined using the above formula with H_m determined above and with H_d being the drop height corresponding to the collision speed as listed in Table 6.3-4. The failure probabilities of these events are shown in PEFA Chart.xls included in Attachment H.

Table 6.3-4. Failure Probabilities for Collision Events

				Failure Probabilities for Various Container Types				
Collision Scenario	**Speed**	**Velocity (ft/sec)** [a]	**Equivalent Drop Height (ft)** [b]	**Transportation Cask**	**Canister**	**Waste Package**	**MCO**	**High-Level Radioactive Waste**
Railcar	9.0 mph	13.20	2.71	1.00E-08	—	—	—	—
Truck trailer	9.0 mph	13.20	2.71	1.00E-08	—	—	—	—
Site Transporter	2.5 mph	3.67	0.21	—	1.00E-08	—	1.00E-08	1.00E-08

NOTE: [a]Conversions from the previous column are as follows. From speed in mph: multiply by 5280/3600. From speed in ft / min: divide by 60.
[b]Calculated as follows based on constant acceleration due to gravity (no air resistance): v^2 / (2 × 32.2 ft / sec^2), where v is the velocity in ft / sec. Values are rounded to the nearest hundredth of a ft.
ft = feet; MCO = multicanister overpack; min = minutes; mph = miles per hour; sec = seconds.

Source: Original

6.3.2.3 Probability of Canister Failure in a Fire

In addition to passive equipment failures as a result of structural loads, passive failures can also occur as a result of thermal loads such as exposure to fires or abnormal environmental conditions, for example, loss of HVAC cooling. The PCSA evaluates the probability of loss of containment (breach) due to a fire for several types of waste containers, including: transportation casks containing uncanistered commercial SNF assemblies, and canisters representative of TAD canisters, DPCs, DOE standardized canisters, HLW canisters, and naval SNF canisters.

The methods for analyzing thermally induced passive failures are discussed in Section 4.3.2.2, and detailed in Attachment D. In summary, the probability of failure of a waste container as a result of a fire is evaluated by comparing the demand upon a container (which represents the thermal challenges of the fire vis-à-vis the container), with the capacity of the container (which represents the variability in the temperature at which failure would occur). The demand upon the container is controlled by the fire duration and temperature, because these factors control the amount of energy that the fire could transfer to the container.

In response to a fire, the temperature of the waste container under consideration increases as a function of the fire duration. The maximum temperature is calculated using a heat transfer model that is simplified to allow a probabilistic analysis to be performed that accounts for the variability of key parameters. The model accounts for radiative and convective heat transfers from the fire, and also for the decay heat from the waste form inside a container. The temperature evolution of waste containers is analyzed based on a simplified geometry with a wall thickness that, for the range of waste containers of interest in the PCSA, is representative or conservatively small. Specifically, two characteristic canister wall thicknesses are modeled: 0.5 inches, characteristic of some DPCs and other waste canisters; and 1.0 inches, the anticipated thickness of TAD canisters and naval SNF canisters. The wall thickness of a container is an important parameter that governs both container heating and failure. Other conservative and realistic modeling approaches are introduced in the heat transfer model, as appropriate. For example, fires are conservatively considered to engulf a container, regardless of the fact that a fire at the GROA may simply be in the same room as a container. When handled, TAD canisters, DPCs, DOE standardized canisters, HLW canisters and naval SNF canisters are enclosed within another SSC, for example a transportation cask, the shielded bell of a canister transfer machine, or a waste package. Therefore, a fire does not directly impinge on such canisters. In contrast, the external surface of a transportation cask containing uncanistered commercial SNF may be impinged upon directly by the flames of the fire.

Accounting for the uncertainty of the key parameters of the fires and the heat transfer model, the maximum temperature reached by a waste container, which represents the demand upon the container due to a fire, is characterized with a probability distribution. The distribution is obtained through Monte Carlo simulations.

To determine whether the temperature reached by a waste container is sufficient to cause the container to fail, the fire fragility distribution curve for the container is evaluated. In the PCSA, this curve is expressed as the probability of breach of the container as a function of its temperature. Two failure modes are considered for a container that is subjected to a thermal challenge: creep-induced failure and limit load failure. Creep, the plastic deformation that takes place when a material is held at high temperature for an extended period under tensile load, is possible for long duration fires. Limit load failure corresponds to situations where the load exerted on a material exceeds its structural strength. This failure mode is considered because the strength of a container decreases as its temperature increases. The variability of the key parameters that can lead to a creep-induced failure or limit load failure is modeled with probability distributions. Monte Carlo simulations are then carried out to produce the fire fragility distribution curve for a container.

The probability of a waste container losing its containment function as a result of a fire is calculated by running numerous Monte Carlo simulations in which the temperature reached by the container, sampled from the probability distribution representing the demand on the container, is compared to the sampled failure temperature from the fragility curve. The model counts the simulation result as a failure if the container temperature exceeds the failure temperature. Statistics based upon the number of recorded failures in the total number of simulations are used to estimate the mean of the canister failure probability.

Table 6.3-5 shows the calculated mean and standard deviation for the failure probability of a canister in the following configurations: a canister in a transportation cask, a canister in a waste package, and a canister in a shielded bell.

Table 6.3-5. Summary of Canister Failure Probabilities in Fire

Configuration[a]	Failure Probability	
	Mean	Standard Deviation
Thin-Walled Canister in a Transportation Cask	2.0E−06	1.4E−06
Thick-Walled Canister in a Transportation Cask[b]	1.0E−06	1.0E−06

NOTE: [a]Configurations not addressed in this table include any canister inside an aging overpack. In this configuration, the canister is protected from the fire by the massive concrete overpack. Calculations have shown that the temperatures experienced by the canister in these configurations are well below the canister failure temperature, so that failures for these configurations can be screened. For conservatism, a screening conditional probability of 1E−06 could be used.
[b]Naval SNF canisters are modeled as thick walled. Other canisters are modeled as thin walled.

Source: Attachment D, Table D2.1-9

Note that no failure probability is provided for a bare canister configuration. The reason for this is that the canister is outside of a cask for only a short time. During that time, the canister is usually inside the shielded bell of the CTM. The preceding analysis addressed a fire outside the shielded bell. When in that configuration, the canister is shielded from the direct effects of the fire. A fire inside the shielded bell, which could directly heat the canister, is not considered to be credible for two reasons. First, the hydraulic fluid used in the CTM equipment is non-flammable and no other combustible material could be present inside the bell to cause a fire. Second, the annular gap between the canister and the bell is only three inches wide, but is approximately 27 feet long. Given this configuration, it is unlikely that there is sufficient inflow of air to sustain a large fire that could heat a significant portion of the canister wall. There may be sufficient inflow to sustain a localized fire, but such a fire would not be adequate to heat the canister to failure.

The canister is also outside of a cask, or shielded bell as it is being moved from a cask into the shielded bell or from the shielded bell into a waste package. The time during which the canister is in this configuration is extremely short, a matter of minutes, so a fire that occurs during this time is extremely unlikely. In addition, because the gap between the top of the cask and ceiling of the transfer cell is generally much shorter than the height of the canister, only a small portion of the canister surface is exposed to the fire. Furthermore, this exposure would only be for the short time that the canister was in motion.

For these reasons, failure of a bare canister was not considered credible and is not explicitly modeled in the PCSA. The bare canister configuration is not applicable to Intra-Site Operations.

6.3.2.4 Probability of Loss of Containment from Heat-up

In addition to fire-related passive failures, the PCSA considered other passive equipment failures due to abnormal thermal conditions. The thermal event of greatest concern for Intra-Site Operations is loss of cooling on the aging pad (e.g., caused by blockage of the vents of an aging overpack or HAM are blocked for a prolonged period). However, this initiating event has been screened out based on thermal analysis, which determined it is not a challenge to canister containment (Table 6.0-2). Aging overpacks and HAMs are designed to use natural ventilation to move decay heat away from the canister during aging. If all of the vents become blocked for a prolonged period, the process would be impeded. However, each aging overpack and HAM has multiple vents, and each vent opening has a screen to prevent large debris and animal interference from creating blockage. In addition, the aging overpacks and HAMs have instrumentation to monitor canister temperature to determine completion of aging. This instrumentation can also serve to provide a warning if the temperature increases. Lastly, because the instrumentation on each aging overpack and HAM will be checked regularly, it is unlikely that blocked vents will go unnoticed and will be cleared as standard maintenance and housekeeping activities.

6.3.2.5 Probability of Loss/Degradation of Shielding

Loss or degradation of shielding probabilities are summarized in Table 6.3-6. Some of the items discussed in this section and listed in Table 6.3-6 are not used for Intra-Site Operations, such as the WPTT, but they are included in this section to illustrate the consistency of methodology across facilities and equipment.

Shielding of a waste form that is being transported inside the GROA is accomplished by several types of shielded containers, including: transportation casks, horizontal or vertical shielded transfer casks, aging overpacks, shielded components of a WPTT, and shielded components of a TEV. In addition to a shielding function, sealed transportation casks and horizontal or vertical shielded transfer casks exert a containment function.

A structural challenge may cause shielding degradation or shielding loss. LOS occurs when an SSC fails in a manner that leaves a direct path for radiation to stream, for example as a result of a breach. Degradation of shielding occurs when a shielding SSC is not breached, but its shielding function is degraded. In the PCSA, a shielding degradation probability after a structural challenge is derived for those transportation casks that employ lead for shielding. Finite-element analyses on the behavior of transportation casks subjected to impacts associated with various collision speeds, reported in *Reexamination of Spent Fuel Shipment Risk Estimates,* NUREG/CR-6672 (Ref. 2.2.82, Section 5.1.4), indicate that lead slumping after an end impact could result in a reduction of shielding; transportation casks without lead are not susceptible to such shielding degradation. This information is used in Attachment D, Section D3, to derive the shielding degradation probability of a transportation cask at drop heights characteristic of crane operations. The distribution is developed for impacts on surfaces made of concrete, which compare to the surfaces onto which drops could occur at the GROA. No impact limiter is relied upon to limit the severity of the impact. Conservatively, the distribution is applied to transportation casks and also shielded transfer casks, regardless of whether or not they use lead for shielding. Thus, for containers that have both a containment and shielding function, the PCSA considers a probability of containment failure (which is considered to result in a concurrent LOS), and also a probability of shielding degradation (which is associated with those structural challenges that are not sufficiently severe to cause loss of containment). Table 6.3-6 displays the resulting shielding degradation probabilities for transportation casks and shielded transfer casks after a structural challenge. Given that there is significant conservatism in the calculation of strain and the uncertainty associated with the fragility (strength), the resulting estimates include uncertainties and are considered conservative

Shielding loss is also considered to potentially affect an aging overpack subjected to a structural challenge, if the waste container inside does not breach. Given the robustness of aging overpacks, a shielding loss after a 3-ft drop height is calculated to have a probability of 5E-06 per aging overpack impact, based upon the judgment that this probability may be conservatively related to but lower than the probability of breach of an unprotected waste container inside the aging overpack (Attachment D, Section D3). If the structural challenge is sufficiently severe to cause the loss of containment (breach) of the waste container inside the aging overpack, the loss of the aging overpack shielding function is considered guaranteed to occur.

A CTM provides shielding with the shield bell, shield skirt, and associated slide gates. Also, the CTM is surrounded by shield walls and doors, which are unaffected by structural challenges resulting from internal random initiating events. Therefore, such challenges leave the shielding function intact. (CTMs are not used for Intra-Site Operations.) The PCSA treats the degradation or loss of shielding of an SSC due to a thermal challenge as described in the following paragraphs.

If the thermal challenge causes the loss of containment (breach) of a canister, the SSC that provides shielding and in which the canister is enclosed is considered to have lost its shielding capability. A transportation cask containing uncanistered commercial SNF is also considered to have lost its shielding if it has lost its containment function.

The shielding structure provided by the CTM is not subjected to drops. Such shields may be subjected to collisions or dropped heavy objects. The analysis detailed in Attachment D, Section D3, indicates there is no challenge to the shielding from these events. Therefore, these components are assigned zero probability in Table 6.3-6.

If the thermal challenge is not sufficiently severe to cause a loss of containment function, it is nevertheless postulated that it will cause shielding loss of the transportation cask, shielded transfer cask, canister transfer machine, or cask transfer trolley affected by the thermal challenge and in which the waste container is enclosed. This is because the neutron shield on these SSCs is made of a polymer which is not anticipated to withstand a fire without failing. Note, however, that the degradation of gamma shielding of these SSCs is unlikely to be affected by a credible fire. Although credible fires could result in the lead melting in a lead-sandwich transportation cask, there is no way to displace the lead, unless the fire is accompanied by a puncture or rupture of the outer steel wall of the cask. Preliminary calculations were unable to disprove the possibility of hydraulic failure of the steel encasing due to the thermal expansion of molten lead, so loss of gamma shielding for steel-lead-steel transportation casks engulfed in fire is postulated. Conservatively, in the PCSA, transportation casks and shielded transfer casks are postulated to lose their shielding function with a probability of one, regardless of whether or not they use lead for shielding.

Aging overpacks made of concrete are not anticipated to lose their shielding function as a consequence of a fire because the type of concrete used for aging overpacks is not sensitive to spallation. In addition, it is likely that the aging overpacks will have an outer steel liner. For these reasons, a loss of aging overpack shielding in a fire has been screened from consideration in the PCSA

Table 6.3-6. Probabilities of Loss of Shielding

Event	Probability	Note
Sealed Transportation cask and shielded transfer casks shielding degradation after structural challenge	1.0E-05	Section D, Section D3.4.
Aging overpack shielding loss after structural challenge	5E-06	Section D, Section D3.4.
Shielding loss by fire for waste forms in transportation casks or shielded transfer casks	1	Lead shielding could potential expand and degrade. This probability is conservatively applied to transportation casks that do not use lead for shielding.
Shielding loss by fire for aging overpacks	0	Type of concrete used for aging overpacks is not sensitive to spallation.

Source: Attachment D, Table D3.4-1

6.3.2.6 Probability of Other Fire-Related Passive Failures

In addition to the canisters, other passive equipment could fail as a result of a fire. For the PCSA, only failures that would result in a radionuclide release or radiation exposure are considered.

6.3.2.7 Application to Event Sequence Models

Table 6.3-7 lists the basic event names for passive failure events used in the event sequence modeling and quantification for Intra-Site Operations. The values are either specifically developed in Attachment D, or are values from bounding events. Probabilities for some events were obtained by extrapolation from developed probabilities as described in this section or in

Attachment D. The derivation of all passive failure probabilities is described in Attachment D and shown in PEFA Chart.xls, included in Attachment H.

It is noted that Table 6.3-7 addresses all passive event failures for the various waste form configurations. Table 6.3-8 identifies the specific passive failure basic events used in event sequence modeling and quantification. The probability of each basic event is based on one of the values presented in Tables 6.3-2 through 6.3-7.

Table 6.3-7. Summary of Passive Event Failure Probabilities

	10 T dropped on container	Container vertical drop from normal operating height	Container 30-foot vertical drop	6-foot Horizontal Drop, Rollover	2.5 mph Flat side impact/ collision	2.5 mph Localized side impact/ collision	9 mph Flat side impact/ collision	2.5 mph end-to-end Collision	9 mph end-to-end Collision	Thin-Walled Canister Fire or UCSNF on TT-Cask Fire	Thick-Walled Canister (NAV only) Fire
Loss of Containment											
Canister in Transport Cask	1.E-05	1.E-05	1.E-05	1.E-05	1.E-08	1.E-08	1.E-08	1.E-08	1.E-08	2.E-06	1.E-06
Transport Cask with Bare Fuel	1.E-05	1.E-05	1.E-05	1.E-05	1.E-08	1.E-08	1.E-08	1.E-08	1.E-08	5.E-02 [1]	6.E-03 [2]
Canister	1.E-05	1.E-05	1.E-05 [3]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Canister in AO	1.E-05	1.E-05	N/A	1E-08	1.E-08	1.E-08	1.E-08	N/A	N/A	1.E-06	1.E-06
Loss of Shielding											
Transport Cask	1.E-05	1.E-05	N/A	1.E-05	1.E-08	1.E-08	1.E-08	1.E-08	1.E-08	~ 1	~ 1
Aging Overpack	1.E-05	5.E-06	N/A	N/A	1.E-05	1.E-05	1.E-05	1.E-05	1.E-05	~ 0	~ 0

NOTE: [1]Truck cask
[2]Rail cask
[3]Ram impact or vertical drop (used 30-ft canister drop, but actual height is 6 ft); ram strength by design not to puncture, therefore less than force of 30-ft drop)

AO = aging overpack; mph = miles per hour; N/A = not applicable, no scenarios identified.

Source: Attachment D

Table 6.3-8. Passive Failure Basic Events used in Intra-Site Operations Event Sequence Analysis

Basic Event ID	Basic Event Description	Basic Event Value
CANISTER_AO_DROP	Canister in aging overpack fails due to drop	1E-05
CANISTER_AO_IMPACT	Canister in aging overpack fails due to impact	1E-08
CANISTER_HAM_IMPACT	HAM fails due to impact	1E-08
CANISTER_HAM_OPS	Canister fails due to impact	1E-05
CANISTER1	Canister inside a transportation cask fails due to derailment, collision, or impact event (that is, when canister failure is included as part of transportation cask failure)	1
CONTAINER_LLW	LLW container fails	1
MODERATOR_SOP	Presence of moderator during nonfire event sequences	0
SHIELD_AO_DROP	Aging overpack shielding loss due to drop	5E-06
SHIELD_AO_IMPACT	Aging overpack shielding loss due to impact	1E-05
SHIELD_HAM_IMPACT	HAM shielding loss due to impact	1E-05
SHIELD_TCASK_COL	Transportation cask shielding loss due to a collision event	1E-08
SHIELD_TCASK_DROP	Transportation cask shielding loss due to drop event	1E-05
SHIELD_TCASK_DROPON	Transportation cask shielding loss due to an object dropping on the cask	1E-05
TCASK_COLLIDE_RC	Transportation cask on railcar fails due to collision	1E-08
TCASK_COLLIDE_TT	Transportation cask with impact limiters on truck trailer fails due to collision, resulting in drop/rollover (see note)	1E-08
TCASK_DERAIL	Transportation cask fails due to derailment	1E-05
TCASK_DROPON	Transportation cask fails due to object impact	1E-05
TCASK_DROPON_UCSNF	Transportation cask containing UCSNF fails due to object impact	1E-05
TCASK_HTC_DROP	HTC or HSTC fails due to drop	1E-05
TCASK_HTC_IMPACT	HTC or HSTC fails due to collision/impact	1E-08
THERMAL	—	—
FIRE_CANISTER_AO	Canister inside an aging overpack/HAM fails due to thermal challenge	1E-06
FIRE_CANISTER_TC	Canister inside a transportation cask fails due to thermal challenge	2E-06
FIRE_CANISTER_TC_NAV	Naval canister inside a transportation cask fails due to thermal challenge	1E-06
FIRE_MODERATOR	Presence of moderator during fire event sequences	1
FIRE_MODERATOR_NA	Moderator ability to reach contents in a fire	0
FIRE_SHIELD_AO	Aging overpack shielding loss due to fire	0
FIRE_SHIELD_TCASK	Transportation cask shielding loss due to fire	1
FIRE_TCASK_UCSNF	Transportation cask containing UCSNF fails due to fire	5E-02

NOTE: Refer to Attachment D, Section D2, provides a detailed discussion of PEFA.
HAM = horizontal aging module; HSTC = horizontal shielded transfer cask; HTC = transportation cask that is never upended; LLW = low-level radioactive waste; UCSNF = uncanistered commercial spent nuclear fuel.

Source: Original

6.3.3 Miscellaneous Data

Table 6.3-9 identifies the frequencies associated with fires evaluated for Intra-Site operations. Data that are not defined as Active Component Reliability Data (Section 6.3.1) or Passive Equipment Failure Data (Section 6.3.2), but are used in the reliability analysis for this facility are listed in Table 6.3-10.

Table 6.3-9. Fire Analysis Frequencies

Initiating Event	Mean frequency (per 50 years)
Fire Threatens a Waste Form During Onsite Transport	9E-07 fires/operation
Fire Threatens a Waste Form in Buffer Area	0.3 fires
Fire Threatens a Waste Form on Aging Pad	0.6 fires
Fire Threatens LLW in the LLWF	4.1E-01 fires
Large Fire Threatens LLW in the LLWF	6.8E-02 fires

NOTE: LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility.

Source: Attachment F, Table F5.3-1 and Table F6-1

Table 6.3-10. Miscellaneous Data Used in the Reliability Analysis

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	Reference(s)
CONTAINER_LLW	LLW container fails	1	To be conservative, initiating events involving LLW containers are modeled as if the container always fails.	N/A
MODERATOR_SOP	Presence of moderator during nonfire event sequences	0	There is no other moderator source outside of the waste handling facilities. Moderator is only present for Intra-Site Operations during fire events in which a fire brigade attempts to extinguish the fire with water.	N/A
FIRE_MODERATOR	Presence of moderator during fire event sequences	1	Moderator is only present for Intra-Site Operations during fire events in which a fire brigade attempts to extinguish the fire with water. To be conservative, the fire initiating events are modeled as if the fire brigade always responds and always uses sufficient water to act as a moderator.	N/A
FIRE_MODERATOR_NA	Used for waste forms for which moderator is not a concern during fire events (i.e., HLW and UCSNF)	0	Criticality safety design control features are not necessary for HLW canisters because the concentration of fissile isotopes in an HLW canister is too low to have criticality potential (Ref. 2.2.31, Table 6). As described in Section 6.0.7, moderator cannot reach cask contents for the UCSNF waste form during fire events.	(Ref. 2.2.31, Table 6), and Section 6.0.7
DPC_RC	Number of transportation casks containing DPCs on railcars	346	This basic event represents the number of transportation casks containing DPCs estimated to arrive on railcars over the preclosure period. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)
HDPC_RC	Number of transportation casks containing HDPCs on railcars	346	This basic event represents the number of transportation casks containing HDPCs estimated to arrive on railcars over the preclosure period. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)
HLW_RC	Number of transportation casks containing HLW on railcars	1,860	This basic event represents the number of transportation casks containing HLW estimated to arrive on railcars over the preclosure period. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)

Table 6.3-10. Miscellaneous Data Used in the Reliability Analysis (Continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	Reference(s)
NAV_RC	Number of transportation casks containing naval canisters on railcars	400	This basic event represents the number of transportation casks containing naval canisters estimated to arrive on railcars over the preclosure period.	(Ref. 2.2.23)
MCO_RC	Number of transportation casks containing MCOs on railcars	113	This basic event represents the number of transportation casks containing MCOs estimated to arrive on railcars over the preclosure period. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)
DSTD_RC	Number of transportation casks containing DOE standardized canisters on railcars	385	This basic event represents the number of transportation casks containing DOE standardized canisters estimated to arrive on railcars over the preclosure period. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)
TAD_RC	Number of transportation casks containing TAD canisters on railcars	6,978	This basic event represents the number of transportation casks containing TAD canisters estimated to arrive on railcars over the preclosure period. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)
UCSNF_RC	Number of transportation casks containing uncanistered commercial spent nuclear fuel on railcars	0	This basic event represents the number of transportation casks containing uncanistered commercial spent nuclear fuel estimated to arrive on railcars over the preclosure period. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)
DPC_TT	Number of transportation casks containing DPCs on truck trailers	0	This basic event represents the number of transportation casks containing DPCs estimated to arrive on truck trailers over the preclosure period. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)
HDPC_TT	Number of transportation casks containing HDPCs on truck trailers	0	This basic event represents the number of transportation casks containing HDPCs estimated to arrive on truck trailers over the preclosure period. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)

Table 6.3-10. Miscellaneous Data Used in the Reliability Analysis (Continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	Reference(s)
HLW_TT	Number of transportation casks containing HLW on truck trailers	500	This basic event represents the number of transportation casks containing HLW estimated to arrive on truck trailers over the preclosure period. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)
NAV_TT	Number of transportation casks containing naval canisters on truck trailers	0	This basic event represents the number of transportation casks containing naval canisters estimated to arrive on truck trailers over the preclosure period. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)
MCO_TT	Number of transportation casks containing MCOs on truck trailers	113	This basic event represents the number of transportation casks containing MCOs estimated to arrive on truck trailers over the preclosure period. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)
DSTD_TT	Number of transportation casks containing DOE standardized canisters on truck trailers	385	This basic event represents the number of transportation casks containing DOE standardized canisters estimated to arrive on truck trailers over the preclosure period. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)
TAD_TT	Number of transportation casks containing TAD canisters on truck trailers	0	This basic event represents the number of transportation casks containing TAD canisters estimated to arrive on truck trailers over the preclosure period. The value for this basic event is obtained from the throughput analysis, and engineering judgment. That is, TADs will not arrive on truck trailers because fully loaded TADs are too heavy to allow transport on truck trailers. If the rail system is not fully operational when the repository is opened, it is logical that, if necessary, other truck casks (or truck cask/canister systems) would be used. Therefore, it is not necessary to analyze TADs on truck trailers.	(Ref. 2.2.23), and engineering judgment
UCSNF_TT	Number of transportation casks containing uncanistered commercial spent nuclear fuel on truck trailers	3,775	This basic event represents the number of transportation casks containing uncanistered commercial spent nuclear fuel estimated to arrive on truck trailers over the preclosure period. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)

Table 6.3-10. Miscellaneous Data Used in the Reliability Analysis (Continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	Reference(s)
DPC_AO	Number of DPCs aged in an aging overpack at the Aging Facility	346	This basic event represents the estimated number of aging overpacks containing DPCs to be sent to the Aging Facility over the preclosure period for thermal management. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)
TAD_AO	Number of TAD canisters aged in an aging overpack at the Aging Facility	8,143	This basic event represents the estimated number of aging overpacks containing TAD canisters to be sent to the Aging Facility over the preclosure period for thermal management. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)
HDPC_HAM	Number of HDPCs aged in a HAM at the Aging Facility	346	This basic event represents the estimated number of HTCs containing HDPCs to be sent to the Aging Facility for thermal management in HAMs over the preclosure period. The value for this basic event is obtained from the throughput analysis.	(Ref. 2.2.23)
DAW_HEPAs_WHF_ITS_STAGE1_ONLY	Number of DAW HEPAs (WHF ITS STAGE 1 only)	1,800	For dose calculations, these HEPA filters are the only DAW that are anticipated to have significant levels of contaminants; "1,800" is based on *Shielding Requirements and Dose Rate Calculations for WHF and LLWF* (Ref. 2.2.22,Section 3.1.9), which estimated 30 filters are changed every 10 months (to maintain contamination levels at or below Class B for LLW), over the 50-year preclosure period. In addition, it is conservatively estimated that each HEPA filter will be containerized and moved to the LLWF individually.	(Ref. 2.2.22, Section 3.1.9)
WET_SOLID_RESIN_XFRS	Number of HICs containing WET-res (from WHF resin beds)	150	Sluicing each resin bed once per year (3 beds total), results in 150 high-integrity containers (HICs) over the preclosure period. This is conservative, because the WHF could opt to do a maintenance shutdown of the facility and sluice all three resin beds into one HIC. This would result in a minimum number of HICs, that is, 50 HICs over the preclosure period.	(Ref. 2.2.22, Sections 3.1.6 and 3.1.8)

Table 6.3-10. Miscellaneous Data Used in the Reliability Analysis (Continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	Reference(s)
WET_SOLID_NONRESIN_XFR	WET-nr (WHF pool filters)	150	Operational plan for storing and moving pool filters: Filters from WHF PWTS will be stored in WHF in a HIC. It is estimated that 520 filters will be generated annually, and each HIC holds up to 200 filters. This results in 3 HICs per year, and each filled HIC will be moved to the LLWF (or directly offsite) on a flatbed trailer (lowboy or equivalent). Over the 50-yr preclosure period, this results in 150 HICs.	(Ref. 2.2.85)
Boundary to CRCF3 (080)	Distance between the GROA boundary and the furthest waste handling facility (CRCF3 (080)	2	Manually measured on scale drawing the travel distance (miles) between the GROA boundary and the furthest waste handling facility (CRCF-3). Rounded to one significant figure.	(Ref. 2.2.28)
Furthest Aging Pad to CRCF3 (080)	Distance between CRCF3 (080) and the furthest aging pad (17P)	2	Manually measured on scale drawing the travel distance (miles) between CRCF3 (080) and the furthest aging pad (17P). Rounded to one significant figure.	(Ref. 2.2.27)
No. Moves Each Transportation Cask – ESD-01	Number of times a transportation cask on a railcar or a transportation cask on a truck trailer travels between the site boundary and a facility	1	The TC/RC or TC/TT is only moved once between the site boundary and the facility: upon receipt of the TC, it is moved to a facility where the TC is removed from the RC or TT.	(Ref. 2.2.29)
No. Moves via ST – ESD-02	Number of times an aging overpack travels between a surface handling facility and the Aging Facility (via the site transporter)	2	The aging overpack is moved twice - once from a handling facility to the Aging Facility for thermal management, and once from the Aging Facility to a handling facility when aging is complete.	Ref. 2.2.29)
No. Moves via Cask Tractor/Cask Transfer Trailer – ESD-03	Number of times an HTC or HSTC containing an HDPC travels between a surface handling facility and the Aging Facility (via the cask tractor/cask transfer trailer)	2	The HDPC is moved twice (in either an HTC or an HSTC) – once to the Aging Facility for thermal management, and once to a handling facility when aging is complete.	(Ref. 2.2.29)
No. Moves via Cask Transfer Trailer – ESD-04	Number of times an HDPC is inserted into or retrieved from a HAM (cask transfer trailer operations)	2	The HDPC is moved twice – once to insert the canister into the HAM for aging, and once to retrieve it for handling at the WHF.	(Ref. 2.2.29)
No. Moves – per LLW container; ESD-05	The average number of movements within the LLWF for a given LLW container	3	Engineering judgment, based on general knowledge of warehouse movements involving typical equipment such as forklifts.	N/A

Table 6.3-10. Miscellaneous Data Used in the Reliability Analysis (Continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	Reference(s)
No. Transfers per LLW container ESD-08	The overall number of transfer movements for each LLW container (i.e., from the generating facility to either the LLWF or offsite)	1	Engineering judgment, based on general knowledge of warehouse movements involving typical equipment such as forklifts.	N/A

NOTE: CRCF = Canister Receipt and Closure Facility; DAW = dry active waste; DOE = Department of Energy; DPC = dual-purpose canister; ESD = event sequence diagram; GROA = geologic repository operations area; HAM = horizontal aging module; HEPA = high-efficiency particulate air filter; HLW = high-level radioactive waste; HDPC = horizontal dual-purpose canister; HIC = high-integrity container; HSTC = horizontal shielded transfer cask; HTC = horizontal transportation cask that is not upended; ITS = important to safety; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; MCO = multicanister overpack; PWTS = pool water treatment system; RC = railcar; ST = site transporter; TAD = transportation, aging, and disposal; TT = truck trailer; UCSNF = uncanistered commercial spent nuclear fuel; WHF = Wet Handling Facility.

Source: Original (further information provided in “References” column)

6.4 HUMAN RELIABILITY ANALYSIS

The PCSA has emphasized HRA because the waste handling processes include substantial interactions between equipment and operating personnel. If there are human interactions that are typically associated with the operation, test, calibration, or maintenance of a certain type of SSC (e.g., drops from a crane when using slings), and this SSC has been treated using industry-wide data, per Attachment C, then HFEs may be implicit in the reliability data. The analyst is tasked with determining whether that is the case. Otherwise, the analyst includes explicit identification, qualitative modeling, and quantification of HFEs, as described in this section. The methodology applied is provided in Section 4.3.4, and the detailed description of the HRA is presented in Attachment E.

6.4.1 HRA Scope

The scope of the HRA is established in order to focus the analysis on the issues pertinent to the goals of the overall PCSA. Thus, the scope is as follows:

1. HFEs are only considered if they contribute to a scenario that has the potential to result in a release of radioactivity, a criticality event, or a radiation exposure to workers. Such scenarios may include the need for mitigation of radionuclides, such as provided by the confinement HVAC system in a waste handling facility.

2. Pursuant to the above, the following types of HFEs are excluded:

   A. HFEs resulting in standard industrial injuries (e.g., falls)

   B. HFEs resulting in the release of hazardous nonradioactive materials, regardless of amount

   C. HFEs resulting solely in delays to or losses of process availability, capacity, or efficiency.

3. The identification of HFEs is restricted to those areas of the facility that handle waste forms, and only during the times that waste forms are being handled (e.g., HFEs are not identified for the site transportation of empty aging overpacks).

4. The exception to #3 is that system-level HFEs are considered for support systems when those HFEs could result in a loss of a safety function related to the occurrence or consequences associated with the events specified in #1.

5. Post-initiator recovery actions (as defined in Attachment E, Section E5.1.1.1) are not credited in the analysis; therefore, HFEs associated with them are not considered.

6. In accordance with the boundary conditions of the PCSA discussed in Section 4.3.10.1, initiating events associated with conditions introduced in SSCs before they reach the site are not, by definition of 10 CFR 63.2 (Ref. 2.3.2) within the scope of the PCSA nor, by extension, within the scope of the HRA.

6.4.2 Base Case Scenarios

The first step in this analysis is to describe Intra-Site Operations in sufficient detail such that the human reliability analysts can identify specific deviations that would lead to a radiation release, a direct exposure, or a criticality event.

Intra-Site Operations cover the following four high-level operational activities:

1. Site transportation of SNF and HLW

2. Aging activities, including transit between the waste handling facilities and the Aging Facility, and thermal aging of TAD canisters and DPCs

3. LLWF operations

4. BOP facilities that directly or indirectly establish or support the repository infrastructure and operating services systems.

The base case scenario represents a realistic description of expected facility, equipment, and operator behavior for the selected operation. These scenarios are created from discussions between the human reliability analysts, other PCSA analysts, and personnel from engineering and operations. In addition to a detailed description of the operation itself, these base case scenarios include a brief description of the initial conditions and relevant equipment features (e.g., interlocks).

6.4.3 Identification of Human Failure Events

There are many possible human errors that could occur at YMP, the effects of which might be significant to safety. Human errors, based upon the three temporal phases used in PRA modeling, are categorized as follows:

- Pre-initiator HFEs
- Human-induced initiator HFEs
- Post-initiator HFEs[1]:
  - Non-recovery
  - Recovery.

Each of these types of HFEs is defined in Attachment E, Section E5.1.1.1. The PCSA model was developed and quantified with pre-initiator and human-induced initiator HFEs included in the model. The safety philosophy of waste handling operations is that an operator need not take any action after an initiating event, and there are no actions identified that could exacerbate the consequences of an initiating event. This stems from the definitions and modeling of initiating events and subsequent pivotal events as described in Section 6.1 and Attachment A. All initiating events are proximal causes of either radionuclide release or direct exposure to

[1] Terminology common to nuclear power plants refers to post-initiator non-recovery events as Type C events and recovery events as Type CR events.

personnel. With respect to the latter, personnel evacuation was not considered in reducing the frequency of direct exposure, but personnel action could cause an initiating event. With respect to the former, pivotal events address containment integrity, confinement availability, shielding integrity, and moderator availability that have no post-initiator human interactions. Containment and shielding integrity are associated only with the physical robustness of the waste containers. For waste handling facilities, confinement availability is associated with a continuously operating HVAC and the status of equipment confinement doors. Human interactions for HVAC are pre-initiator. Human actions for shielding are associated the initiator phase. Recovery post-initiator HFEs were not identified and not relied upon to reduce event sequence frequency. Thus, the focus of the HRA task is to support the other PCSA tasks to identify these two HFE phases.

Pre-Initiator HFEs

Pre-initiator HFEs are identified by the system analysts when modeling fault trees during the system analysis task. Special attention is paid to the possibility that an error can be repeated in similar redundant components or trains, leading to a human CCF.

Human-Induced Initiator HFEs

Human-induced initiator HFEs are identified through an iterative process whereby the human reliability analysts, in conjunction with other PCSA analysts and engineering and operations personnel, meet and discuss the design and operations of the facility and the SSCs in order to appropriately model the human interface. This iterative process began with the HAZOP evaluation, the MLD and event sequence development, and the event tree and fault tree modeling, and it culminated in the preliminary analysis and incorporation of HFEs into the model. Included in this process is an extensive information collection process where industry data for potential vulnerabilities and HFE scenarios are reviewed. The following sources were examined:

- "Summary Tables." *Large Truck Crash Causation Study.* (Ref. 2.2.38)
- "Speeding Counts...on All Roads!" (Ref. 2.2.39)
- *Traffic Safety Facts 2002: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System* (Ref. 2.2.40)
- *Comparative Risks of Hazardous Materials and Non-Hazardous Materials Truck Shipment Accidents/Incidents, Final Report* (Ref. 2.2.9)
- *A Survey of Crane Operating Experience at U.S. Nuclear Power Plants from 1968 – 2002*, NUREG-1774 (Ref. 2.2.53)
- Control of Heavy Loads at Nuclear Power Plants, NUREG-0612 (Ref. 2.2.63)

- *Naval Facilities Engineering Command (NAVFAC)* Internet Web Site, Navy Crane Center. The database includes the following information:

  - Naval Crane Center Quarterly Reports ("Crane Corner") 2001 through 2007

  - Naval Crane Center Fiscal Year 2006 Crane Safety Reports (covers fiscal year 2001 through 2006)

  - Naval Crane Center Fiscal Year 2006 Audit Report

- *DOE Occurrence Reporting and Processing System (ORPS)* Internet Web Site, Operational Experience Summaries (2002 through 2007)

- Institute of Nuclear Power Operations database, which contains the following information:

  - Licensee event reports
  - Equipment Performance and Information Exchange System

- Nuclear Plant Reliability Data System.

- *Savannah River Site Human Error Data Base Development for Nonreactor Nuclear Facilities (U)* (Ref. 2.2.10)

- All SCIENTECH/Licensing Information Service data on independent SNF storage installation events (1994 through 2007) and Dry Storage Information Forum (New Orleans, LA, May 2-3, 2001). This database includes the following information:

  - Inspection reports
  - Trip reports
  - Correspondence

HFEs identified include both errors of omission and errors of commission.

The result of this identification process is a list of HFEs and a description of each HFE scenario, including system and equipment conditions and any resident or triggered human factor concerns (e.g., PSFs). This combination of conditions and human factor concerns then becomes the EFC for a specific HFE. Additions and refinements to these initial EFCs are made during the preliminary and detailed analyses.

6.4.4 Preliminary Analysis

A preliminary analysis is performed to allow HRA resources for the detailed analyses to be focused on only the most risk-significant HFEs. The preliminary analysis includes verification of the validity of HFEs included in the initial PCSA model, assignment of conservative HEPs to all HFEs and verification of those probabilities. The actual quantification of preliminary values is a six-step process that is described in detail in Appendix E.III of Attachment E. Once the preliminary probabilities are assigned, the PCSA model is quantified (initial quantification) to determine which HFEs require a detailed quantification. HFEs are identified for a detailed analysis if (1) the HFE is a risk-driver for a dominant sequence, and (2) using the preliminary values, an aggregated event sequence is Category 1 or Category 2 according to 10 CFR 63.111 (Ref. 2.3.2) performance objectives.

In cases where HFEs are completely mitigated by hardware (i.e., interlocks), the HFE is generally assigned a value of 1.0 unless otherwise noted, and the hardware is modeled explicitly in the fault tree.

HFE probabilities produced in this HRA are mean values; uncertainties are accounted for by applying an error factor to the mean value of the overall HFE, according to the guidelines presented in Section E3.4 of Attachment E.

6.4.5 Detailed Analysis

Once preliminary values have been assigned, the model is run and HFEs are identified for a detailed analysis if (1) the HFE is a risk-driver for a dominant sequence, and (2) using the preliminary values, that sequence is Category 1 or Category 2. A dominant sequence is one that does not meet the performance objectives according to 10 CFR 63.111 (Ref. 2.3.2). The objective of a detailed analysis is to develop a more realistic HRA and identify design features to be added that will provide compliance with the aforementioned regulation. Many of the ITS features in Section 6.9 were identified during the HRA. The preliminary values were sufficient to demonstrate compliance with the performance objectives of 10 CFR 63.111; therefore no detailed analyses were performed for this HRA.

6.4.6 Human Failure Event Probabilities used in Intra-Site Operations Event Sequences Analysis

The results of the HRA are the HFE probabilities used in the event tree and fault tree quantification process, which are listed in Table 6.4-1.

Table 6.4-1. Human Failure Event Probability Summary

Basic Event Name	HFE Description	ESD	Basic Event Mean Probability	Error Factor	Type of Analysis
ISO-OPSICOMPDROP-HFI-NOD	Operator drops object onto transportation cask	1	N/A [a]	N/A	Historic Data
ISO-HEPA-XFER-L-FORKLIFT	Operator punctures drum of LLW with forklift	5	N/A [a]	N/A	Historic Data
ISO-OPHTCOLLIDE1-HFI-NOD	Operator causes collision of HCTT in the facility	3	3E−03	5	Preliminary
ISO-OPHTINTCOL01-HFI-NOD	Operator causes collision of HCTT due to cask tractor overspeed	3	1	N/A	Preliminary
ISO-OP-HAMIMPACT-HFI-NOD	Operator causes HAM impact with crane	4	3E−03	5	Preliminary
ISO-OP-HAMINSERT-HFI-NOD	Operator misaligns transport and HAM opening	4	1E−03	5	Preliminary
ISO-OPRCCOLLIDE1-HFI-NOD	Operator causes SPM/railcar collision in the facility	1	3E−03	5	Preliminary
ISO-OPRCINTCOL01-HFI-NOD	Operator initiates PMRC runaway	1	1	N/A	Preliminary
ISO-OPSTCOLLIDE2-HFI-NOD	Operator error causes site transporter collision in the facility	2	3E−03	5	Preliminary
ISO-OPTTCOLLIDE1-HFI-NOD	Operator causes SPM/truck trailer collision in the facility	1	3E−03	5	Preliminary
ISO-OPTTINTCOL01-HFI-NOD	Operator initiates truck trailer runaway	1	1	N/A	Preliminary
ISO-PMRC-DERAIL-PER-MILE	PMRC derailment	1	N/A [a]	N/A	Historic Data
ISO-VEH-COLISION-COL-RAT	Collision of RC, TT, ST or HCTT with SSC during transport across the GROA	8	7E−07	10	Historic Data

NOTE: [a] Historical data was used to produce a probability of crane drops; this historical data is not included as part of the HRA, but is addressed in Attachment C.

ESD = event sequence diagram; GROA = geologic repository operations area; HAM = horizontal aging module; HCTT = cask tractor and cask transfer trailer; HFE = human failure event; LLW = low-level radioactive waste; N/A = not applicable; PMRC = prime mover railcar; RC = railcar; SPM = site prime mover; SSC = structure, system, or component; ST = site transporter; TT = truck trailer.

Source: Attachment E, Table E7-1

6.5 FIRE INITIATING EVENTS

Attachment F of this document describes the work scope, definitions and terms, method, and results for the fire analysis performed as part of the PCSA. The internal events of the PCSA are evaluated with respect to the fire initiating events and modified as necessary to address fire-induced failure that lead to exposures. The list of fire-induced failures included in the model, are evaluated as to fire vulnerability, and fragility analyses are conducted as needed (Section 6.3.2 and Attachment D, Section D2).

Fire initiating event frequencies have been calculated for each initiating event for Intra-Site operations. Section F5 of Attachment F details the analysis performed to determine the frequencies, using the methodology described in Section F4 of Attachment F.

6.5.1 Input to Initiating Events

Frequency of vehicle fire per operation and the number of movements of waste forms on site are the values that contribute to calculating initiating event frequencies for on-site transportation of waste form. Locations where waste forms may be placed for short periods of time during on-site receipt or long periods of time for on-site storage (i.e., aging) while awaiting processing are the inputs to calculating initiating event frequencies for waste forms outside buildings that are not in active transport. An uncertainty distribution is applied to the ignition frequency, and contributes to the resulting distribution for fire initiating event frequencies. The uncertainty distribution is determined by using a team judgment process.

In addition, the floor area of the LLW building is the value that contributes to calculating the initiating event frequency for a fire in that building. An uncertainty distribution is applied to the ignition frequency based on the uncertainty in the historically observed fire information that serves as the basis for the building fire model.

6.5.2 Initiating Event Frequencies

The results of the fire initiating event analysis are the fire initiating event frequencies and their associated distributions, as presented in Table 6.5-1. The frequencies represent the probability, over the length of the pre-closure surface operation period, that a fire will threaten the stated waste container. Calculations performed to obtain the initiating event frequencies are detailed in Section F5.2 of Attachment F.

Uncertainty distributions are utilized in the contribution to initiating event frequency calculations to account for the statistical uncertainty in the data. Uncertainty distributions utilized for this analysis are lognormal distributions.

Table 6.5-1. Fire Initiating Event Frequency Distributions

Initiating Event	Mean frequency (per 50 years)	Error Factor	Distribution
Fire Threatens a Waste Form During Onsite Transport	9 E-07 fires/operation	15	lognormal
Fire Threatens a Waste Form in Buffer Area	0.3 fires	15	lognormal
Fire Threatens a Waste Form on Aging Pad	0.6 fires	15	lognormal
Fire Threatens LLW in the LLWF	4.1E-01 fires	2.0	lognormal
Large Fire Threatens LLW in the LLWF	6.8E-02 fires	2.0	lognormal

NOTE: LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility.

Source: Attachment F, Tables F5.3-1 and F6-1

6.6 NOT USED

6.7 EVENT SEQUENCE FREQUENCY RESULTS

This section provides the results of the event sequence quantification as produced from the Excel spreadsheet and the SAPHIRE (Ref. 2.2.76) FTA. Quantification of an event sequence consists of calculating its number of occurrences over the preclosure period by combining the frequency of a single initiating event with the conditional probabilities of pivotal events that comprise the sequence. The quantification results are presented as an expression of the mean and median number of occurrences of each event sequence over the preclosure period, and the standard deviation as a measure of uncertainty. Section 6.8 describes the process for aggregation of similar event sequences to permit categorization as Category 1, Category 2, or beyond Category 2 event sequences.

This section presents a summary of how the quantification is performed for Intra-Site Operations using a combination of Excel (for quantification) and SAPHIRE (to produce probability and uncertainty values for the calculation), as described in Section 4.3. The results presented in this section, in Attachment G, and in Section 6.8 include a summary of all event sequences that are quantified, a list of off-normal events not analyzed for categorization, and a table summarizing the results of the final (grouped) quantification.

6.7.1 Process for Event Sequence Quantification

Internal event sequences that are based on the event trees presented in Section 6.1 and fault trees presented in Section 6.2 are quantified using Excel and SAPHIRE. The event sequence quantification methodology is presented in Section 4.3.1.1 (using SAPHIRE with Excel) and Section 4.3.6 (general). An event sequence frequency is the product of several factors, as follows (with examples):

- *Number of times the operation or activity that gives rise to the event sequence is performed over the preclosure period*: An example of this value would be the total number of transfers of a waste form between waste handling facilities over the preclosure period.

- *Probability of occurrence of the initiating event for the event sequence considered*: Continuing with the previous example, this could be the probability of collision involving a mover carrying the waste form between waste handling facilities. The initiating event probability is entered into Excel as parameters of the distribution (mean, median, and standard deviation), which are either produced from a fault tree in SAPHIRE or are based on a basic event value (data).

- *Conditional probability of each of the pivotal events of the event sequence (shown graphically in the SRET for each ESD)*: For Intra-Site Operations, the pivotal events represent a passive failure, for example, cask/canister breach.

As illustrated in Section 4.3.1.1, uncertainties in input parameters such as throughput rates, equipment failure rates, passive failure probabilities, and HFEs used to calculate basic event probabilities are propagated through the fault trees used and the event sequence logic to quantify the uncertainty in the event sequence quantification.

6.7.2 Event Sequence Quantification Summary

Table G-1 in Attachment G presents the results of the event sequence quantifications. Table G-1 summarizes the results of the quantification and lists the following elements: (1) event tree from which the sequence is generated, (2) event sequence designator (ID), (3) initiating event description, (4) event sequence logic, (5) event sequence end state, (6) event sequence mean value, (7) event sequence median value, and (8) event sequence standard deviation (i.e., the uncertainty). As an example, Table 6.7-1 below presents an excerpt from Table G-1, showing ISO-ESD-01 event sequence quantifications for DPC waste forms only.

Table 6.7-1.Example Event Sequence Quantification Summary Table

Event Tree	Sequence	Description	Logic	End State	Calc'd Mean	Calc'd Median	Calc'd Std. Deviation
ISO-ESD01-DPC	3-2	This sequence represents a structural challenge to a DPC inside a transportation cask resulting in a direct exposure from degradation of shielding due to a railcar collision. In this sequence the transportation cask remains intact, and the shielding fails.	INTRASITE_SPMRC_COLLIDE, /TCASK_COLLIDE_RC, SHIELD_TCASK_COL	DED	1.E-08	7.E-09	7.E-08
ISO-ESD01-DPC	3-3	This sequence represents a structural challenge to a DPC inside a transportation cask resulting in a direct exposure from loss of shielding due to a railcar collision. In this sequence the transportation cask fails, and the canister remains intact.	INTRASITE_SPMRC_COLLIDE, TCASK_COLLIDE_RC, /CANISTER1	DEL	0.E+00	0.E+00	0.E+00
ISO-ESD01-DPC	3-4	This sequence represents a structural challenge to a DPC inside a transportation cask resulting in an unfiltered radiological release from cask/canister breach due to a railcar collision. In this sequence the transportation cask and the canister fail, but moderator is prevented from entering the canister.	INTRASITE_SPMRC_COLLIDE, TCASK_COLLIDE_RC, CANISTER1, /MODERATOR_SOP	RRU	1.E-08	7.E-09	7.E-08
ISO-ESD01-DPC	3-5	This sequence represents a structural challenge to a DPC inside a transportation cask resulting in an unfiltered radiological release important to criticality from cask/canister breach due to a railcar collision. In this sequence the transportation cask and the canister fail, and moderator is not prevented from entering the canister.	INTRASITE_SPMRC_COLLIDE, TCASK_COLLIDE_RC, CANISTER1, MODERATOR_SOP	RUC	0.E+00	0.E+00	0.E+00
ISO-ESD01-DPC	2-2	This sequence represents a structural challenge to a DPC inside a transportation cask resulting in a direct exposure from degradation of shielding due to a railcar derailment. In this sequence the transportation cask remains intact, and the shielding fails.	INTRASITE_DERAIL, /TCASK_DERAIL, SHIELD_TCASK_DROP	DED	7.E-08	7.E-08	1.E-08

Table 6.7-1. Example Event Sequence Quantification Summary Table (Continued)

Event Tree	Sequence	Description	Logic	End State	Calc'd Mean	Calc'd Median	Calc'd Std. Deviation
ISO-ESD01-DPC	2-3	This sequence represents a structural challenge to a DPC inside a transportation cask resulting in a direct exposure from loss of shielding due to a railcar derailment. In this sequence the transportation cask fails, and the canister remains intact.	INTRASITE_DERAIL, TCASK_DERAIL, /CANISTER1	DEL	0.E+00	0.E+00	0.E+00
ISO-ESD01-DPC	2-4	This sequence represents a structural challenge to a DPC inside a transportation cask resulting in an unfiltered radiological release from cask/canister breach due to a railcar derailment. In this sequence the transportation cask and the canister fail, but moderator is prevented from entering the canister.	INTRASITE_DERAIL, TCASK_DERAIL, CANISTER1, /MODERATOR_SOP	RRU	7.E-08	7.E-08	1.E-08
ISO-ESD01-DPC	2-5	This sequence represents a structural challenge to a DPC inside a transportation cask resulting in an unfiltered radiological release important to criticality from cask/canister breach due to a railcar derailment. In this sequence the transportation cask and the canister fail, and moderator is not prevented from entering the canister.	INTRASITE_DERAIL, TCASK_DERAIL, CANISTER1, MODERATOR_SOP	RUC	0.E+00	0.E+00	0.E+00
ISO-ESD01-DPC	4-2	N/A - No DPCs will be transported by TT	—	N/A	—	—	—
ISO-ESD01-DPC	4-3	N/A - No DPCs will be transported by TT	—	N/A	—	—	—
ISO-ESD01-DPC	4-4	N/A - No DPCs will be transported by TT	—	N/A	—	—	—
ISO-ESD01-DPC	4-5	N/A - No DPCs will be transported by TT	—	N/A	—	—	—
ISO-ESD01-DPC	5-2	This sequence represents a structural challenge to a DPC inside a transportation cask resulting in a direct exposure from degradation of shielding due to an object dropped onto the transportation cask. In this sequence the transportation cask remains intact, and the shielding fails.	INTRASITE_JIB_CRANE, /TCASK_DROPON, SHIELD_TCASK_DROPON	DED	1.E-07	7.E-08	7.E-08

Table 6.7-1. Example Event Sequence Quantification Summary Table (Continued)

Event Tree	Sequence	Description	Logic	End State	Calc'd Mean	Calc'd Median	Calc'd Std. Deviation
ISO-ESD01-DPC	5-3	This sequence represents a structural challenge to a DPC inside a transportation cask resulting in a direct exposure from loss of shielding due to an object dropped onto the transportation cask. In this sequence the transportation cask fails, and the canister remains intact.	INTRASITE_JIB_CRANE, TCASK_DROPON, /CANISTER1	DEL	0.E+00	0.E+00	0.E+00
ISO-ESD01-DPC	5-4	This sequence represents a structural challenge to a DPC inside a transportation cask resulting in an unfiltered radiological release from cask/canister breach due to an object dropped onto the transportation cask. In this sequence the transportation cask and the canister fail, but moderator is prevented from entering the canister.	INTRASITE_JIB_CRANE, TCASK_DROPON, CANISTER1, /MODERATOR_SOP	RRU	1.E-07	7.E-08	7.E-08
ISO-ESD01-DPC	5-5	This sequence represents a structural challenge to a DPC inside a transportation cask resulting in an unfiltered radiological release important to criticality from cask/canister breach due to an object dropped onto the transportation cask. In this sequence the transportation cask and the canister fail, and moderator is not prevented from entering the canister.	INTRASITE_JIB_CRANE, TCASK_DROPON, CANISTER1, MODERATOR_SOP	RUC	0.E+00	0.E+00	0.E+00
ISO-…	*Refer to Attachment G, Table G-1 for the complete table of event sequence quantifications.*						

NOTE: DPC = dual-purpose canister, N/A = not applicable; TT = truck trailer.

Source: Original

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6.8 EVENT SEQUENCE GROUPING AND CATEGORIZATION

An aggregation process is applied prior to a categorization of event sequences, as described in Section 4.3.1. It is appropriate for purposes of categorization to add the frequencies of event sequences derived from an ESD that elicit the same combination of failure and success of pivotal events and that have the same end state. This is termed final event sequence quantification (Section 6.8.1), and the results give the final frequency of occurrence. Using the final frequency of occurrence, the event sequences are categorized according to the definition of Category 1 and Category 2 event sequences given in 10 CFR 63.2 (Ref. 2.3.2). Dose consequences for Category 1 and Category 2 event sequences are subject to the performance objectives of 10 CFR 63.111 (Ref. 2.3.2), and are evaluated in *Preclosure Consequence Analyses* (Ref. 2.2.30). Event sequences with a frequency of occurrence less than one chance in 10,000 of occurring before closure of the repository are designated as beyond Category 2 event sequences and are not analyzed for dose consequences.

Rather than calculate dose consequences for each Category 2 event sequence identified in the categorization process, dose consequences are performed for a set of bounding events that encompass the end states and material at risk for event sequences. Therefore, dose consequences are determined for a representative set of postulated Category 2 event sequences, identified in Table 6.8-1 (Ref. 2.2.30, Table 2). Because all waste containers types and configurations that are applicable to the repository are included in Table 6.8-1, some of the bounding event sequences do not apply to this analysis (e.g., 2-06, "Uncanistered commercial SNF in pool"). Once event sequence categorization is complete, Category 2 event sequences are cross referenced with the bounding event number given in Table 6.8-1, thus assuring that Category 2 event sequences have been evaluated for dose consequences and compared to the 10 CFR 63.111 performance objectives.

Table 6.8-1. Bounding Category 2 Event Sequences

Bounding Event Number	Affected Waste Form	Description of End State	Material At Risk
2-01	LLWF inventory and HEPA filters	Seismic event resulting in LLWF collapse and failure of HEPA filters and ductwork in other facilities.	HEPA filters LLWF inventory
2-02	HLW canister in transportation cask	Breach of sealed HLW canisters in a sealed transportation cask	5 HLW canisters
2-03	HLW canister	Breach of sealed HLW canisters in an unsealed waste package	5 HLW canisters
2-04	HLW canister	Breach of sealed HLW canister during transfer (one drops onto another)	2 HLW canisters
2-05	Uncanistered commercial SNF in transportation cask	Breach of uncanistered commercial SNF in a sealed truck transportation cask in air	4 PWR or 9 BWR commercial SNF
2-06	Uncanistered commercial SNF in pool	Breach of uncanistered commercial SNF in an unsealed truck transportation cask in pool	4 PWR or 9 BWR commercial SNF
2-07	DPC in air	Breach of a sealed DPC in air	36 PWR or 74 BWR commercial SNF
2-08	DPC in pool	Breach of commercial SNF in unsealed DPC in pool	36 PWR or 74 BWR commercial SNF

Table 6.8-1. Bounding Category 2 Event Sequences (Continued)

Bounding Event Number	Affected Waste Form	Description of End State	Material At Risk
2-09	TAD canister in air	Breach of a sealed TAD canister in air within facility	21 PWR or 44 BWR commercial SNF
2-10	TAD canister in pool	Breach of commercial SNF in unsealed TAD canister in pool	21 PWR or 44 BWR commercial SNF
2-11	Uncanistered commercial SNF	Breach of uncanistered commercial SNF assembly in pool (one drops onto another)	2 PWR or 2 BWR commercial SNF
2-12	Uncanistered commercial SNF	Breach of uncanistered commercial SNF in pool	1 PWR or 1 BWR commercial SNF
2-13	Combustible and noncombustible LLW	Fire involving LLWF inventory	Combustible and noncombustible inventory
2-14	Uncanistered commercial SNF in truck transportation cask	Breach of a sealed truck transportation cask due to a fire	4 PWR or 9 BWR commercial SNF

NOTE: BWR = boiling water reactor; DPC = dual-purpose canister; HEPA = high-efficiency particulate air; HLW = high-level radioactive waste; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; PWR = pressurized water reactor; SNF = spent nuclear fuel;
TAD = transportation, aging, and disposal canister.

Source: Ref. 2.2.30, Table 2

6.8.1 Event Sequence Grouping and Final Quantification

Event sequences are modeled to represent the GROA operations and SSCs. Accordingly, an event sequence is unique to a given operational activity in a given operational area, which is depicted in an ESD. When more than one initiating event shares the same ESD and, thus, elicits the same pivotal events and the same end states, it may be necessary to quantify the event sequence for each initiating event individually because the conditional probabilities of the pivotal events depend on the specific initiating event. In such cases, the frequencies of event sequences from the same ESD, with the same path through the event tree and with the same end state, are added together, thus comprising an event sequence grouping.

For example, an ESD may show event sequences that could occur during movement of a canister in an aging overpack via site transporter between a surface facility and the Aging Facility. More than one initiating event, such as a drop or collision, may share the same ESD, and, therefore, elicit the same pivotal events and end states; however, it may give rise to event sequences that are quantified for each initiating event because the conditional probabilities of their pivotal events depend on the specific initiating event.

By contrast, some ESDs indicate a single initiating event. Such initiating events may be composites of several individual initiating events, but because the conditional probabilities of pivotal events and the end states are the same for each of the constituents, the initiators are grouped before the event sequence quantification. In the PCSA, this grouping is performed for a given waste container configuration at the ESD level. The waste container configurations considered are listed below.

- Naval SNF canister in a transportation cask.
- HLW canister in a transportation cask.
- DOE standardized canister, containing DOE-owned SNF in a transportation cask.
- Multicanister overpack in a transportation cask.
- TAD canister in a transportation cask or in an aging overpack.
- DPC in a transportation cask or in an aging overpack.
- Horizontal DPC in a transportation cask (a transportation cask that is never upended or a horizontal shielded transfer cask) or in a HAM.
- Uncanistered commercial SNF in a transportation cask.
- LLW, including dry active waste, wet-solid LLW (evaluated separately as resin or non-resin), and liquid LLW.

In Excel, the grouping of event sequences is carried out by calculating the combined mean, median, and standard deviation of the event sequence lines that end in the same end state for each waste form in an ESD. The event sequence frequencies from this step comprise the final event sequence quantification, used for categorization.

An illustration of the grouping of event sequences is described in the following. The potential structural challenges to a given canister during its transfer by the site transporter to the Aging Facility are due to drops and collisions. The event sequences involving the aging overpack are quantified separately twice, once for each initiating event. After an initiating event occurs, the event sequences that elicit the same system response and lead to the same end state, that is, those event sequences that follow the same path on the SRET, are grouped together for purposes of categorization. Thus, the two individual event sequences initiated by a drop or collision that eventually result in a specific end state, such as an unfiltered radionuclide release, are grouped together for the purposes of categorization as a single aggregated event sequence with a unique name termed the "event sequence group ID". Since there are three different end states that can lead to exposure of personnel to radiation (i.e., result in an end state other than "OK"), there are three aggregated event sequences involving the TAD canister in an aging overpack, each having a unique name. The frequency of each of these aggregated event sequences represents the sum of frequencies of the two individual event sequences.

The uncertainties in the grouped event sequences are generated as described in Section 4.3.1.1.

6.8.2 Event Sequence Categorization

Based on the resultant frequency of occurrence, the event sequences are categorized as Category 1 or Category 2, per the definitions in 10 CFR 63.2 (Ref. 2.3.2), or as beyond Category 2. The categorization is done on the basis of the expected number of occurrences of each event sequence during the preclosure period. For purposes of this discussion, the expected number of occurrences of a given event sequence over the preclosure period is represented by the quantity m.

Some event sequences are not directly dependent on the duration of the preclosure period. For example, the expected number of occurrences of drops of an aging overpack containing a TAD canister during transportation operations over the preclosure period is essentially controlled by the number of TAD canisters and the number of movements of these canisters in aging overpacks. The duration of the preclosure period is not directly relevant for this event sequence, but it is implicitly built into the operations. In contrast, for other event sequences, time is a direct input. For example, fire-induced event sequences are evaluated over a period of time. Fire-induced event sequences for Intra-Site Operations are evaluated over a period of 50 years, because the surface facilities are expected to operate for no longer than 50 years (*Basis of Design for the TAD Canister-Based Repository Design Concept* (Ref. 2.2.16, Section 2.2.2.7)).

Using the parameter m for a given event sequence, categorization is performed using the screening criteria specified in 10 CFR 63.2 (Ref. 2.3.2), as follows:

- Event sequences that are expected to occur one or more times before permanent closure of the GROA are referred to as Category 1 event sequences (Ref. 2.3.2). Thus, a value of m greater than or equal to one means the event sequence is a Category 1 event sequence.

- Event sequences that have at least one chance in 10,000 of occurring before permanent closure are referred to as Category 2 event sequences (Ref. 2.3.2). Thus, a value of m less than one but greater than or equal to 1E-04, means the event sequence is a Category 2 event sequence.

- A measure of the probability of occurrence of the event sequence over the preclosure period is given by a Poisson distribution that has a parameter taken equal to m. The probability, P, that the event sequence occurs at least one time before permanent closure is the complement to one that the event sequence occurs exactly zero times during the preclosure period. Using the Poisson distribution, $P = 1 - e^{-m}$ (Ref. 2.2.8, p. A-3) a value of P greater than or equal to 1E-04 implies the value of m is greater than or equal to $-\ln(1 - P) = -\ln(1 - \text{1E-04})$, which is numerically equal to 1E-04. Thus, a value of m greater than or equal to 1E-04, but less than one, implies the corresponding event sequence is a Category 2 event sequence.

- Event sequences that have a value of m less than 1E-04 are designated as beyond Category 2.

An uncertainty analysis is performed on m to determine the main characteristics of its associated probability distribution, specifically the mean, 50th percentile (i.e., the median), and the standard deviation.

6.8.3 Final Event Sequence Quantification Summary

Initially, the results of the event sequence quantification process are reported in a single table of all event sequences (Attachment G, Table G-1) generated from the model presented in Attachment H. Following the final categorization, the event sequences for the respective Category 2 (Table 6.8-3) and beyond Category 2 (Attachment G, Table G-3) are tabulated separately. There are no Category 1 (Table 6.8-2) events for Intra-Site Operations. Other sorting may be performed, for example, event sequences that have end states ITC are tabulated separately (Attachment G, Table G-4). The format of the table headings and content are essentially the same for Tables 6.8-2, 6.8-3, G-2, G-3, and G-4, as follows:

1. Event Sequence Group ID – manually assigned in Excel.
2. End State – from ESD development.
3. Description (of the event sequence) – narrative that describes the initiating event(s) and identifies the pivotal events that are involved for the sequence.
4. Material-At-Risk – describes the type of waste form involved and the amount of material (e.g., an event involving one transportation cask containing HLW would involve 5 HLW canisters, which represents the material-at-risk).
5. Mean (event sequence frequency) – number of occurrences over the preclosure period.
6. Median (event sequence frequency) – number of occurrences over the preclosure period.
7. Standard Deviation (of the event sequence frequency) – the calculated standard deviation.
8. Event Sequence Category – declaration of Category 1, Category 2, or beyond Category 2.
9. Basis for Categorization – the foundation for categorization declaration (e.g., categorization by mean value or from sensitivity study (using an error factor) for near threshold means, as described in Section 4.3.6.2)
10. Consequence analysis (applies to Tables 6.8-2 and 6.8-3 only) – cross-reference to the bounding event number in the dose consequence analysis (Table 6.8-1 and (Ref. 2.2.30), Appendices IV and V, Table 2, and Section 7).

An additional table (Table 6.8-4) is included for events that were identified during ESD development (Ref. 2.2.29) but were not analyzed for categorization. Separate analyses identified these events as off-normal because the consequences to a worker for this type of release are a small fraction of the performance objectives (Ref. 2.2.30).

Table 6.8-2. Category 1 Final Event Sequences Summary

Event Sequence Group ID	End State	Description	Material-At-Risk	Mean	Median	Std Dev	Event Seq. Cat.	Basis for Categorization	Consequence Analysis
None	—	—	—	—	—	—	—	—	—

NOTE: ID = identification.

Source: Original

Table 6.8-3. Category 2 Final Event Sequences Summary

Event Sequence Group ID [a]	End State	Description	Material-At-Risk [b]	Mean [c]	Median [c]	Std Dev [c]	Event Seq. Cat.	Basis for Categorization	Consequence Analysis [d]
ISO09-TAD-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a thermal challenge to a TAD canister inside a transportation cask or aging overpack, due to a fire, resulting in a direct exposure from loss of shielding. In this sequence, the canister remains intact, and the shielding fails.	1 TAD canister	3.E-01	8.E-02	1.E+00	Category 2	Mean of distribution for number of occurrences of event sequence near a category threshold. Categorization confirmed by alternative distribution	N/A [e]
ISO09-HLW-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a thermal challenge to an HLW canister inside a transportation cask, due to a fire, resulting in a direct exposure from loss of shielding. In this sequence, the canister remains intact, and the shielding fails.	5 HLW canisters	3.E-01	8.E-02	1.E+00	Category 2	Mean of distribution for number of occurrences of event sequence near a category threshold. Categorization confirmed by alternative distribution	N/A [e]
ISO09-NAV-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a thermal challenge to a naval SNF canister inside a transportation cask, due to a fire, resulting in a direct exposure from loss of shielding. In this sequence, the canister remains intact, and the shielding fails.	1 naval SNF canister	3.E-01	8.E-02	1.E+00	Category 2	Mean of distribution for number of occurrences of event sequence near a category threshold. Categorization confirmed by alternative distribution	N/A [e]

Table 6.8-3. Category 2 Final Event Sequences Summary (Continued)

Event Sequence Group ID [a]	End State	Description	Material-At-Risk [b]	Mean [c]	Median [c]	Std Dev [c]	Event Seq. Cat.	Basis for Categorization	Consequence Analysis [d]
ISO09-DSTD-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a thermal challenge to a DOE standardized canister inside a transportation cask, due to a fire, resulting in a direct exposure from loss of shielding. In this sequence, the canister remains intact, and the shielding fails.	9 DOE standardized canisters	3.E-01	8.E-02	1.E+00	Category 2	Mean of distribution for number of occurrences of event sequence near a category threshold. Categorization confirmed by alternative distribution	N/A [e]
ISO09-DPC-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a thermal challenge to a DPC inside a transportation cask or aging overpack, due to a fire, resulting in a direct exposure from loss of shielding. In this sequence, the canister remains intact, and the shielding fails.	1 DPC	3.E-01	8.E-02	1.E+00	Category 2	Mean of distribution for number of occurrences of event sequence near a category threshold. Categorization confirmed by alternative distribution	N/A [e]
ISO09-HDPC-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a thermal challenge to a horizontal DPC inside a transportation cask, a horizontal aging module, or a horizontal STC, due to a fire, resulting in a direct exposure from loss of shielding. In this sequence, the canister remains intact, and the shielding fails.	1 DPC	3.E-01	8.E-02	1.E+00	Category 2	Mean of distribution for number of occurrences of event sequence near a category threshold. Categorization confirmed by alternative distribution	N/A [e]

Table 6.8-3. Category 2 Final Event Sequences Summary (Continued)

Event Sequence Group ID [a]	End State	Description	Material-At-Risk [b]	Mean [c]	Median [c]	Std Dev [c]	Event Seq. Cat.	Basis for Categorization	Consequence Analysis [d]
ISO09-MCO-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a thermal challenge to an MCO inside a transportation cask, due to a fire, resulting in a direct exposure from loss of shielding. In this sequence, the canister remains intact, and the shielding fails.	4 MCOs	3.E-01	8.E-02	1.E+00	Category 2	Mean of distribution for number of occurrences of event sequence near a category threshold. Categorization confirmed by alternative distribution	N/A [e,a]
ISO09-UCSNF-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a thermal challenge to a transportation cask with uncanistered SNF assemblies, due to a fire, resulting in a direct exposure from loss of shielding. In this sequence, the transportation cask containment function remains intact, and the shielding fails.	1 transportation cask with uncanistered SNF assemblies	3.E-01	8.E-02	1.E+00	Category 2	Mean of distribution for number of occurrences of event sequence near a category threshold. Categorization confirmed by alternative distribution	N/A [e]
ISO07-LLW-SEQ2-RRU	Unfiltered radionuclide release	This event sequence represents a thermal challenge to the inventory of LLW present in the LLW Facility, due to a fire at that facility, resulting in an unfiltered radionuclide release. In this sequence, the combustible LLW forms present in the facility burn.	inventory of LLW at the LLW Facility	7.E-02	6.E-02	3.E-02	Category 2	Mean of distribution for number of occurrences of event sequence	2-13

Table 6.8-3. Category 2 Final Event Sequences Summary (Continued)

Event Sequence Group ID [a]	**End State**	**Description**	**Material-At-Risk [b]**	**Mean [c]**	**Median [c]**	**Std Dev [c]**	**Event Seq. Cat.**	**Basis for Categorization**	**Consequence Analysis [d]**
ISO05-DAW-SEQ2-RRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to a container with a HEPA filter from the WHF, during processing operations at the LLW Facility, resulting in an unfiltered radionuclide release. In this sequence, the container fails.	1 container with HEPA filter from the WHF	6.E-02	2.E-02	2.E-01	Category 2	Mean of distribution for number of occurrences of event sequence	2-01
ISO09-UCSNF-SEQ3-RRU	Unfiltered radionuclide release	This event sequence represents a thermal challenge to a transportation cask with uncanistered SNF assemblies, due to a fire, resulting in an unfiltered radionuclide release. In this sequence, the transportation cask fails, and a moderator is excluded from entering the cask.	1 transportation cask with uncanistered SNF assemblies	2.E-02	4.E-03	6.E-02	Category 2	Mean of distribution for number of occurrences of event sequence	2-14
ISO05-WETnr-SEQ2-RRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to a container with wet-solid waste (pool filter) from the WHF, during processing operations at the LLW Facility, resulting in an unfiltered radionuclide release. In this sequence, the container fails.	1 container with pool filter from the WHF	5.E-03	2.E-03	1.E-02	Category 2	Mean of distribution for number of occurrences of event sequence	2-01

Table 6.8-3. Category 2 Final Event Sequences Summary (Continued)

Event Sequence Group ID [a]	End State	Description	Material-At-Risk [b]	Mean [c]	Median [c]	Std Dev [c]	Event Seq. Cat.	Basis for Categorization	Consequence Analysis [d]
ISO08-DAW-SEQ2-RRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to a container with a HEPA filter from the WHF, during transfer to the LLW Facility, resulting in an unfiltered radionuclide release. In this sequence, the container fails.	1 container with HEPA filter from the WHF	2.E-03	6.E-04	5.E-03	Category 2	Mean of distribution for number of occurrences of event sequence	2-01
ISO08-WETnr-SEQ2-RRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to a container with wet-solid waste (pool filter) from the WHF, during transfer to the LLW Facility, resulting in an unfiltered radionuclide release. In this sequence, the container fails.	1 container with pool filter from the WHF	2.E-03	7.E-04	3.E-03	Category 2	Mean of distribution for number of occurrences of event sequence	2-01
ISO02-TAD-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a structural challenge to a TAD canister inside an aging overpack, during transit to or from the Aging facility, resulting in a direct exposure from loss of shielding. In this sequence, the canister remains intact, and the shielding fails.	1 TAD canister	8.E-04	4.E-04	2.E-03	Category 2	Mean of distribution for number of occurrences of event sequence	N/A [e]

Table 6.8-3. Category 2 Final Event Sequences Summary (Continued)

Event Sequence Group ID [a]	End State	Description	Material-At-Risk [b]	Mean [c]	Median [c]	Std Dev [c]	Event Seq. Cat.	Basis for Categorization	Consequence Analysis [d]
ISO01-UCSNF-SEQ2-DED	Direct exposure, degradation of shielding	This event sequence represents a structural challenge to a transportation cask with uncanistered SNF assemblies, during intra-site movement, resulting in a direct exposure from degradation of shielding. In this sequence, the transportation cask containment function remains intact, and the shielding fails.	1 transportation cask with uncanistered SNF assemblies	2.E-04	6.E-05	4.E-04	Category 2	Mean of distribution for number of occurrences of event sequence	N/A [e]
ISO08-WETr-SEQ2-RRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to a container with wet-solid resin from the WHF, during transfer to the LLW Facility, resulting in an unfiltered radionuclide release. In this sequence, the container fails.	1 container with wet-solid resin from the WHF	2.E-04	5.E-05	5.E-04	Category 2	Mean of distribution for number of occurrences of event sequence	2-01

NOTE: [a] The expected number of occurrences, over the preclosure period, of event sequences involving MCOs may not lead to an acceptable categorization with regard to 10 CFR 63.111 (Ref. 2.3.2) performance objectives. Therefore, further investigation of these event sequences may be needed. As a consequence, the categorization of event sequences involving MCOs is considered to be preliminary and no bounding event number for consequence analyses is provided.

[b] The material at risk is, as relevant, based upon the nominal capacity of the waste container involved in the event sequence under consideration, or accounts for the specific operation covered by the event sequence.

[c] The mean, median, and standard deviation displayed are for the number of occurrences, over the preclosure period, of the event sequence under consideration.

[d] The bounding event number provided in this column identifies the bounding Category 2 event sequence identified in Table 6.8-1 from the *Preclosure Consequence Analyses* (Ref. 2.2.30, Table 2) that results in dose consequences that bound the event sequence under consideration.

[e] Because of the large distances to the locations of the offsite receptors, dose to members of the public from direct radiation after a Category 2 event sequence is reduced by more than 13 orders of magnitude to insignificant levels (Ref. 2.2.19).

DOE = U.S. Department of Energy; DPC = dual-purpose canister; HEPA = high-efficiency particulate air; HLW = high-level radioactive waste; ID = identification; LLW = Low Level Waste; MCO = multicanister overpack; N/A = not applicable; SNF = spent nuclear fuel; STC = shielded transfer cask; TAD = transportation, aging, and disposal; WHF = Wet Handling Facility.

Source: Original

Table 6.8-4. Off-Normal Events Not Analyzed for Categorization

Event Sequence Group ID or Description	End State	Description	Material-At-Risk	Basis
ISO-ESD-05				
ISO05-DAW-SEQ2-RRU	RR-UNFILTERED	This sequence represents a structural challenge to a DAW LLW container containing DAW (other than stage 1 ITS HEPA filters generated by the WHF), during handling operations at the LLW Facility, resulting in an unfiltered radiological release in the LLWF. In this sequence the container fails.	DAW LLW (55-gal drum)	Off-normal event (Ref. 2.2.30, Appendix V) Except for stage 1 ITS HEPA filters generated by the WHF, DAW LLW release for this event is not analyzed for categorization, because the consequences to a worker for this type of release are a small fraction of the performance objectives.
ISO05-LIQ-SEQ2-RRU	RR-UNFILTERED	This sequence represents a structural challenge to a liquid LLW processing component, during processing operations at the LLW Facility, resulting in an unfiltered radiological release.	Liquid LLW tank contents	Off-normal event (Ref. 2.2.30, Appendix IV) Liquid LLW release for this event is not analyzed for categorization, because the consequences to a worker for this type of release are a small fraction of the performance objectives.
ISO-ESD-08				
ISO08-LIQ-SEQ2-RRU	RR-UNFILTERED	This sequence represents a structural challenge to a liquid LLW processing component during transfer to the LLW Facility, resulting in an unfiltered radiological release. In this sequence the container fails.	Liquid LLW tank contents	Off-normal event (Ref. 2.2.30, Appendix IV) Liquid LLW release for this event is not analyzed for categorization, because the consequences to a worker for this type of release are a small fraction of the performance objectives.

NOTE: [1] Except for the Wet Handling Facilities, liquid LLW is moved from generating facilities to the tanks at the LLWF in HICs.

DAW = dry active (low-level radioactive) waste; ESD = event sequence diagram; HEPA = high-efficiency particulate air; HIC = high-integrity container; ID = identification; ISO = Intra-Site Operations; ITS = important to safety; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; WHF = Wet Handling Facility.

Source: Original

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6.9 IMPORTANT TO SAFETY STRUCTURES, SYSTEMS, AND COMPONENTS AND PROCEDURAL SAFETY CONTROL REQUIREMENTS

The results of the PCSA are used to define design bases for repository SSCs to prevent or mitigate event sequences that could lead to the release of radioactive material and/or result in radiological exposure of workers or the public. Potential releases of radioactive material are minimized to ensure resulting worker and public exposures to radiation are below the limits established by 10 CFR 63.111 (Ref. 2.3.2). This strategy requires using prevention features in the repository design wherever reasonable. This strategy is implemented by performing the PCSA as an integral part of the design process in a manner consistent with a performance-based, risk-informed philosophy. This integral design approach ensures the ITS design features and operational controls are selected in a manner that ensures safety while minimizing design and operational complexity through the use of proven technology. Using this strategy, design rules are developed to provide guidance on the safety classification of SSCs. The following information is developed in order to implement this strategy:

- Essential safety functions needed to ensure worker and public safety.
- SSCs relied upon to ensure essential safety functions.
- Design criteria that will ensure that the essential safety functions will be performed with a high degree of reliability and margin of safety.
- Administrative and PSCs that, in conjunction with the repository design ensure operations are conducted within the limits of the PCSA.

Section 6.9.1 identifies ITS SSCs, and Section 6.9.2 identifies the PSCs.

6.9.1 Important to Safety Structures, Systems, and Components

Table 6.9-1 contains the nuclear safety design bases for the Intra-Site Operations and BOP ITS SSCs. The first three columns identify the ITS system or facility, the subsystem or function, and the component. The fourth column identifies the safety function relied upon in the event sequence analysis. The fifth column provides the characteristics of the safety function (i.e., controlling parameter or value) that is demonstrated to occur or exist in the design. The sixth column provides an example event sequence in which the safety function and the characteristic is relied upon. The seventh column provides the source for the controlling parameter or value. It is either a fault tree or basic event. If it is a fault tree, it can be found in the reliability model provided in Attachment A. If it is a basic event, it can be traced to section 6.3 of this report.

Table 6.9-1. Preclosure Nuclear Safety Design Bases for Intra-Site Operations ITS SSCs

System or Facility (System Code)	Subsystem or Function (as Applicable)[c]	Component	Nuclear Safety Design Bases		Representative Event Sequence (Sequence Number)	Source
			Safety Function	Controlling Parameters and Values		
Aging Facility (AP)	Aging Handling/ Aging Overpack	Horizontal Aging Module (HAM) (170-HAC0-ENCL-00001)	Protect against[b] direct exposure to personnel	1. The mean conditional probability of loss of HAM gamma shielding due to an impact or collision shall be less than or equal to 1 x 10^{-5} per impact.	ISO-ESD04-HDPC (Seq. 3-2)	SHIELD_HAM_IMPACT Table 6.3-7
	Aging Handling/ Cask Transfer	Cask Tractor (for use with the Cask Transfer Trailer) (170-HAT0-HEQ-00001)	Limit speed	2. The speed of the cask tractor shall be limited to 2.5 mph.	ISO-ESD03-HDPC (Seq. 2-4)	TCASK_HTC_IMPACT Table 6.3-7
			Preclude fuel tank explosion	3. The cask tractor fuel tank shall preclude fuel tank explosions.	Initiating event does not require further analysis[a]	Section 6.0
		Cask Transfer Trailer (for use with Transportation Casks and Horizontal Shielded Transfer Casks) (PWR DPC: [170-HAT0-TRLY-00001]) (BWR DPC: [170-HAT0-TRLY-00002])	Limit speed	4. The speed of the cask transfer trailer shall be limited to 2.5 mph.	ISO-ESD03-HDPC (Seq. 2-4)	TCASK_HTC_IMPACT Table 6.3-7
			Preclude fuel tank explosion	5. The cask transfer trailer fuel tank shall preclude fuel tank explosions.	Initiating event does not require further analysis[a]	Section 6.0
			Reduce severity of a drop	6. The cask transfer trailer shall preclude dropping a cask from a height greater than 6 feet measured from the equipment base.	ISO-ESD03-HDPC (Seq. 3-4)	TCASK_HTC_DROP Table 6.3-7

Table 6.9-1. Preclosure Nuclear Safety Design Bases for Intra-Site Operations ITS SSCs (Continued)

System or Facility (System Code)	Subsystem or Function (as Applicable)[c]	Component	Nuclear Safety Design Bases		Representative Event Sequence (Sequence Number)	Source
			Safety Function	Controlling Parameters and Values		
Aging Facility (AP) (continued)	Aging Handling/ Cask Transfer (continued)	Cask Transfer Trailer (for use with Transportation Casks and Horizontal Shielded Transfer Casks) (PWR DPC: [170-HAT0-TRLY-00001]) (BWR DPC: [170-HAT0-TRLY-00002]) (continued)	Preclude puncture of a cask	7. The cask transfer trailer shall preclude puncture of a cask due to collision.	Initiating event does not require further analysis[a]	Section 6.0
			Preclude puncture of a canister	8. The cask transfer trailer shall preclude puncture of a canister by the hydraulic ram.	Initiating event does not require further analysis[a]	Section 6.0
		Site Transporter (170-HAT0-MEQ-00001)	Limit speed	9. The speed of the site transporter shall be limited to 2.5 mph.	ISO-ESD02-TAD (Seq. 2-3)	CANISTER_AO_IMPACT Table 6.3-7
			Preclude fuel tank explosion	10. The site transporter fuel tank shall preclude fuel tank explosions.	Initiating event does not require further analysis[a]	Section 6.0
			Reduce severity of a drop	11. The site transporter shall preclude a vertical drop of an aging overpack from a height greater than 3 ft measured from the equipment base.	ISO-ESD02-TAD (Seq. 3-3)	CANISTER_AO_DROP Table 6.3-7

Table 6.9-1. Preclosure Nuclear Safety Design Bases for Intra-Site Operations ITS SSCs (Continued)

System or Facility (System Code)	Subsystem or Function (as Applicable)[c]	Component	Nuclear Safety Design Bases		Representative Event Sequence (Sequence Number)	Source
			Safety Function	Controlling Parameters and Values		
Aging Facility (AP) (continued)	Aging Handling/ Cask Transfer (continued)	Horizontal Shielded Transfer Cask (170-HAC0-HEQ-00001)	Provide containment	12. The mean conditional probability of breach of a canister in a sealed HSTC on a cask transfer trailer resulting from a drop shall be less than or equal to 1×10^{-5} per drop.	ISO-ESD03-HDPC (Seq. 3-4)	TCASK_HTC_DROP Table 6.3-7
				13. The mean probability of breach of a canister in an HSTC on a cask transfer trailer resulting from a drop of a load onto the HSTC shall be less than or equal to 1×10^{-5} per drop.	ISO-ESD04-HDPC (Seq. 2-3)	CANISTER_HAM_OPS Table 6.3-7
				14. The mean conditional probability of breach of a canister in a sealed HSTC on a cask transfer trailer resulting from a side impact or collision shall be less than or equal to 1×10^{-8} per impact.	ISO-ESD03-HDPC (Seq. 2-4)	TCASK_HTC_IMPACT Table 6.3-7