Table 6.3-1. Active Component Reliability Data Summary (Continued)

Basic Event Name	Basic Event Description	SAPHIRE Calculation Type[a]	Basic Event Mean Failure Probability[b]	Mean Failure Rate[b]	Mission Time[a] (Hours)
51A-SPMRC-SC021--SC--FOH	Speed Controller on SPMRC Pendant Fails	3	1.28E-04	1.28E-04	1
51A-SPMRC-SEL021-SEL-FOH	Speed Selector on SPMRC Pendant Fails	3	4.16E-06	4.16E-06	1
51A-SPMRC-STU01-STU--FOH	SPMRC End Stop Fails	3	2.11E-04	4.81E-08	4380
51A-SPMTT-BRK000-BRP-FOD	Pneumatic Brakes on SPMTT Fail on Demand	1	5.02E-05	–	–
51A-SPMTT-BRP001-BRP-FOD	Brake (Pneumatic) Failure on Demand	1	5.02E-05	–	–
51A-SPMTT-CBP002-CBP-OPC	SPMTT Power Cable - Open Circuit	3	9.13E-08	9.13E-08	1
51A-SPMTT-CBP003-CBP-SHC	SPMTT Power Cable Short Circuit	3	1.88E-08	1.88E-08	1
51A-SPMTT-CPL00-CPL-FOH	SPMTT Automatic Coupler System Fails	3	1.91E-06	1.91E-06	1
51A-SPMTT-CT000--CT--FOD	SPMTT Primary Stop Switch Fails	1	4.00E-06	–	–
51A-SPMTT-CT001--CT--FOD	On-Board Controller Fails to Respond	1	4.00E-06	–	–
51A-SPMTT-CT002--CT--FOH	Pendant Direction Controller Fails	3	6.88E-05	6.88E-05	1
51A-SPMTT-G65000-G65-FOH	SPMTT Speed Control (Speed Limiter) Fails	3	1.16E-05	1.16E-05	1
51A-SPMTT-HC001-HC-FOD	SPMTT Emergency Stop Switch Fails	1	1.74E-03	–	–
51A-SPMTT-HC002--HC--SPO	Handheld Radio Remote Controller Spurious Operation	3	5.23E-07	5.23E-07	1
51A-SPMTT-IEL102-IEL-FOD	Failure of Mobile Platform Anti-Collision Interlock	1	2.75E-05	–	–
51A-SPMTT-MOE000-MOE-FSO	SPMTT Lock Mode State Fails on Loss of Power	3	1.35E-08	1.35E-08	1
51A-SPMTT-SC001--CT--SPO	On-Board Controller Initiates Spurious Signal	3	2.27E-05	2.27E-05	1
51A-SPMTT-SC021--SC--FOH	Speed Controller on SPMTT Pendant Fails	3	1.28E-04	1.28E-04	1

Table 6.3-1. Active Component Reliability Data Summary (Continued)

Basic Event Name	Basic Event Description	SAPHIRE Calculation Type[a]	Basic Event Mean Failure Probability[b]	Mean Failure Rate[b]	Mission Time[a] (Hours)
51A-SPMTT-SEL021-SEL-FOH	Speed Selector on SPMTT Pendant Fails	3	4.16E-06	4.16E-06	1
51A-SPMTT-STU001-STU-FOH	SPMTT End Stops Fail	3	2.11E-04	4.81E-08	4380
51A-WPCRN-DROPON-CRW-DRP	WP (Non-SFP) Crane Drop	1	1.07E-04	–	–
51A-WPCRN-DROPON-CRW-TBK	WP (Non-SFP) Crane Two Block Drop	1	4.59E-05	–	–
51A-WPTT--CAM001-CAM-FOH	Locking Mechanism at Unload Area Fails	3	3.19E-06	3.19E-06	1
51A-WPTT--HC001--HC--SPO	Remote Control Sends Spurious Signal	3	5.23E-07	5.23E-07	1
51A-WPTT--ZS002--ZS--FOD	Gate Closed Limit Switch #2 Spurious Transfer	1	2.93E-04	–	–
51A-WPTT-BRK401--BRK-FOD	Brakes Fail	1	1.46E-06	–	–
51A-WPTT-DERAIL-DER-FOM	Probability of WPTT Derailment per Mile	3	1.18E-05	1.18E-05	1
51A-WPTT-HC002---HC--SPO	Remote Controller Sends Spurious Signal	3	5.23E-07	5.23E-07	1
51A-WPTT-HC002-HC-SPO	Remote Controller Sends Spurious Signal	3	5.23E-07	5.23E-07	1
51A-WPTT-IEL001-IEL-FOD	Carriage Motor Interlock Fails	1	2.75E-05	–	–
51A-WPTT-IEL001-IEL-FOH	Docking Interlock Fails Closed	1	2.75E-05	–	–
51A-WPTT-IEL003--IEL-FOD	WPTT Dock Interlock Fails to Halt Power to Trolley	1	2.75E-05	–	–
51A-WPTT-IELDK3--IEL-FOD	WPTT Dock Interlock Fails	1	2.75E-05	–	–
51A-WPTT-IME001--IEL-FOD	Interlock Failure on Demand	1	2.75E-05	–	–
51A-WPTT-MOE001-MOE-FSO	Motor (Electric) Fails to Shut Off	3	1.35E-08	1.35E-08	1
51A-WPTT-PLC001-PLC-SPO	On-Board PLC Initiated Spurious Signal	3	3.65E-07	3.65E-07	1
51A-WPTT-PLC002--PLC-SPO	On-Board PLC Initiates Spurious Signal	3	3.65E-07	3.65E-07	1

Table 6.3-1. Active Component Reliability Data Summary (Continued)

Basic Event Name	Basic Event Description	SAPHIRE Calculation Type[a]	Basic Event Mean Failure Probability[b]	Mean Failure Rate[b]	Mission Time[a] (Hours)
51A-WPTT-PLC002-PLC-SPO	On-Board PLC Initiates Spurious Signal	3	3.65E-07	3.65E-07	1
51A-WPTT-ZS000---ZS--CCF	CCF of Gate Closed Limit Switches	C	1.38E-05	–	–
51A-WPTT-ZS001---ZS--FOD	Gate Closed Limit Switch #1 Spurious Transfer	1	2.93E-04	–	–

NOTES: [a] The relevant SAPHIRE calculation types are as follows: (1) For failure on demand, the value specified is used directly as the basic event mean failure probability. (3) For failure of an operating component without repair in nondemand failure mode, the basic event mean failure probability is calculated as $P = 1 - \exp(-L \times t_m)$, where L is the hourly failure rate and t_m is the mission time in hours. For type 3 calculations with an unspecified mission time or a mission time specified as 0, SAPHIRE performs the quantifications using the system mission time of 1 hour. (7) For a standby component in nondemand failure mode, with consideration of periodic testing, the basic event mean failure probability is calculated as $P = 1 + [\exp(-L \times T) - 1] / (L \times T)$, where L is the hourly failure rate and T is the testing interval in hours. For Type 7 calculations, the mission time column contains the testing interval. . A calculation of type "C", i.e., "compound event" is used to evaluate CCFs. For this type of calculation, SAPHIRE uses 1) information on the failure rate or failure probability of the underlying components and 2) information on the probability distribution of the alpha factors involved in the CCF to internally evaluate the probability distribution of the resulting basic event (see Attachment C, Section C3). The number shown in the "Basic event mean probability" column is actually a point estimate which approximates the mean..

[b] Although the values in this table are shown to a precision of three significant figures, the values are not known to that level of precision. The values in Attachment C may show fewer significant figures. Such differences are not meaningful in the context of this analysis because the corresponding uncertainties (which are accounted for in the analysis) are much greater than differences due to rounding.

CCF = common-cause failure; CTM = canister transfer machine; CTT = cask transfer trolley; PLC = programmable logic controller; SPMRC = site prime mover railcar; SPMTT = site prime mover truck trailer; WP = waste package; WPTT = waste package transfer trolley.

Source: Attachment C, Section C4

6.3.2 Passive Equipment Failure Analysis

Many event sequences described in Section 6.1 include pivotal events that arise from loss of integrity of a passive component, namely one of the aging overpacks, casks or canisters that contain a radioactive waste form. Such pivotal events involve (1) loss of containment of radioactive material that prevents airborne releases, or (2) LOS effectiveness. Both types of pivotal events may be caused by failure modes caused by either physical impact to the container or by thermal energy transferred to the container. This section summarizes the results of the passive failure analyses detailed in Attachment D that yield the conditional probability of loss of containment or LOS.

6.3.2.1 Probability of Loss of Containment

An overview of the methodology for calculating the probability of failure of passive equipment from drops and impact loads is presented in Section 4.3.2.2. Consistent with HLWRS-ISG-02

(Ref. 2.2.66), the methodology essentially consists of comparing the demand upon the equipment to a capacity curve. The probability of failure is the value of the cumulative distribution function for the capacity curve, evaluated at the demand upon the container. More detailed discussion is presented in Attachment D. The methodology is applicable to all of the waste containers that are processed in the IHF, as well as the other waste handling facilities, including transportation casks, aging overpacks, canisters, and waste packages. As described in Section 4.3.2.2, the condition at which a passive component is said to fail depends on the success criteria defined for the component in the IHF operation. Passive components are designed and manufactured to ensure that the success criteria are met in normal operating conditions and with margin, to ensure that the success criteria are also met when subjected to abnormal loads, including those expected during event sequences. The design margins, and in some cases materials, may be dictated by the code and standards applied to a given type of container as characterized by tensile elongation data for impact loads and by strength at temperature data for thermal loads.

As described in Sections 4.3.2.2, the probability of a passive failure is often based on consideration of variability (uncertainty) in the applied load, and the variability in the strength (resistance) of the component. The variability in the physical and thermal loading are derived from the systems analysis that defines the probabilities of physical or thermal loads of a given magnitude in a given event sequence. Such conditions arise from the event sequence analysis described in Section 6.1. For the analysis of the effects of fires on waste containers, probability distributions were developed for both the load and the response. For drops and impacts, however, an event sequence analysis is used to define conservative conditions for the load rather than deal with possible ranges of such parameters. Therefore, the calculation of the probability of passive failures is based on the response or resistance characteristics of the container, given the conservative point value for the drop or impact load defined for a given event sequence.

6.3.2.2 Probability of Loss of Containment for Drops and Impacts

Calculation of the probability of failure of the various containers is based on the variability in the strength (resistance) of the container as derived from tests, and structural analysis, including Finite Element Analysis (FEA), detailed in Attachment D. Loss of containment probability analysis has been evaluated for various containers by three different studies:

- *Seismic and Structural Container Analyses for the PCSA* (Ref. 2.2.33)
- *Structural Analysis Results of the DOE SNF Canisters Subjected to the 23-Foot Vertical Repository Drop Event to Support Probabilistic Risk Evaluations* (Ref. 2.2.74) and *Qualitative Analysis of the Standardized DOE SNF Canister Specific Canister-on-Canister Drop Events at the Repository* (Ref. 2.2.75)
- *Naval Long Waste Package Vertical Impact on Emplacement Pallet and Invert* (Ref. 2.2.24)

All analyses have applied essentially the same methods that include FEA to determine the structural response of the various canisters and cask to drop and impact loads, developing a fragility function for the material used in the respective container, and using the calculated responses (strains) with the fragility function to derive the probability of container breach.

Failure probabilities for drops are summarized in Table 6.3-2. Conservative representations of drop height are defined for operations with each type of container. Sometimes more than one conservative drop height is specified, for example, for normal height crane lifts and two-block height crane lifts. Lawrence Livermore National Laboratory (LLNL), in *Seismic and Structural Container Analyses for the* PCSA (Ref. 2.2.33), predicts failure probabilities of $<1.0 \times 10^{-8}$ for most of the events. If a probability for the event sequence is less than 1×10^{-8}, additional conservatism is incorporated in the PCSA by using a failure probability of 1.0×10^{-5}, which is termed "LLNL, adjusted". This additional conservatism is added to account for, (a) future evolutions of cask and canister designs, and (b) uncertainties, such as undetected material defects, undetected manufacturing deviations, and undetected damage associated with handling before the container reaches the repository, which are not included in the tensile elongation data.

LLNL calculates strains by modeling representative casks, aging overpacks, and canisters that encompass TAD canisters, naval SNF canisters, and a variety of DPCs, with the dynamic finite element code, LS-DYNA (Ref. 2.2.33). For these canisters, only flat-bottom drops are considered to model transfers by a CTM. This is justified because these canisters fit sufficiently tightly within the CTM and potential dropped canisters are guided by the canister guide sleeve of the CTM to remain in a vertical position.

INL calculates strains by modeling DOE SNF and multicanister overpacks (MCOs) with the static finite element code, ABAQUS (Ref. 2.2.74). The structural evaluations consider off-vertical drops. In such cases, the deformation of the waste form container is greater on the localized area of impact than for a flat-bottom drop, and will therefore yield a greater calculated probability of breach.

Probability of failure is conservatively calculated by comparing the peak strain to the cumulative distribution function derived from tensile strain to failure test data reported in the literature, representing aleatory uncertainty associated with the variability of test coupon data.

BSC FEA analysis used LS-DYNA to model waste packages. Alloy 22 is not stainless steel but a nickel-based alloy, and the most appropriate metric for probability of failure is a cumulative distribution function over extended toughness fraction (See Attachment D, Section D1.4). The probability of failure is calculated using the peak toughness index over the waste package, which is a measure of the alloy's energy absorbing capability.

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

Item	Drop Height (ft)	Failure Probability	Note
Representative Transportation Cask[a]	13.1	1.0×10^{-5}	4 degrees from vertical, LLNL, adjusted, no impact limiters
	6	1.0×10^{-5}	3 degrees from horizontal, LLNL, adjusted, no impact limiters
(Continued)	Slapdown after 13.1 foot drop	1.0×10^{-5}	LLNL, adjusted, no impact limiters
Representative Canister	40	1.0×10^{-5}	Flat bottomed, LLNL, adjusted
DOE Standardized 24” or 18” canister	23	1.0×10^{-5}	3 degrees from vertical, LLNL, adjusted using INL FEA
Aging overpack	3	1.0×10^{-5}	LLNL, adjusted
MCO canister	23	9.0×10^{-2}	LLNL using INL FEA
HLW canister	30	6.7×10^{-2}	Bayesian interpretation of test data, 0 failures in 13 drops.
Waste package	2	1.0×10^{-5}	BSC FEA, horizontal orientation

NOTE: [a] Also applies to shielded transfer casks used on-site and horizontal transfer casks. Although shielded transfer casks are not used in the IHF, they are mentioned here for completeness.

BSC = Bechtel SAIC; DOE = U.S. Department of Energy; FEA=finite element analysis; HLW = high-level radioactive waste; INL = Idaho National Laboratory; LLNL = Lawrence Livermore National Laboratory; MCO = multicanister overpack.

Source: Attachment D

Containment failure probabilities due to other physical impact conditions, equivalent to drops, are listed in Table 6.3-3. These probabilities were modeled by Lawrence Livermore National Laboratory (LLNL) using FEA, resulting in prediction of failure probabilities of <1.0 × 10-8. Again, additional conservatism was incorporated by using a failure probability of 1.0 × 10-5 for most of these events. The side impact event was not adjusted from the LLNL result of < 1.0 × 10-8 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	1.0×10^{-5}	LLNL, adjusted, analogous to 6', 3° from horizontal
Rollover	1.0×10^{-5}	LLNL, adjusted, analogous to 6', 3° from horizontal
Drop on	1.0×10^{-5}	LLNL, adjusted 10-metric-ton load onto container
Tipover	1.0×10^{-5}	LLNL, adjusted, analogous to 13.1-foot drop plus slap-down
Side Impact from collision with rigid surface	1.0 × 10-8	Or value for low speed collision, whichever is greater (Table 6.3-4) Crane moving 20 ft/min
Tilt down/Up	1.0×10^{-5}	LLNL, adjusted; Bounded by slap-down

NOTE: LLNL = Lawrence Livermore National Laboratory.

Source: Attachment D

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 mph or ft/min 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 of 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, is the value listed in Table 6.3-2 for the drop height, H_d, listed in Table 6.3-2.

$$P = \int_{-\infty}^{x} N(t)\,dt \quad and \quad x = \frac{H_d / H_m - 1}{COV} \qquad \text{(Eq. 17)}$$

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 = 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.

Table 6.3-4. Failure Probabilities for Collision Events and Two-Blocking

Collision Scenario	Speed	Velocity (ft/sec)[a]	Equivalent Drop Height (ft)[b]	Failure Probabilities for Various Container Types				
				Transportation Cask	**Canister**	**Waste Package**	**MCO**	**High-Level Radioactive Waste**
Railcar	2.5 mph	3.67	0.21	1.00E-08	–	–	–	–
Truck Trailer	2.5 mph	3.67	0.21	1.00E-08	–	–	–	–
Crane	20 ft/min	0.33	0.00	1.00E-08	–	–	–	–
CTT	10 ft/min	0.17	0.00	1.00E-08	1.00E-08	–	1.00E-08	1.00E-08
ST	2.5 mph	3.67	0.21	–	1.00E-08	–	1.00E-08	1.00E-08
WPTT	40 ft/min	0.67	0.01	–	1.00E-08	1.00E-08	1.00E-08	1.00E-08
WP (in TEV)	1.7 mph	2.49	0.10	–	–	1.00E-08	–	–
CTM	20 ft/min	0.33	0.00	–	1.00E-08	–	1.00E-08	1.00E-08
CTM	40 ft/min	0.67	0.01	–	1.00E-08	–	1.00E-08	1.00E-08
Two-blocking	–	–	–	1.00E-04	1.00E-05	–	1.00E+00	1.40E-02

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.

bCalculated as follows based on constant acceleration due to gravity (no air resistance): v2 / (2 × 32.2 ft / sec2), where v is the velocity in ft / sec. Values are rounded to the nearest hundredth of a ft. Values that are less than 0.005 are reported as 0.00.

CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; DSTD = DOE standardized canister; ft = feet; MCO = multicanister overpack; min = minutes; mph = miles per hour; sec = seconds; ST = site transporter; TAD = transportation, aging, and disposal; TEV = transport and emplacement vehicle; WP =waste package; WPTT = waste package transfer trolley.

Source: Original

Two-blocking events are also included in Table 6.3-4. The two-blocking events for the transportation cask and representative canister were modeled by finite element analysis and included in Tables D1.2-4 (case T.IC 1c) and D1.2-3 (case D.IC 1b). For both of these cases, failure probabilities of $< 1 \times 10^{-8}$ are listed, and 1×10^{-5} is used as before. The failure probability for the two-blocking drop height of 30 feet for the high level waste was determined in Attachment D, Section D1.3. For the MCO, a failure probability of 9×10^{-2} was determined for a drop height of 23 feet (Attachment D, Table D1.2-7). The MCO is assumed to fail when dropped 40 feet.

The CTM, which lifts canisters, is designed such that drops from the height associated with two-blocking is very low probability and no higher than drops from normal operation. The design features that ensure this are: slide gate closure and two levels of shut-off switches as the normal lift height is exceeded, and a tension relief device that prevents over tensioning of hoist cables if the two-block height is reached. Transportation cask handling cranes are also equipped with the shut-off switches and the tension relief device.

During transfers by a CTM, a shear-type structural challenge was identified as a potential initiating event. This challenge would be caused, for example, by the spurious movement of the CTT from which the canister is extracted, before the canister is fully lifted inside the CTM shield bell. A bounding value of one is selected for the probability of failure of the transferred canister. This conservative estimate is used because the structural response of a canister to a shear-type structural challenge was not evaluated and its probability cannot be inferred from comparison with other structural challenges to the canister.

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 form containers, including: transportation casks containing uncanistered 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 form 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 form 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 form containers is analyzed based on a simplified geometry with a wall thickness that, for the range of waste form 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 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 form 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 form 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 form 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[b]	Failure Probability	
	Mean	Standard Deviation
Thin-Walledc Canister in a Waste Package[a]	3.2×10^{-4}	5.7×10^{-5}
Thick-Walled[c] Canister in a Waste Package[a]	1.0×10^{-4}	2.2×10^{-5}
Thin-Walled Canister in a Transport Cask	2.0×10^{-6}	1.4×10^{-6}
Thick-Walled Canister in a Transport Cask	1.0×10^{-6}	1.0×10^{-6}
Thin-Walled Canister in a Shielded Bell	1.4×10^{-4}	2.6×10^{-5}
Thick-Walled Canister in a Shielded Bell	9.0×10^{-5}	1.7×10^{-5}

NOTE: [a] For the 5-DHLW/DOE SNF waste package, this probability applies only to the DOE HLW canisters located on the periphery of the waste package. The DOE SNF canister in the center of the waste package would not be heated appreciably by the fire.

[b] Configurations not addressed in this table include, any canister in a waste package that is inside the transfer trolley or any canister inside an aging overpack. In these configurations, the canister is protected from the fire by the massive steel transfer trolley or 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 1×10^{-6} could be used.

[c] 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 waste package or 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 3 inches wide, but is approximately 27 feet long. Given this configuration, it is unlikely that there would be 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, waste package, 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 would be 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 waste package or 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 would be 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.

6.3.2.4 Probability of Loss of Containment from Heatup

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 the surface facilities is loss of HVAC cooling. If HVAC cooling is lost, the ambient temperature in the facility will increase. This increase is particularly significant for relatively small enclosures such as the transfer cells.

A series of bounding calculations was performed to determine the maximum temperature that could be reached by a canister following loss of HVAC cooling (Ref. 2.2.14). These calculations consider a range of decay heat levels and a loss of cooling for 30 days, which is consistent with NUREG-0800, Section 9.2.5 (Ref. 2.2.63). These analyses indicate that the canister temperature would remain well below 500°C (773°K) (Ref. 2.2.14). This temperature is hundreds of degrees below the temperature at which the canister would fail (Figure D.2.1-4 Attachment D). For that reason, canister failure due to a loss of HVAC is physically unrealizable and considered Beyond Category 2.

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 in the IHF, such as aging overpacks and the TEV. However, there are included in this section at drop heights characteristic of crane operations.

Shielding of a waste form that is being transported inside the GROA is accomplished by several types of shielded containers, including: transportation casks, 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 shielded transfer casks exert a containment function.

A structural challenge may cause shielding degradation or shielding loss. Loss of shielding 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. 2.2.76152476), 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 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 loss of shielding), 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 considered to potentially affect an aging overpack subjected to a structural challenge, if the waste form 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 5 × 10-6 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 form container inside the aging overpack (Attachment D). If the structural challenge is sufficiently severe to cause the loss of containment (breach) of the waste form 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.

A WPTT that transports a waste package is considered to lose its shielding function, if it is subjected to a structural challenge sufficiently severe to cause the breach of the sealed waste package, or, when the waste package is not yet sealed, the breach of one or more canisters inside, as applicable. Conversely, if the structural challenge is not sufficiently severe to cause a canister or waste package breach, it is postulated to also be sufficiently mild to leave the shielding function intact.

Similarly, a TEV that transports a waste package is considered to lose its shielding function if it is subjected to a structural challenge sufficiently severe to cause the breach of the waste package. Conversely, if the structural challenge is not sufficiently severe to cause a waste package breach, it is postulated to also be sufficiently mild to leave the shielding function of the TEV intact

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. The SSC providing shielding may be, for example, a WPTT. A transportation cask containing uncanistered SNF is also considered to have lost its shielding if it has lost its containment function.

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, cask transfer trolley, waste package transfer trolley, or TEV affected by the thermal challenge and in which the waste form 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 most 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 subjected to a fire are postulated to lose their shielding function with a probability of 1, regardless or 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 Degradation or Loss of Shielding

Event	Probability	Note
Sealed transportation cask and shielded transfer casks shielding degradation after structural challenge	1×10^{-5}	Attachment D.
Aging overpack shielding loss after structural challenge	5×10^{-6}	Attachment D.
CTM shielding loss after structural challenge	0	Structural challenges sufficiently mild to leave the shielding function intact.
WPTT shielding loss after structural challenge	0	Structural challenges sufficiently mild to leave the shielding function intact.
TEV shielding loss (shield end)	0	Structural challenges sufficiently mild to leave the shielding function intact.
Shielding loss by fire for waste forms in transportation casks or shielded transfer casks	1	Lead shielding could potentially expand and degrade. This probability is conservatively applied to transportation casks and STCs that do not use lead for shielding.
Shielding loss by fire for aging overpacks, CTM shield bell, and WPTT shielding	0	Type of concrete used for aging overpacks is not sensitive to spallation; Uranium used in CTM shield bell and WPTT shielding does not lose its shielding function as a result of a fire.

NOTE: CTM = canister transfer machine; TEV = transport and emplacement vehicle; WPTT = waste package transfer trolley.

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 summarizes passive failure events needed for the event sequence modeling. The values are either specifically developed in Attachment D, or are values from bounding events. Probabilities for some other 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 should be 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 for the IHF. The probability of each basic event is based on one of the values presented in Tables 6.3-2 through 6.3-7.

6.3.3 Miscellaneous Data

Split fractions for specific fire scenarios are derived from the exposure frequencies detailed in Section 6.5 and Attachment F. Table 6.3-9 identifies the frequency associated with a waste type in a specific configuration and location with or without diesel fuel present.

Table 6.3-10 provides details on how specific residence time fractions were developed for the IHF fire event sequence analysis. The formulas use the index notation in Table 6.3-9. For example, index A1 represents the HLW waste package present in the Positioning/Closure Room over the entire preclosure period. Index A2 represents a naval waste package present in the room over the preclosure period.

Data that is 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 the Table 6.3-11.

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	Container 45-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	Slapdown (bounds tip over)	Thin-Walled Canister Fire	Thick-Walled Canister Fire
Loss of Containment													
Canister in Transport Cask	1.E-05	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.E-05	2.E-06	1.E-06
Transport Cask with Bare Fuel	1.E-05	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.E-05	5.E-02 [1]	6.E-03 [2]
Canister	1.E-05	1.E-05	1.E-05	1.E-05	N/A	N/A	N/A	N/A	N/A	N/A	1.E-05	N/A	N/A
Waste Package	1.E-05	N/A	N/A	N/A	1.E-05	1.E-08	N/A	1.E-08	1.E-05	1.E-05	No challenge	3.E-04	1.E-04
Bare MCO	N/A	1.E-01	~ 1	~ 1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Bare DOE Standard Canister	1.E-05	1.E-05	1.E-05	1.E-05	N/A	N/A	N/A	N/A	1.E-05	1.E-05	N/A	N/A	N/A
Bare High Level Waste	3.E-02 [3]	3.E-02	7.E-02	~ 1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Canister in Shield Bell	N/A	1.E-05	N/A	N/A	N/A	1.E-08	N/A	N/A	N/A	N/A	N/A	1.E-04	9.E-05
Canister in AO	1.E-05	1.E-05	N/A	N/A	N/A	1.E-08	1.E-08	1.E-08	N/A	N/A	1.E-05	1.E-06	1.E-06
Loss of Shielding													
Transport Cask	1.E-05	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.E-05	~ 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	1.E-05	1.E-05	~ 0	~ 0
TEV, CTM, WPTT	No challenge	No challenge	N/A	N/A	No challenge	No challenge	N/A	No challenge	No challenge	No challenge	No challenge	~ 0	~ 0

NOTE: [1] Truck cask
[2] Rail cask
[3] Represents passive event failure probabilities for a drop of a HLW canister onto another HLW canister.

N/A = not applicable, no scenarios identified.

Source: Attachment D

INTENTIONALLY LEFT BLANK

Table 6.3-8. Passive Equipment Failure Basic Events used in IHF Event Sequence Analysis

Basic Event (BE) ID	Basic Event Description	BE Value	Condition
51A-HLW-CAN-FAIL-2BLK	Canister Fails from 2-Block Drop	1.00E+00	40-Foot Vertical Drop
51A-HLW-CAN-FAIL-COLL	Canister fails from Low Speed Collision	1.000E-08	20 Feet per minute flat side impact/collision
51A-HLW-CAN-FAIL-DERAIL	Canister Fails from Derailment	1.000E-05	2.5 mph end-to-end collision
51A-HLW-CAN-FAIL-DROP	Canister Fails from Drop	3.000E-02	Canister drop normal height
51A-HLW-CAN-FAIL-DROPIN	Canister fails from Drop inside CTM Bell	0.000E+00	Canister Drop from CTM Bell
51A-HLW-CAN-FAIL-DROPON	Canister Fails from Object dropped on Canister	3.000E-02	Canister Drops on Canister
51A-HLW-CAN-FAIL-DRPONWP	Canister fails from Object dropped on WP	0.000E+00	Object Dropped on HLW Canister in WP
51A-HLW-CAN-FAIL-IMPACT	Canister Failure from Impact	1.000E+00	HLW Canister Shear
51A-HLW-CAN-FAIL-IN-WP	Canister Failure from Fire	3.000E-004	HLW in WP Fail from Fire
51A-HLW-CAN-FAIL-LID	Canister Fails from Impact by Lid During Lid Removal	0.000E+00	10-Ton Drop On Canister in TC
51A-HLW-CAN-FAILS-CTM	HLW Canister Failure in CTM	1.000E-04	Thin-walled canister fire
51A-HLW-CAN-FAIL-SIMP	Canister Fails from Side impact from Shield Door	1.000E+00	Canister in TC; fails if TC fails
51A-HLW-CAN-FAIL-TILT	Canister Fails from Pre-Tiltdown	1.000E-05	Tipover
51A-HLW-CANTC-FAIL-COLL	Failure of HLW Canister in TC from Collision	1.000E-05	Canister in TC : TC lid unbolted
51A-HLW-CANTC-FAIL-IMP	Failure of HLW Canister in TC from Impact	1.000E-05	Canister in TC : TC lid unbolted
51A-HLW-CANWP-FAIL-COLL	Canister in WP Fails from Collision	1.000E+00	Canister in WP; fails if WP fails
51A-HLW-CANWP-FAIL-DERAL	Canister in WP Fails from Derailment	1.000E+00	Canister in WP; fails if WP fails
51A-HLW-CANWP-FAIL-TILT	Canister in WP Fails from Tiltdown	1.000E+00	Canister in WP; fails if WP fails
51A-HLW-CONT-FAIL-IMP	HLW Containment Fails from Impact with Shield Door	1.000E-08	Shield doors impact TC
51A-HLW-IMPACT-WP	WP Fails from Impact	1.00E-08	Canister in WP; fails if WP fails
51A-HLW-SHIELD-FAIL-COLL	WP Shield Fails from Low Speed Collision	0.000E+00	Loss of shielding-low speed collision; shielding provide by WPTT
51A-HLW-SHIELD-FAIL-TILT	WP Shielding fails from Pre-Tiltdown	0.000E+00	Loss of shielding-tipover; shielding provide by WPTT
51A-HLW-SHLDWP-FAIL-COLL	WP Shield Fails from Collision	0.000E+00	WP shielding failure; shielding provide by WPTT
51A-HLW-SHLDWP-FAIL-TILT	WP Shield Fails from Tiltdown	0.000E+00	WP shielding failure; shielding provide by WPTT
51A-HLW-TCASK-FAIL-COLL	HLW TC Failure in Low Speed Collision	1.000E-08	9 mph end-to-end collision; WP sealed
51A-HLW-TCASK-FAIL-DERAL	HLW TC Failure in Derailment	1.000E-08	2.5 mph end-to-end collision;: WP sealed

Table 6.3-8. Passive Equipment Failure Basic Events used in IHF Event Sequence Analysis (Continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Condition
51A-HLW-TCASK-FAIL-ROLL	HLW TC Failure in Rollover	1.000E-05	6 ft horizontal drop
51A-HLW-TC-FAIL-2BLK	Failure of HLW TC from 2-Block Drop	1.000E-05	30 ft vertical drop
51A-HLW-TC-FAIL-DROP	Failure of HLW TC from Drop	1.000E-05	15 ft vertical drop
51A-HLW-TC-FAIL-DROPON	Failure of HLW Cask from Object Dropped on Cask	1.000E-05	10 ton drop on TC
51A-HLW-TC-FAIL-SIMP	Failure of HLW Cask from Side Impact	1.000E-08	2.5 mph side impact to TC
51A-HLW-TC-FAIL-SPURMOV	Failure of HLW Cask from Spurious Movement	1.000E-08	2.5 mph side impact to TC
51A-HLW-TC-FAIL-TIPOVER	Failure of HLW Cask from Tipover	1.000E-05	TC tipover
51A-HLW-TC-TIPOVER	HLW TC Tipover	1.000E-05	TC tipover
51A-HLW-WP-FAIL-COLLIDE	WP Fails from Collision	1.000E-08	2.5 mph flat side collision of WPTT
51A-HLW-WP-FAIL-DERAIL	WP Fails from Derailment	1.000E-05	2.5 mph end-to-end collision
51A-HLW-WP-FAILS-DROPON	WP Fails from Object dropped on WP	1.000E-05	10-Ton drop on WP
51A-HLW-WP-FAIL-TILT	WP Fails from Tiltdown	0.000E+00	WP in WPTT during Tiltdown
51A-HLW-WPSHLD-FAIL-DERL	WP Shielding fails from WPTT Derailment	0.000E+00	WP shielding
51A-HLW-WPTT-IMPACT-TEV	WP Fails from Impact	1.000E-005	Canister in WP; fails if WP fails
51A-NVL-CAN-FAIL-2BLK	Canister Fails from 2-Block Drop	1.000E-05	40-foot vertical drop
51A-NVL-CAN-FAIL-COLL	Canister Fails in Low Speed Collision	1.000E-08	2.5 mph flat side collisions; in CTM
51A-NVL-CAN-FAIL-DERAIL	Canister fails from WPTT Derailment	1.000E-05	2.5 mph end-to-end collisions
51A-NVL-CAN-FAIL-DROP	Canister Fails from Drop	1.000E-05	15-foot vertical drop
51A-NVL-CAN-FAIL-DROPIN	Canister Fails from drop in CTM Bell	0.000E+00	Canister drops in CTM Bell
51A-NVL-CAN-FAIL-DROPON	Failure of NVL Canister from Dropped Object	1.000E-05	10-Ton object drops on canister
51A-NVL-CAN-FAIL-DRPONWP	Canister fails from Object Dropped on WP	1.000E-05	10-Ton object drops on canister
51A-NVL-CAN-FAIL-IMPACT	Canister failure from Impact	1.000E+00	NVL canister in TC; fails if TC fails
51A-NVL-CAN-FAIL-IN-TC	Failure of NVL Canister in TC	1.000E+00	NVL canister in TC; fails if TC fails
51A-NVL-CAN-FAIL-SIMP	Canister Fails from Side impact by Slide Gate	1.000E-08	Shear event
51A-NVL-CAN-FAIL-TILT	Canister Fails During WPTT Pre-Tiltdown	1.000E-05	Canister tipover in unsealed WP
51A-NVL-CANTC-FAIL-COLL	Failure of NVL Canister in TC from Collision	1.000E-05	Lid unbolted on TC; 2.5 mph collision
51A-NVL-CANTC-FAIL-IMP	Failure of NVL Canister in TC from impact	1.000E-05	Lid unbolted on TC; 2.5 mph impact
51A-NVL-CANWP-FAIL-COLL	Canister in WP Fails from Collision	1.000E+00	Canister fails if WP Fails
51A-NVL-CANWP-FAIL-DERAL	Canister in WP Fails from Derailment	1.000E+00	Canister fails if WP Fails
51A-NVL-CANWP-FAIL-TILT	Canister in WP Fails from Tiltdown	1.000E+00	Canister fails if WP Fails

Table 6.3-8. Passive Equipment Failure Basic Events used in IHF Event Sequence Analysis (Continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Condition
51A-NVL-CONT-FAIL-IMP	NVL Containment Fails from Impact into Shield Door	1.000E-08	2.5 mph side impact
51A-NVL-SHIELD-FAIL-COLL	WPTT Shield Fails in Low Speed Collision	0.000E+00	2.5 mph collision—shield failure
51A-NVL-SHIELD-FAIL-DERL	WPTT Shield Fails During Derailment	0.000E+00	WPTT shielding failure—derailment
51A-NVL-SHIELD-FAIL-TILT	WPTT Shield Fails During pre-Tiltdown	0.000E+00	WPTT shielding failure—pretiltdown
51A-NVL-SHLDWP-FAIL-TILT	WP Shield Fails from Tiltdown	0.000E+00	WP shielding failure—tiltdown
51A-NVL-TC-FAIL-2-BLOCK	NVL Cask Fails from 2-Block Drop	1.000E-05	30-foot vertical drop
51A-NVL-TC-FAIL-COLLIDE	NVL Cask Fails in Prime Mover Collision	1.000E-08	9 mph end-to-end collision
51A-NVL-TC-FAIL-DERAIL	Failure of NVL Cask from Derailment	1.000E-08	9 mph side impact
51A-NVL-TC-FAIL-DROP	Failure of NVL Cask from Dropping	1.000E-05	15-foot vertical drop
51A-NVL-TC-FAIL-DROPON	Failure of NVL Cask from Object Dropped on Cask	1.000E-05	10-ton drop on TC
51A-NVL-TC-FAIL-OFFPMCOL	NVL Cask Fails from Collision off of Prime Mover	1.000E-08	2.5 localized side impact
51A-NVL-TC-FAIL-SIMP	Failure of NVL Cask from Side Impact	1.000E-08	2.5 mph flat side impact
51A-NVL-TC-FAIL-TIP	Failure of NVL Cask from Tipover	1.000E-05	TC vertical tipover
51A-NVL-WP-FAIL-COLLIDE	WP Fails from Collision	1.000E-05	2.5 mph end-to-end collision
51A-NVL-WP-FAIL-DERAIL	WP Fails from Derailment	1.000E-05	2.5 mph end-to-end collision
51A-NVL-WP-FAIL-DROPON	WP Fails from Object dropped on WP	1.000E-05	10-ton object dropped on WP
51A-NVL-WP-FAIL-TILT	WP Fails from Tiltdown	0.000E+00	WP in WPTT tiltdown
51A-NVL-WPSHLD-FAIL-COLL	WP Shield from Collision	0.000E+00	WP in WPTT shielding failure
51A-NVL-WPSHLD-FAIL-DERL	WP Shield Fails from Derailment	0.000E+00	WP in WPTT shielding failure
51A-NVL-WPTT-COLLIDE-TEV	WP failure due to Collision	1.000E-05	WPTT Collision with TEV
51A-WPSHIELD-FAIL-EXPORT	WP Shield Fails During Export	0.000E+00	WP shielding failure
CTM-SHIELDING	Shielding associated with CTM	0.000E+00	Canister shielding failure in CTM
Thermal PEFA			
51A-HLW-CAN-CONT-PR-FIR	Can Failure in WP in Positioning Room	3.000E-04	Thin wall canister
51A-HLW-CAN-CONT-CUR-FIR	Fire Fails Can in TC	2.000E-06	Thin wall canister
51A-HLW-CAN-CONT-CTM-FIR	Can Failure in CTM	1.000E-004	Thin wall canister
51A-HLW-CAN-CONT-LR-FIR	Can Failure in WP in Loading Room	3.000E-04	Thin wall canister
51A-HLWCAN-WP-FAIL-FIRE	HLW Canister in WP fails in Fire	3.000E-04	Thin wall canister
51A-HLWCAN-WPTT-FAIL-FIR	HLW Canister in WPTT fails in Fire	3.000E-04	Thin wall canister
51A-NVL-CAN-CONT-CTM-FIR	Canister Fails in Fire Involving CTM	9.000E-05	Thick wall canister

Table 6.3-8. Passive Equipment Failure Basic Events used in IHF Event Sequence Analysis (Continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Condition
51A-NVL-CAN-CONT-CTM-FIR	NVL Canister in CTM During Facility Fire	9.000E-05	Thick wall canister
51A-NVL-CAN-CONT-CUR-FIR	Canister Failure Cask Unloading Room	1.000E-06	Thick wall canister
51A-NVL-CAN-CONT-CUR-FIR	NVL Canister in Cask Unloading Room During Fire	1.000E-06	Thick wall canister
51A-NVL-CAN-CONT-LR-FIRE	Canister Fails WP Loading Room	1.000E-04	Thick wall canister
51A-NVL-CAN-CONT-PR-FIRE	Canister Fails WP Positioning Room	1.000E-04	Thick wall canister
51A-NVLCAN-FAILWP-LOR	Canister Fails WP Loadout Room	1.000E-04	Thick wall canister
51A-NVLCAN-FAILWPTT-LOR	Localized Fire Threatens WP in WPTT in Loadout Room	1.000E-04	Thick wall canister
51A-NVL-CAN-FAIL-IN-WP	Failure of NVL Canister in Waste Package	1.000E-04	Thick wall canister
51A-NVL-CAN-FAILS-CTM	NVL Canister Failure in CTM	9.000E-05	Thick wall canister

NOTE: CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; DSTD = DOE standardized canister; ft = feet; HLW = high-level radioactive waste; MCO = multicanister overpack; min = minutes; mph = miles per hour; NVL = naval; sec = seconds; ST = site transporter; TAD = transportation, aging, and disposal; TC = transportation cask; TEV = transport and emplacement vehicle; WP =waste package; WPTT = waste package transfer trolley.

Source: Original

Table 6.3-9. Fire Analysis for Wastes Types in Specific Configuration

Location	Index	HLW 1	Naval 2	Container Type or Location
Positioning/Closure Room (WPTT)	A	3.8E-05	3.8E-05	WP
WPTT in Loadout Room	B	4.9E-07	4.9E-07	WP
WP in TEV in Loadout Room	C	8.8E-08	8.8E-08	WP
On CTT in Unloading Room	D	2.2E-08	1.2E-08	TC
WPTT in Loading Room	E	1.2E-05	3.5E-07	WP
Vestibule/Preparation Area w/SPM (Diesel Present)	F	1.5E-07	2.3E-07	TC
Preparation Area w/o SPM (No Diesel Present)	G	9.3E-07	2.0E-06	TC
On CTT in Preparation Area	H	5.3E-07	1.3E-06	TC
In CTM in Transfer Room	I	6.9E-08	8.1E-08	CTM
Large Fire Threatens TC/NSNF w/SPM Present (Diesel)	J	–	3.7E-07	TC
Large Fire Threatens TC/NSNF w/o SPM Present (No Diesel)	K	–	9.7E-06	TC
Large Fire Threatens NSNF in CTM	L	–	2.0E-07	CTM
Large Fire Threatens NSNF in WP	M	–	5.9E-05	WP
Large Fire Threatens TC/HLW w/SPM Present (Diesel)	N	2.5E-07	–	TC
Large Fire Threatens TC/HLW w/o SPM Present (No Diesel)	O	5.1E-06	–	TC
Large Fire Threatens HLW in CTM	P	1.6E-06	–	CTM
Large Fire Threatens HLW in WP	Q	1.0E-04	–	WP

NOTE: CTM = canister transfer machine; CTT = cask transfer trolley; HLW = high-level radioactive waste; NSNF = naval spent nuclear fuel; SPM = site prime mover; TC = transportation cask; TEV = transportation emplacement vehicle; WP = waste package; WPTT = waste package transfer trolley.

Source: Table 6.5-4

Table 6.3-10. Split Fractions for Waste Types in Various Configurations

Reference Index for Table 6.3-12	Basic Event Identifier	Formula for Split Fraction	Resultant Value
Naval-Localized Fires			
(1)	51A-NVL-SPMRC-DIESEL	[(F2)/(F2+G2+H2)]	6.5E-02
(2)	51A-NVL-SPMRC-WODIESEL	[(G2+H2)/(F2+G2+H2)]	9.4E-01
(3)	51A-PROB-NVLCAN-WPTT-LOR	[(B2)/(B2+C2)]	8.5E-01
(4)	51A-PROB-NVLCAN-WP-LOR	[(C2)/(B2+C2)]	1.5E-01
Naval-Large Fire			
(5)	51A-NVL-FREQ-DIESEL	[(J2)/(J2+K2+L2+M2)]	5.4-03
(6)	51A-NVL-FREQ-NODIESEL	[(K2)/(J2+K2+L2+M2)]	1.4E-01
(7)	51A-NVL-LARGE-FIRE-CTM	[(L2)/(J2+K2+L2+M2)]	2.9E-03
(8)	51A-NVL-FREQ-WP-FAILS	[(M2)/(J2+K2+L2+M2)]	8.5E-01
HLW-Localized Fire			
(9)	51A-HLWSPMRC-DIESEL	[(F1)/(F1+G1+H1)]	9.6E-02
(10)	51A-HLWSPMRC-NODIESEL	[(G1+H1)/(F1+G1+H1)]	9.0E-01
(11)	51A-PROB-HLWCAN-WPTT-LOR	[(B1)/(B1+C1)]	8.5E-01
(12)	51A-PROB-HLWCAN-WP-LOR	[(C1)/(B1+C1)]	1.5E-01
HLW-Large Fire			
(13)	51A-HLW-FREQ-WITH DIESEL	[(N1)/(N1+O1+P1+Q1)]	2.3E-03
(14)	51A-HLW-FREQ-NO-DIESEL	[(O1)/(N1+O1+P1+Q1)]	4.7E-02
(15)	51A-HLW-LARGE-FIRE-CTM	[(P1)/(N1+O1+P1+Q1)]	1.5E-02
(16)	51A-HLW-FREQ-WP-FAILS	[(Q1)/(N1+O1+P1+Q1)]	9.4E-01
(17)	51A-HLW-FREQ-NODIESEL	[(Q1)/(N1+O1+P1+Q1)]	9.4E-01

NOTE: HLW = high-level radioactive waste.

Source: Original

Table 6.3-11. Miscellaneous Data Used In the Reliability Analysis

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	References
51A-#HLW-TC-LIFTS	Number of Crane Lifts of HLW TCs	1.00E+00	During preparation activities associated with a HLW TC, there is one lift of a heavy object such as a lift fixture over the cask. Therefore, a value of 1 is assigned to this basic event.	N/A
51A-%-HLW-ON-SPMRC	Percentage of Time HLW is Received on SPMRC	1.67E-01	600 HLW TCs can be received by rail or by truck. 100 HLW TCs with multiple canisters will arrive by railcar and 500 TCs with single canisters will arrive by truck trailer.	000-PSA-MGR0-01800-000-00A (Ref. 2.2.26)
51A-%-HLW-ON-SPMTT	Percentage of Time HLW is Received on SPMTT	8.33E-01	600 HLW TCs can be received by rail or by truck. 100 HLW TCs with multiple canisters will arrive by railcar and 500 TCs with single canisters will arrive by truck trailer.	000-PSA-MGR0-01800-000-00A (Ref. 2.2.26)
51A-CTMOBJLIFTNUMBER-HLW	Number of Object Lifts	1.00E+00	During canister transfer from a HLW TC to a WP, the CTM lifts a lid over the cask. Therefore, a value of 1 is assigned to this basic event.	N/A
51A-CTMOBJLIFTNUMBER-NVL	Number of Objects Lifted	1.00E+00	During canister transfer from a Naval TC to a WP, the CTM lifts a lid over the cask. Therefore, a value of 1 is assigned to this basic event.	N/A
51A-DOORFAIL-IMPACT	Shield Door Fails from Impact	0.00E+00	Failure of shield door can not occur as a result of any collisions within the IHF.	N/A
51A-FIRE-SUPPRESSION	Inadvertent Fire Suppression Actuation	9.30E-07	Fire suppression system inadvertently activates during normal IHF operations (no fire).	Section 6.2.2.9
51A-LIFTS-PER-HLW-CAN	Number of Lifts per HLW Canister	1.00E+00	HLW is lifted out of a TC by the CTM and placed in a WP.	N/A
51A-HLW-FAIL-CAN-DIESEL	Relative Frequency with Diesel Present	2.00E-06	Based on the fire frequency analysis, this value represents the relative frequency for a HLW Canister in the Cask Prep Area with diesel present.	Section 6.5

Table 6.3-11. Miscellaneous Data Used in the Reliability Analysis (Continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	References
51A-HLW-FREQ WITH DIESEL	Relative Frequency with Diesel Present	2.30E-03	Based on the fire frequency analysis, this value represents relative frequency an HLW canister is possibly subjected to a large facility fire with diesel present.	Table 6.3-10 (13)
51A-HLW-FREQ-NO-DIESEL	Relative Frequency with no Diesel Present	4.67E-02	Based on the fire frequency analysis, this value represents the relative frequency an HLW canister is possibly subjected to a large facility fire without diesel present.	Table 6.3-10 (14)
51A-HLW-FREQ-WODIESEL	Relative Frequency of WP in Large Fire without Diesel	9.37E-01	Based on the fire frequency analysis, this value represents the relative frequency a WP is subject to a possible large facility fire without diesel present.	Table 6.3-10 (17)
51A-HLW-FREQ-WP-FAILS	Relative Frequency of WP in Large Fire	9.37E-01	Based on the fire frequency analysis. This value represents the fraction of time an HLW WP is in the IHF.	Table 6.3-10 (16)
51A-HLW-LARGE-FIRE-CTM	Relative Frequency of Large Fire in CTM	1.45E-02	Based on fire frequency analysis. Large facility fire threatens HLW canister inside the CTM.	Table 6.3-10 (15)
51A-LIFTS-PER-NVL-CAN	Number of Lifts per NVL Canister	1.00E+00	Naval canister is lifted out of a TC by the CTM and placed directly into a WP.	N/A
51A-LOSS-OFFSITE-PWR	Loss of offsite power	2.99E-03	Commercial power reliability requirement	N/A
51A-MODERATOR-ENTERS-CAN	Moderator Enters Canister in a Fire	1.00E+00	Water enters canister during facility fire–conservative value assigned.	Section 6.2.2.7
51A-OBJECTLIFTNUMBER	Number of Object Lifts	1.00E+00	Number of crane lifts that could result in dropping objects on the transpiration cask.	N/A
51A-OIL-MODERATOR	Oil Moderator Sources in IHF (Gearbox)	9.00E-05	Crane gearbox leaks oil during normal IHF operations (no fire) that could potentially create a moderator source.	Section 6.2.2.9.2
51A-OTHER-WATER	Water Moderator Sources Other Than Fire Suppression	1.40E-03	Other water sources provide moderator for canisters such as water pipes or valves in IHF leak.	Section 6.2.2.9.1
51A-PROB-HLWCAN-WP-LOR	Probability HLW Canister in WP in Loadout Room	1.51E-01	Based on fire frequency analysis. Fire threatens WP with HLW canister in Loadout room.	Table 6.3-10 (12)

Table 6.3-11. Miscellaneous Data Used in the Reliability Analysis (Continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	References
51A-HLWSPMRC-DIESEL	Fire in Prep Area SPMRC with Diesel	9.61E-02	Based on the fire frequency analysis, this value represents the failure of the HLW canister in a Cask Prep Area fire when diesel is present.	Table 6.3-10 (9)
51A-HLWSPMRC-WODIESEL	Fire in Prep Area SPMRC Without Diesel	9.04E-01	Based on the fire frequency analysis, this value represents the failure of the HLW canister in a Cask Prep Area fire when no diesel is present on the SPMRC.	Table 6.3-10 (10)
51A-PROB-HLWCAN-WPTT-LOR	Probability HLW Canister in WPTT in Loadout Room	8.49E-01	Based on fire frequency analysis. Fire threatens WPTT with HLW canister in Loadout room.	Table 6.3-10 (11)
51A-NVL-FREQ-DIESEL	Relative Frequency with Diesel Present	5.35E-03	Based on the fire frequency analysis. Large facility fire when diesel is present threatens naval cask inside the IHF.	Table 6.3-10 (5)
51A-NVL-FREQ-NO-DIESEL	Relative Frequency without Diesel Present	1.39E-01	Based on the fire frequency analysis. Large facility fire when no diesel is present threatens naval cask inside the IHF.	Table 6.3-10 (6)
51A-NVL-FREQ-WP-FAILS	Relative Frequency WP Fails due to Fire	8.53E-01	Based on fire frequency analysis. Large facility fire threatens naval canister inside the IHF.	Table 6.3-10 (8)
51A-NVL-LARGE-FIRE-CTM	Relative Frequency of Large Fire in CTM	2.91E-03	Based on fire frequency analysis. Large facility fire threatens naval canister inside the CTM.	Table 6.3-10 (7)
51A-NVL-SPMRC-WODIESEL	Fire in Preparation Area without Diesel	9.35E-01	Based on Fire frequency analysis. Fire threatens naval transportation cask after SPM has left cask preparation room.	Table 6.3-10 (2)
51A-NVL-SPMRC-DIESEL	Fire in Preparation Area SPMRC with Diesel	6.53E-02	Based on Fire frequency analysis. Fire threatens naval transportation cask while SPM is present in cask preparation room.	Table 6.3-10 (1)
51A-PROB-HLW-WP	Probability of HLW WP Cask in Process	6.00E-01	Probability a HLW canister in WP—based on 600 of 1000 canisters processed through IHF over entire preclosure period.	N/A

Table 6.3-11. Miscellaneous Data Used in the Reliability Analysis (Continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	References
51A-PROB-LEAD	Probability of Lead Casks	1.00E+00	The number of leaded TC received by the IHF is unknown. This value is set to a value of 1.0 to ensure a conservative analysis.	N/A
51A-PROB-NON-LEAD	Probability of Non-Lead Casks	0.00E+00	Since all TCs received by the IHF are considered as leaded casks, then the probability of receiving a non-leaded cask is 0.0.	N/A
51A-PROB-NVLCAN-WP-LOR	Probability NVL Canister in WP in Loadout Room	1.51E-01	Based on fire frequency analysis. Fire threatens WP with Naval canister in Loadout room.	Table 6.3-10 (4)
51A-PROB-NVLCAN-WPTT-LOR	Probability NVL Canister in WPTT in Loadout Room	8.49E-01	Based on fire frequency analysis. Fire threatens WPTT with Naval canister in Loadout room.	Table 6.3-10 (3)
51A-PROB-NVL-WP	Probability of NVL WP Cask in Process	4.00E-01	Probability a Naval canister in WP.	N/A
51A-PWR-LOSS	Loss of Power	4.10E-06	Commercial power reliability requirement	N/A
51A-PWR-LOSS-2	Loss of Power	4.10E-06	Commercial power reliability requirement	N/A
51A-RHSLIFTNUMBER-000001	Number of RHS Lifts	2.00E+00	This value represents the number of lifts performed by the remote handling system during the process of sealing the WP.	N/A
51A-SLIDEGATECLOSES-CAN	Slide Gate Impact Damages Canister	0.00E+00	The port slide gate and the CTM bell slide gate are designed to operate with a low-torque motor that prevent crushing a canister, should the canister be in transit through the gate.	Section 6.0
51A-SPMRC-MILES-IN-IHF	Miles SPMRC travels in IHF	4.00E-02	This value represents the number of miles that the SPMRC will travel in the IHF during normal operations.	N/A
51A-TRANSNSCTTLIFTNUMBER	Number of Crane Lifts	1.00E+00	Number of lifts by the 300-ton crane that could potentially drop an object on the TC while the cask is on the CTT.	N/A
51A-WPTT-MILES-IN-IHF	Miles WPTT travels during transfer	4.00E-02	This value represents the number of miles that the WPTT will travel in the IHF during normal operations.	N/A

Table 6.3-11. Miscellaneous Data Used in the Reliability Analysis (Continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	References
51A-WELD-DAMAGE	Weld Generates Sufficient Heat to Damage Canister	0.00E+00	Welder malfunction during the inner lid or outer lid welding. Since the welder can not generate sufficient heat to damage the WP, a value of 0.00 is assigned to the event.	N/A
NUM_NVL	Number of Naval Casks	4.00E+02	Number of naval TC processed by the IHF over the preclosure period.	000-PSA-MGR0-01800-000-00A (Ref. 2.2.26)
NUMBER-NAVAL-CANISTERS	Number of Naval Canisters	4.00E+02	400 naval TC containing a single canister will be processed by the IHF over the preclosure period.	000-PSA-MGR0-01800-000-00A (Ref. 2.2.26)
NUM-HLW-CAN	Number of HLW canisters received at IHF over the preclosure period	1.00E+03	There will be 500 single canisters and 100 multi-pack HLW TCs containing up to 5 canisters at the IHF for a total of 1000 canisters.	000-PSA-MGR0-01800-000-00A (Ref. 2.2.26)
NUM-HLW-CSK	Number of HLW casks received during preclosure period	6.00E+02	The total number of HLW TCs processed by the IHF over the preclosure period.	000-PSA-MGR0-01800-000-00A (Ref. 2.2.26)
NUM-HLW-WP	Number of HLW WPs processed over the preclosure period.	2.00E+02	200 HLW WP will be processed by the IHF over the preclosure period.	000-PSA-MGR0-01800-000-00A (Ref. 2.2.26)
NUM-NVL	Number of Naval casks received at IHF over the preclosure period.	4.00E+02	400 naval TCs will be processed over the preclosure period.	000-PSA-MGR0-01800-000-00A (Ref. 2.2.26)
SHIELD-BELL-DROPS-SUBSUM	Shield bell drops addressed in general CTM drop Events	0.00E+00	Added to the fault trees for completeness.	N/A
NVL-SHIELDING-FAILS5	Naval Trans Cask Shielding Fails–Drops	1.00E-05	PEFA for naval TC shielding failure for drops.	Table 6.3-7
NVL-SHIELDING-FAILS8	Naval Trans Cask Shielding Fails–Collisions	1.00E-08	PEFA for naval TC shielding failure for Collisions.	Table 6.3-7
HLW-SHIELDING-FAILS5	HLW Trans Cask Shielding Fails–Drops	1.00E-05	PEFA for HLW TC shielding failure for drops.	Table 6.3-7
HLW-SHIELDING-FAILS8	HLW Trans Cask Shielding Fails–Collisions	1.00E-08	PEFA for HLW TC shielding failure for collisions.	Table 6.3-7
51A-MOD-FIRE-HLW-NOIMP	Moderator Has No Impact on Criticality for HLW	0.00E+00	A moderator source has no impact on HLW—can not criticality. Probability set to 0.00.	N/A

Table 6.3-11. Miscellaneous Data Used in the Reliability Analysis (Continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	References
MOD-NOFIRE-HLW-NOIMP	Moderator Has No Criticality Impact on HLW	0.00E+00	A moderator source has no impact on HLW—no criticality. Probability set to 0.00.	N/A
51A-MODERATOR-ENTERS-CAN	Moderator Enters Canister in a Fire	1.000E+00	A moderator source enters naval canister during a facility fire.	N/A
51A-PERCENT-RC-RECEIPT	Percentage of time Naval Canister is Received on SPMRC	1.000E+00	All naval waste packages will arrive at the IHF on the SPMRC.	000-PSA-MGR0-01800-000-00A (Ref. 2.2.26)
51A-PERCENT-TT-RECEIPT	Percentage of time Naval Canister is Received on TT	0.000E+00	No Naval waste packages will arrive at the IHF on the SPMTT.	000-PSA-MGR0-01800-000-00A (Ref. 2.2.26)

NOTE: IHF =Initial Handling Facility; CTM = canister transfer machine; CTT = cask transfer trolley; HLW = high-level radioactive waste; SPMRC = site prime mover railcar; SPMTT = site prime mover truck trailer; RHS = remote handling system; SD = shield doors; TC = transportation cask; WP =waste package; WPTT = waste package transfer trolley.

Source: Original

6.4 HUMAN RELIABILITY ANALYSIS

The PCSA has emphasized human reliability analysis 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 human failure events 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 detailed description of the HRA is presented in Attachment E.

6.4.1 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, for example, provided by the confinement HVAC system.

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 Cask Preparation Room during the export of empty transportation casks).

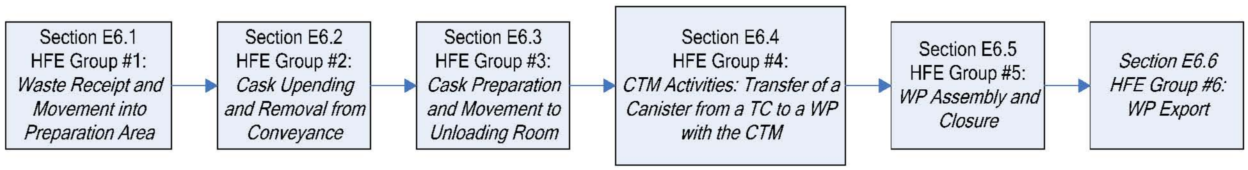
4. The exception to #3 is that system-level HFEs are considered for support systems (e.g., electrical power for confinement HVAC) when those HFEs could result in a loss of a safety function related to the occurrence or consequences associated with the events specified in #1.

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 Section 4.3.10.1 (on boundary conditions of the PCSA), 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 the IHF 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. To do this, the IHF operations were broken into six separate operational steps, as depicted in Figure 6.4-1.



NOTE: CTM = canister transfer machine; HFE =human failure event; TC = transportation cask; WP = waste package.

Source: Original

Figure 6.4-1. Initial Handling Facility Operations

The base case scenario for each HFE group 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). The relationship between these HFE groups and the corresponding PFD nodes and ESDs are mapped in Attachment E, Table E6.0-1.

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 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

[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.

initiating events are proximal causes of either radionuclide release or direct exposure to 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. 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 with the initiator phase. Moreover, 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-initiators 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:

- *A Survey of Crane Operating Experience at U.S. Nuclear Power Plants from 1968 – 2002, NUREG-1774* (Ref. 2.2.48)
- *Control of Heavy Loads at Nuclear Power Plants, NUREG-0612* (Ref. 2.2.58)
- 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 (INPO) database. The INPO database 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. 2.2.11)

- All Scientech/ Licensing Information Service (LIS) data on independent spent fuel 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
  - Letters, etc.

HFEs identified include both EOOs and EOCs.

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 factors concerns then becomes the EFC for a specific HFE. Additions and refinements to these initial EFCs are made during the preliminary and detailed analyses.

Post-Initiator, Non-Recovery HFEs

Post-initiator, non-recovery HFEs are identified by examining the human contribution to pivotal events in the event tree analysis. The event sequence analysts, with support from the human reliability analysts, identify HFEs that represent an operator's failure to perform the proper action to mitigate the initiating event and/or the unavailability of automatic mitigation function as called for in the emergency operating procedures or in accordance with their emergency response training. This identification includes all actions required, whether in a control room or locally. Post-initiator EOCs and EOOs are also considered. No post-initiator HFEs were identified in this analysis.

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 above 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.

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 the performance objectives in 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 important to safety features of Section 6.9 were identified during the HRA. The remaining HFEs retain their assigned preliminary values. For the preliminary analysis, many of the HFEs are modeled in a simplified form in the event trees and fault trees; although, for the preliminary analysis, each action is separated as much as possible for the detailed analysis. This separation is done to ensure that the detailed analysis is thorough and that the relationship between the system functionality and operations crew is transparent. First an HFE is broken down into the various scenarios that lead to the failure. Then, each scenario is further broken down into specific required actions and their applicable procedures, along with the systems and components that must be operated during performance of each action. Each action in each scenario has its own unique context, dependencies, and set of PSFs, and each is quantified independently. The failure probabilities for these unsafe actions are quantified by the HRA method appropriate to the HFE, its classification (e.g., EOC, EOO, observation error, execution error), and the context. For this analysis, several HRA methods were considered, and the following four methods were selected (Appendix E.IV of Attachment E provides a discussion of the selection process):

- CREAM (Ref. 2.2.47)
- HEART/NARA (Ref. 2.2.81)/(Ref. 2.2.35) THERP with some modifications (Ref. 2.2.77)
- ATHEANA's expert elicitation approach (Ref. 2.2.62).

For the preliminary analysis, HFEs are modeled at a high level where several subtasks are combined into a single task so that explicit consideration of dependencies between subtasks is eliminated. For a detailed assessment, where the various actions that constitute an HFE are explicitly quantified, dependencies are also explicitly addressed using the basic formulae in Table 6.4-1 from the THERP method (Ref. 2.2.77), where N is the independently derived HEP.

Table 6.4-1. Formulae for Addressing HFE Dependencies

Level of Dependence	Zero	Low	Medium	High	Complete
Conditional Probability	N	$\frac{1 + 19N}{20}$	$\frac{1 + 6N}{7}$	$\frac{1 + N}{2}$	1.0

Source: Modified from *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications*. NUREG/CR-1278 (Ref. 2.2.77), Table 20-17, p. 20–33

After estimates for HFE probabilities are generated, these results are reviewed by the HRA team and, in some cases, by knowledgeable operations personnel, as a "sanity check." Principally, such checks are used, for example, to compare the probabilities of different HFEs and determine whether or not these probabilities are consistent with the judgment of experts regarding the associated operator actions. A review of this type is particularly important for HFE probabilities that are generated using data from the THERP method (Ref. 2.2.77) since it is difficult to identify all important PSFs that are appropriate for repository operations. In addition, the HFE probability estimates are reviewed to ensure that they do not exceed the lower limit of credible human performance as defined by NARA (Ref. 2.2.35). 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.

6.4.6 Human Failure Event Probabilities used in IHF 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 6.4-2.

Table 6.4-2. Human Failure Event Probability Summary

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
51A-Liddisplace1-HFI-NOD	Operator inadvertently displaces cask lid during preparation activities	12	3	N/A[b]	N/A	Omitted from analysis
51A-OpCaskDrop01-HFI-NOD	Operator drops cask during cask preparation activities	N/A	3	N/A[b]	N/A	Omitted from analysis
51A-OpClCTMGate1-HFI-NOD	Operator inappropriately closes slide or port gate during vertical canister movement and continues lifting	7	4	1.00E-03	5	Preliminary
51A-OpCollide001-HFI-NOD	Operator causes low-speed collision of auxiliary vehicle with RC, TT, or CTT	1, 2, 3, 4	2, 3	3.00E-03	5	Preliminary
51A-OpCraneIntfr-HFI-NOD	Operator causes WP handling crane to interfere with TEV or WPTT	11	6	1.00E-04	10	Preliminary
51A-OpCTCollide2-HFI-NOD	Operator causes low-speed collision of CTT during transfer from preparation station to Cask Unloading Room	5	3	1.00E-03	5	Preliminary
51A-OpCTMDrInt01-HFI-COD	Operator lifts object or canister too high with CTM (two-block)	7	4	1.0	N/A	Preliminary
51A-OpCTMdrop001-HFI-COD	Operator drops object onto canister during CTM operations	7	4	4.00E-07	10	Detailed
51A-OpCTMdrop002-HFI-COD	Operator drops canister during CTM operations	7	4	2.00E-04	10	Detailed
51A-OpCTMImpact1-HFI-COD	Operator moves the CTM while canister or object is below or between levels	7	4	4.00E-08	10	Detailed
51A-OpCTMImpact2-HFI-COD	Operator causes canister impact with lid during CTM operations (HLW)	7	4	N/A[b]	N/A	Omitted from analysis
51A-OpCTMImpact5-HFI-COD	Operator causes canister impact with SSC during CTM operations (all)	7	4	1.0	N/A	Preliminary
51A-OpCTTImpact1-HFI-NOD	Operator causes an impact between cask and SSC due to crane operations	1, 2, 3, 4	2, 3	3.00E-03	5	Preliminary
51A-OpDirExpose1-HFI-NOD	Operator causes direct exposure during CTM activities (all waste forms)	12	4	1.0	N/A	Preliminary

Table 6.4-2. Human Failure Event Probability Summary (Continued)

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
51A-OpDirExpose2-HFI-NOD	Operator causes direct exposure during CTM activities (transfer into a WP)	12	4	1.00E-04	10	Preliminary
51A-OpDirExpose3-HFI-NOD	Operator causes direct exposure during TEV loading	12	6	3.00E-05	10	Detailed
51A-OpFailRstInt-HFI-NOM	Operator fails to restore interlock after maintenance	12	4, 6	1.00E-02	3	Preliminary
51A-OpFailSG-HFI-NOD	Operator fails to close the CTM slide gate before lifting shield skirt (while the canister is inside the bell; direct exposure)	12	4	1.00E-3	5	Preliminary
51A-OpFLCollide1-HFI-NOD	Operator causes high-speed collision of auxiliary vehicle with RC, TT, or CTT	1, 2, 3, 4	2, 3	1.0	N/A	Preliminary
51A-OpImpact0000-HFI-NOD	Operator causes impact of cask during transfer from preparation station to Cask Unloading Room	5	3	N/A[b]	N/A	Omitted from analysis
51A-OpNoDiscoAir-HFI-NOD	Operator fails to disconnect air supply from CTT in the Cask Unloading Room	7	4	1.00E-03	5	Preliminary
51A-OpNoUnBolt00-HFI-NOD	Operator fails to fully unbolt the cask lid before moving CTT into the Cask Unloading Room (HLW)	7	4	1.00E-03	5	Preliminary
51A-OpNoUnBoltDP-HFI-NOD	Operator fails to fully unbolt the cask lid before moving CTT into the Cask Unloading Room (naval cask)	7	4	N/A[b]	N/A	Omitted from analysis
51A-OpNVYShield1-HFI-COW	Operator inappropriately removes naval shield ring (direct exposure)	12	3	3.00E-04	5	Preliminary
51A-OpRCCollide1-HFI-NOD	Operator causes low-speed collision between RC and facility SSCs	1	1	3.00E-03	5	Preliminary
51A-OpRCIntCol01-HFI-NOD	Operator causes high-speed collision between RC and facility SSCs	1	1	1.0	N/A	Preliminary
51A-OpRCIntCol2-HFI-NOD	Operator causes MAP to collide into RC	1	1	1.0	N/A	Preliminary
51A-OpSDClose001-HFI-NOD	Operator closes shield door on waste form in conveyance	6	OA (1, 3, 6)	1.0	N/A	Preliminary
51A-OpShieldRing-HFI-NOD	Operator fails to install WP shield ring in WPTT (direct exposure)	12	6	1.00E-04	10	Preliminary

Table 6.4-2. Human Failure Event Probability Summary (Continued)

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
51A-OpSpurMove01-HFI-NOD	Operator causes spurious movement of CTT in the Cask Preparation Area	1, 2, 3, 4	2, 3	1.00E-04	10	Preliminary
51A-OpTEVDrClosd-HFI-NOD	Operator begins WP extraction before TEV doors open	11	6	1.00E-03	5	Preliminary
51A-OpTiltDown01-HFI-NOD	Operator prematurely tilts down the WPTT	7, 8, 10	4, 5, 6	1.0	N/A	Preliminary
51A-OpTipover001-HFI-NOD	Operator causes cask to tip over during cask upending and removal	1, 2	2	1.00E-04	10	Preliminary
51A-OpTipover002-HFI-NOD	Operator causes cask to tip over during cask preparation activities	3, 4	3	1.00E-04	10	Preliminary
51A-OpTTCollide1-HFI-NOD	Operator causes low-speed collision between TT and facility SSCs	1	1	3.00E-03	5	Preliminary
51A-OpTTIntCol01-HFI-NOD	Operator causes high-speed collision between TT and facility SSCs	1	1	1.0	N/A	Preliminary
51A-OpTTIntCol2-HFI-NOD	Operator causes MAP to collide into TT	1	1	1.0	N/A	Preliminary
51A-OpTTRollover-HFI-NOD	Operator causes rollover of TT	1	1	N/A[b]	N/A	Omitted from analysis
51A-OpWPCollide1-HFI-NOD	Operator causes low-speed collision of WPTT into SSC	8, 10	5, 6	3.00E-03	5	Preliminary
51A-OpWPInnerLid-HFI-NOD	Operator causes direct exposure during WP loading	12	5	1.00E-04	10	Preliminary
51A-OpWPTiltUp01-HFI-NOD	Operator prematurely tilts up the WPTT	11	6	1.0	N/A	Preliminary
51A-OpWPTTSpur01-HFI-NOD	Operator causes spurious movement of WPTT during canister loading	7	4	1.00E-03	5	Preliminary
Crane drops	Operator drops cask or drops object onto cask during crane operations	1, 2, 3, 4, 9, 11	2, 3, 5, 6	N/A[a, b]	n/a	Historic data
Improper WP closure	Operator damages canister or fails to properly weld the WP	9	5	N/A[b]	N/A	Omitted from analysis
Load too heavy	Operator causes drop of cask by attempting to lift a load that is too heavy for the crane	N/A	OA	N/A[b]	N/A	Omitted from analysis

Table 6.4-2. Human Failure Event Probability Summary (Continued)

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
Moderator introduced into moderator-controlled area	Operator introduces moderator into a moderator-controlled area of the IHF	N/A	OA	N/A[b]	N/A	Omitted from analysis
RC derailment	Operator causes the RC to derail	1	1	N/A[a, b]	N/A	Historic data
Spurious movement of CTT during CTM activities	Operator causes spurious movement of the CTT during CTM activities	7	4	N/A[b]	N/A	Omitted from analysis
TEV Collision	Operator causes TEV to collide with WP or WPTT	11	6	N/A[b]	N/A	Omitted from analysis
WPTT derailment	Operator causes WPTT to derail	8, 10	5, 6	N/A[a, b]	N/A	Historic data
WPTT uncontrolled tilt-down	Operator causes an uncontrolled tilt down of the WPTT	10	6	N/A[b]	N/A	Omitted from analysis

NOTE: [a] Historical data was used to produce a probability for this HFE – this is not covered as part of the HRA, but is rather addressed in Attachment C, Section C1.3.

[b] These HFEs were initially identified, but omitted from analysis for various reasons, including a design change precluding the human failure, or the failure would require a series of unsafe actions in combination with mechanical failures, such that the event is no longer credible. See the appropriate HFE group in Attachment E for a case-by-case justification for these omissions.

CTM = canister transfer machine; CTT = cask transfer trolley; ESD = event sequence diagram; HFE = human failure event; HLW = high-level radioactive waste; IHF = Initial Handling Facility; MAP = mobile access platform; N/A = not applicable; OA = over arching (applies to multiple HFE groups); RC = railcar; SSC = structure, system, or component; SSCs = structures, systems, and components; TEV = transport and emplacement vehicle; TT = truck trailer; WP = waste package; WPTT = waste package transfer trolley.

Source: Original (Attachment E, Table E7-1)

6.5 FIRE INITIATING EVENTS

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

Fire initiating event frequencies have been calculated for each initiating event identified for the IHF. Section F5 of Attachment F details the analysis performed to determine these frequencies, using the methodology described in Section F4 of Attachment F.

6.5.1 Input to Initiating Events

Room and building areas, ignition frequencies, ignition source distributions, propagation probabilities, and residence fractions are the set of calculated values which contribute to calculating initiating event frequencies.

Room dimensions (Section F5.2.1 of Attachment F) are utilized to determine individual room areas and the total building area. The room areas of the IHF are utilized to evaluate the building ignition frequency. From methodology and equations presented in Section F4.3.1 of Attachment F, the building ignition frequency over the 50-year facility operation period of 1.35 is obtained for the IHF (Attachment F, Table F5.2-1). The results of this portion of the analysis are summarized in Table 6.5-1.

As discussed in Sections F4.3.2.1, F5.3, and F5.4 of Attachment F, an industrial building fire can begin as the result of numerous types of ignition sources, which are grouped into nine categories:

1. Electrical equipment
2. HVAC equipment
3. Mechanical process equipment
4. Heat-generating process equipment
5. Torches, welders, and burners
6. Internal combustion engines
7. Office and kitchen equipment
8. Portable and special equipment
9. No equipment involved.

Table 6.5-1. Room Areas and Total Ignition Frequency

Room	Area (m^2)	Room	Area (m^2)
1001	158	1019	16
1002	502	1020	8
1003	41	1021	10
1200 through 1225	694	1022/24/2024	31
1005	467	1023	184
1006	134	1026	40
1007	172	1027	111
1008	86	2001/2010	218
1009	172	2002	58
1012/1011	1301	2003	307
1013	7	2004	149
1014	18	2005	304
1015/31/30/2009/15	69	2006	220
1016/2016	33	2007	23
1017/2017	61	2008	7
1018/2018	56	—	—
Total Area (sq-m)			5.66E+03
Ignition Frequency (per sq-m/yr)			4.79E-06
Ignition Frequency (per yr)			2.71E-02
Ignition Frequency (over 50-year operating life)			1.35E+00

NOTE: m = meter; sq = square; yr = year.

Source: Table F5.2-1 of Attachment F

Each category has a fraction representing the probability that, given an ignition, that category is the source of the ignition. These fractions are combined with the number of units in each category to determine the ignition frequency per ignition source. Uncertainty distributions have been applied to the ignition frequencies, and contribute to the resulting distribution for fire initiating event frequencies. The number of ignition sources in each category is further divided by location into specific rooms. Each piece of equipment in a category is defined as one ignition source, with some exceptions:

- Motor control centers, load centers, and equipment racks contribute an ignition source for each active vertical cabinet
- An ignition source is counted for each motor over 5 hp for all equipment with motors
- A welding ignition source is counted for each hour of operation expected per year

- The ignition sources for mobile equipment are split between the rooms the equipment occupies in proportion to the amount of time the equipment will spend in each room
- An ignition source is counted for every square meter in the room for the no equipment involved category.

The distribution and determination of ignition sources is further discussed in Section F5.4 of Attachment F, and summarized in Table 6.5-2. Because the no equipment involved category ignition sources are equal to the square meters values (available in Table 6.5-1), and because there is no equipment for any of the facilities that falls under the heat-generating process equipment category (F5.4.4), those categories are not presented in the summary Table 6.5-2.

Table 6.5-2. Ignition Source Category and Room-by-Room Population

Room	Electrical	HVAC	Mechanical Equipment	Torches, Welders, Burners	Internal Combustion Engines	Office/ Kitchen Equipment	Portable Equipment
1001	—	—	—	—	—	—	1
1002	95	4	—	—	—	—	2
1003	2		—	—	—	—	—
1200 through 1225	—	2	—	—	—	9	—
1005	1	2	12.04	5	—	—	2
1006	—	—	4.88	—	—	—	1
1007	—	—	0.08	—	—	—	1
1008	—	—	1.03	—	—	—	1
1009	—	—	—	5	—	—	2
1012/1011	1	4	23.97	15	100	—	4
1013	1	—	—	—	—	—	—
1015/31/30/2009/15	—	—	1	—	—	—	—
1016/2016	—	—	—	—	—	—	—
1017/2017	—	—	—	—	—	—	—
1018/2018	—	—	—	—	—	—	—
1019	—	—	1	—	—	—	—
1020	—	—	1	—	—	—	—
1021	—	—	1	—	—	—	—
1022/24/2024	—	—	1	—	—	—	—
1023	15	—	4	400	—	—	—
1026	—	—	—	—	—	—	—
1027	—	—	—	—	—	—	—
2001	6	2	—	—	—	1	—
2002	13	—	—	—	—	—	1
2003	—	3	—	—	—	—	1
2004	—	—	6	117	—	—	2

Table 6.5-2. Ignition Source Category and Room-by-Room Population (Continued)

Room	Electrical	HVAC	Mechanical Equipment	Torches, Welders, Burners	Internal Combustion Engines	Office/ Kitchen Equipment	Portable Equipment
2005	1	—	7	—	—	—	1
2006	1	—	—	—	—	—	1
2007	1	—	—	—	—	—	—
2008	—	—	—	—	—	—	—
TOTAL	**137**	**23**	**64**	**542**	**100**	**10**	**20**

NOTE: HVAC = heating, ventilation, and air conditioning.

Source: Table F5.5-1 of Attachment F

Propagation probabilities (Section F5.6, Attachment F) are utilized in the analysis to define the probability of a fire spreading to various points specifically identified as areas in which a waste form may be vulnerable. Uncertainty distributions have been applied to the propagation probabilities, and contribute to the resulting distribution for fire initiating even frequencies.

Residence fractions (Section F5.7.1, Attachment F) developed from process throughputs define the length of time (in minutes), a waste form will be vulnerable in a particular area of the building and in a particular configuration. The minutes are converted to the fraction of time the vulnerability is present over the 50-year operating life of the surface facilities, and are summarized in Table 6.5-3.

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 6.5-4. The frequencies represent the probability, over the length of the preclosure surface operation period, that a fire will threaten the stated waste container in the stated location. Initiating event frequencies are divided into two types of calculations, localized fires and large fires, and are calculated for all locations associated with waste handling operations and locations from which a fire can spread to a waste handling operational location. (In Attachment F, these locations are sometimes called vulnerabilities.). Calculations performed to obtain the initiating event are detailed in Section F5.7 of Attachment F.

Uncertainty distributions are utilized in the contribution to initiating event frequency calculations to account statistical uncertainty in the data. Uncertainty distributions utilized for this analysis are lognormal distribution and normal distribution. The normal distribution can be accurately represented by a mean and 97.5% value, the lognormal distribution is represented by a median (50%) and 97.5% value. The mean and median can be inputs to calculate the error factor (EF). The 97.5 percent value is a figure that represents a point at which only 2.5 percent of all possible outcomes will vary from the mean more significantly. Three uncertainty distributions were developed for this analysis, details for which are in Appendices F.II and F.III of Attachment F.

Monte Carlo simulations are performed to determine the mean, median, standard deviation, variance, minimum, and maximum values of each of the initiating event frequencies based on the variance of the contributing data. To accomplish this, the Microsoft Excel add-on package Crystal Ball™ is used (Attachment F, Sections F5.6 and F5.8). This software requires input of two parameters (e.g., in the lognormal case, 50% and 97.5% values), and the figures that the simulation will produce results for (initiating event frequencies). Crystal Ball software allows probability distributions to be combined per formulas or equations representing initiating event frequency inputs entered into Excel. The software randomly selects a value from the possibilities defined by the distribution. This is set within the software to be done 10,000 times to ensure accurate results. Ten-thousand Monte Carlo trials are performed.

Crystal Ball is run for all of the initiating events, the complete output of which is available in Appendix VI of Attachment F. In addition to showing the initiating event frequency distribution, the full output also shows the input distribution for the parameters that are varied, which match the distributions developed and documented in Appendices F.II and F.III of Attachment F.

Table 6.5-3. Residence Fractions

Initiating Event	Residence Fraction
Waste Form in WPTT in Loadout Room	
WP/Naval SNF in WPTT in Loadout Room	5.8E-06
WP/HLW in WPTT in Loadout Room	5.8E-06
Waste Form in WP in TEV in Loadout Room	
WP/Naval SNF in WPTT in TEV in Loadout Room	1.0E-06
WP/HLW in WPTT in TEV in Loadout Room	1.0E-06
Waste Form in Unloading Room	
TC/Naval SNF in Unloading Room	3.2E-06
Threatens TC/HLW in Unloading Room	6.0E-06
Waste Form in Positioning and Closure Rooms	
WP/Naval SNF in Positioning and Closure Rooms	2.7E-04
WP/HLW in Positioning and Closure Rooms	2.7E-04
Waste Form in Loading Room	
WP/Naval SNF in Loading Room	6.2E-06
Threatens WP/HLW in Loading Room	2.0E-04
Waste Form in CTT in Cask Preparation Area	
TC/Naval SNF in CTT in Cask Preparation Area	2.3E-05
TC/HLW in CTT in Cask Preparation Area	9.6E-06
Waste Form on Railcar in the Cask Preparation Area w/ SPM (Diesel Present)	
TC/Naval SNF on Railcar in the Cask Preparation Area w/ SPM (Diesel Present)	1.8E-06
TC/HLW on Railcar in the Cask Preparation Area w/ SPM (Diesel Present)	1.2E-06
Waste Form on Railcar in the Cask Preparation Area w/o SPM (No Diesel Present)	
TC/Naval SNF on Railcar in the Cask Preparation Area w/o SPM (No Diesel Present)	2.0E-5
TC/HLW on Railcar in the Cask Preparation Area w/o SPM (No Diesel Present)	9.4E-06

Table 6.5-3. Residence Fractions (Continued)

Initiating Event	Residence Fraction
Waste Form in CTM in Transfer Room	
Naval SNF in CTM in Transfer Room	1.3E-06
HLW in CTM in Transfer Room	1.1E-06
Large Fire Residence Categories	
TC/Naval SNF w/ SPM (Diesel Present)	1.8E-06
TC/Naval SNF w/o SPM (No Diesel Present)	4.6E-05
Naval SNF in CTM	9.5E-07
Naval SNF in WP	2.8E-04
TC/HLW w/ SPM (Diesel Present)	1.2E-06
TC/HLW w/o SPM (No Diesel Present)	2.4E-05
HLW in CTM	7.4E-06
HLW in WP	4.8E-04

NOTE: CTT = cask transfer trolley; CTM = canister transfer machine; HLW = high-level radioactive waste; SNF = spent nuclear fuel; SPM = site prime mover; TC = transportation cask; TEV = transportation emplacement vehicle; WP = waste package; WPTT = waste package transfer trolley.

Source: Tables F5.7-1 and F5.7-2 of Attachment F

Table 6.5-4. Results from Monte Carlo Simulation of Fire Initiating Event Frequency Distributions

Initiating Event	Equipment	Mean	Median	97.5% Value	EF	Type
Localized Fire Threatens Waste Form in WPTT in Loadout Room	WPTT					
Localized Fire Threatens WP/NSNF in WPTT in Loadout Room		4.9E-07	4.5E-07	1.1E-06	2.1E+00	Lognormal
Localized Fire Threatens WP/HLW in WPTT in Loadout Room		4.9E-07	4.5E-07	1.1E-06	2.1E+00	Lognormal
Localized Fire Threatens Waste Form in WP in TEV Loadout Room	TEV					
Localized Fire Threatens WP/NSNF in TEV in Loadout Room		8.8E-08	7.9E-08	1.9E-07	2.1E+00	Lognormal
Localized Fire Threatens WP/HLW in TEV in Loadout Room		8.8E-08	7.9E-08	1.9E-07	2.1E+00	Lognormal
Localized Fire Threatens Waste Form in Unloading Room	CTT					
Localized Fire Threatens TC/NSNF in Unloading Room		1.2E-08	1.1E-08	2.7E-08	2.2E+00	Lognormal
Localized Fire Threatens TC/HLW in Unloading Room		2.2E-08	2.0E-08	5.1E-08	2.2E+00	Lognormal

Table 6.5-4. Results from Monte Carlo Simulation of Fire Initiating Event Frequency Distributions (Continued)

Localized Fire Threatens Waste Form in Positioning Room	WPTT					
Localized Fire Threatens WP/NSNF in Positioning Room		3.8E-05	3.4E-05	8.3E-05	2.1E+00	Lognormal
Localized Fire Threatens WP/HLW in Positioning Room		3.8E-05	3.4E-05	8.4E-05	2.1E+00	Lognormal
Localized Fire Threatens Waste Form in Loading Room	WPTT					
Localized Fire Threatens WP/NSNF in Loading Room		3.5E-07	3.1E-07	8.5E-07	2.3E+00	Lognormal
Localized Fire Threatens WP/HLW in Loading Room		1.2E-05	1.0E-05	2.8E-05	2.3E+00	Lognormal
Localized Fire Threatens Waste Form in CTT in Cask Preparation Area	CTT					
Localized Fire Threatens TC/NSNF in CTT in Cask Preparation Area		1.3E-06	1.1E-06	3.1E-06	2.3E+00	Lognormal
Localized Fire Threatens TC/HLW in CTT in Cask Preparation Area		5.3E-07	4.6E-07	1.3E-06	2.3E+00	Lognormal
Localized Fire Threatens Waste Form on Railcar in the Cask Preparation Area w/SPM (Diesel Present)	RC					
Localized Fire Threatens TC/NSNF on railcar in the Cask Preparation Area w/SPM (diesel present)		2.3E-07	2.1E-07	5.1E-07	2.1E+00	Lognormal
Localized Fire Threatens TC/HLW on railcar in the Cask Preparation Area w/SPM (diesel present)		1.5E-07	1.4E-07	3.5E-07	2.1E+00	Lognormal
Localized Fire Threatens Waste Form on Railcar in the Cask Preparation Area w/o SPM (No Diesel Present)	RC					
Localized Fire Threatens TC/NSNF on railcar in the Cask Preparation Area w/o SPM (no diesel present)		2.0E-06	1.8E-06	4.5E-06	2.2E+00	Lognormal
Localized fire threatens TC/HLW on railcar in the Cask Preparation Area w/o SPM (no diesel present)		9.3E-07	8.3E-07	2.1E-06	2.2E+00	Lognormal
Localized Fire Threatens Waste Form in CTM in Transfer Room	CTM					
Localized Fire Threatens NSNF in CTM in Transfer Room		8.1E-08	7.1E-08	1.9E-07	2.3E+00	Lognormal
Localized Fire Threatens HLW in CTM in Transfer Room		6.9E-08	6.1E-08	1.7E-07	2.2E+00	Lognormal
Large Fire Threatens TC/NSNF (Diesel)	—	3.7E-07	3.3E-07	8.7E-07	2.2E+00	Lognormal
Large Fire Threatens TC/NSNF (No Diesel)	—	9.7E-06	8.6E-06	2.3E-05	2.2E+00	Lognormal
Large Fire Threatens NSNF in CTM	—	2.0E-07	1.8E-07	4.7E-07	2.2E+00	Lognormal

Table 6.5-4. Results from Monte Carlo Simulation of Fire Initiating Event Frequency Distributions (Continued)

Large Fire Threatens NSNF in WP	—	5.9E-05	5.3E-05	1.4E-04	2.2E+00	Lognormal
Large Fire Threatens TC/HLW (Diesel)	—	2.5E-07	2.2E-07	5.8E-07	2.2E+00	Lognormal
Large Fire Threatens TC/HLW (No Diesel)	—	5.1E-06	4.5E-06	1.2E-05	2.2E+00	Lognormal
Large Fire Threatens HLW in CTM	—	1.6E-06	1.4E-06	3.7E-06	2.2E+00	Lognormal
Large Fire Threatens HLW in WP	—	1.0E-04	9.1E-05	2.4E-04	2.2E+00	Lognormal

NOTE: CTT = cask transfer trolley; CTM = canister transfer machine; HLW = high-level radioactive waste; NSNF = naval spent nuclear fuel; RC = railcar; SPM = site prime mover; TC = transportation cask; TEV = transport and emplacement vehicle; WP = waste package; WPTT = waste package transfer trolley.

Source: Table F5.7-6 of Attachment F

Table 6.5-5 provides the fire analysis data for the basic events in this model.

Table 6.5-5. Basic Events Data Associated with Fire Analysis

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	References
51A-HLW-FREQ WITH DIESEL	Relative Frequency with Diesel Present	2.30E-03	Based on the fire frequency analysis, this value represents relative frequency an HLW canister is possibly subjected to a large facility fire with diesel present.	Table 6.3-10 (13)
51A-HLW-FREQ-NO-DIESEL	Relative Frequency with no Diesel Present	4.67E-02	Based on the fire frequency analysis, this value represents the relative frequency an HLW canister is possibly subjected to a large facility fire without diesel present.	Table 6.3-10 (14)
51A-HLW-FREQ-WODIESEL	Relative Frequency of WP in Large Fire without Diesel	9.37E-01	Based on the fire frequency analysis, this value represents the relative frequency a WP is subject to a possible large facility fire without diesel present.	Table 6.3-10 (17)
51A-HLW-FREQ-WP-FAILS	Relative Frequency of WP in Large Fire	9.37E-01	Based on the fire frequency analysis. This value represents the fraction of time an HLW WP is in the IHF.	Table 6.3-10 (16)
51A-HLW-LARGE-FIRE-CTM	Relative Frequency of Large Fire in CTM	1.45E-02	Based on fire frequency analysis. Large facility fire threatens HLW canister inside the CTM.	Table 6.3-10 (15)
51A-PROB-HLWCAN-WP-LOR	Probability HLW Canister in WP in Loadout Room	1.51E-01	Based on fire frequency analysis. Fire threatens WP with HLW canister in Loadout room.	Table 6.3-10 (12)
51A-HLWSPMRC-DIESEL	Fire in Prep Area SPMRC with Diesel	9.61E-02	Based on the fire frequency analysis, this value represents the failure of the HLW canister in a Cask Prep Area fire when diesel is present.	Table 6.3-10 (9)
51A-HLWSPMRC-WODIESEL	Fire in Prep Area SPMRC Without Diesel	9.04E-01	Based on the fire frequency analysis, this value represents the failure of the HLW canister in a Cask Prep Area fire when no diesel is present on the SPMRC.	Table 6.3-10 (10)
51A-PROB-HLWCAN-WPTT-LOR	Probability HLW Canister in WPTT in Loadout Room	8.49E-01	Based on fire frequency analysis. Fire threatens WPTT with HLW canister in Loadout room.	Table 6.3-10 (11)
51A-NVL-FREQ-DIESEL	Relative Frequency with Diesel Present	5.35E-03	Based on the fire frequency analysis. Large facility fire when diesel is present threatens naval cask inside the IHF.	Table 6.3-10 (5)
51A-NVL-FREQ-NO-DIESEL	Relative Frequency without Diesel Present	1.39E-01	Based on the fire frequency analysis. Large facility fire when no diesel is present threatens naval cask inside the IHF.	Table 6.3-10 (6)
51A-NVL-FREQ-WP-FAILS	Relative Frequency WP Fails due to Fire	8.53E-01	Based on fire frequency analysis. Large facility fire threatens naval canister inside the IHF.	Table 6.3-10 (8)

Table 6.5-5 Basic Events Data Associated with Fire Analysis (Continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	References
51A-NVL-LARGE-FIRE-CTM	Relative Frequency of Large Fire in CTM	2.91E-03	Based on fire frequency analysis. Large facility fire threatens naval canister inside the CTM.	Table 6.3-10 (7)
51A-NVL-SPMRC-WODIESEL	Fire in Preparation Area without Diesel	9.35E-01	Based on Fire frequency analysis. Fire threatens naval transportation cask after SPM has left cask preparation room.	Table 6.3-10 (2)
51A-NVL-SPMRC-DIESEL	Fire in Preparation Area SPMRC with Diesel	6.53E-02	Based on Fire frequency analysis. Fire threatens naval transportation cask while SPM is present in cask preparation room.	Table 6.3-10 (1)
51A-PROB-NVLCAN-WP-LOR	Probability NVL Canister in WP in Loadout Room	1.51E-01	Based on fire frequency analysis. Fire threatens WP with Naval canister in Loadout room.	Table 6.3-10 (4)
51A-PROB-NVLCAN-WPTT-LOR	Probability NVL Canister in WPTT in Loadout Room	8.49E-01	Based on fire frequency analysis. Fire threatens WPTT with Naval canister in Loadout room.	Table 6.3-10 (3)

NOTE: IHF =Initial Handling Facility; CTM = canister transfer machine; HLW = high-level radioactive waste; SPMRC = site prime mover railcar; TC= transportation cask; WP =waste package; WPTT = waste package transfer trolley.

Source: Original