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

Basic Event Name	Basic Event Description	SAPHIRE Calculation Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate[b]	Mission Time (Hours)
GRB-STH					
800-HEE0-GEARBXC-GRB-STH	Common-cause failure of TEV gearboxes	C	1.54E-08	7.12E-01	4
800-HEE0-INTRLCK-IEL-FOH	Interlock Failure - TEV door interlock	3	1.37E-04	3.43E-05	4
800-HEE0-JACK000-SJK-CCF	Screw jack CCF failure	C	1.22E-06	—	—
800-HEE0-JACK001-SJK-FOH	TEV screw jack failure	3	3.26E-05	8.14E-06	4
800-HEE0-JACK002-SJK-FOH	TEV screw jack failure	3	3.26E-05	8.14E-06	4
800-HEE0-JACK003-SJK-FOH	TEV screw jack failure	3	3.26E-05	8.14E-06	4
800-HEE0-JACK004-SJK-FOH	TEV screw jack failure	3	3.26E-05	8.14E-06	4
800-HEE0-LIFT000-LRG-CCF	Common-cause failure of at least two lifting rig/hooks	C	1.11E-07	—	—
800-HEE0-LIFT001-LRG-FOH	Lifting rig or hook failure	3	2.98E-06	7.45E-07	4
800-HEE0-LIFT002-LRG-FOH	Lifting rig or hook failure	3	2.98E-06	7.45E-07	4
800-HEE0-LIFT003-LRG-FOH	Lifting rig or hook failure	3	2.98E-06	7.45E-07	4
800-HEE0-LIFT004-LRG-FOH	Lifting rig or hook failure	3	2.98E-06	7.45E-07	4
800-HEE0-MOTACT1-ATP-SPO	Actuator spurious op - TEV motor	3	1.34E-06	1.34E-06	1
800-HEE0-MOTACT2-ATP-SPO	Actuator spurious op - TEV motor	3	1.34E-06	1.34E-06	1
800-HEE0-MOTACT3-ATP-SPO	Actuator spurious op - TEV motor	3	1.34E-06	1.34E-06	1
800-HEE0-MOTACT4-ATP-SPO	Actuator spurious op - TEV motor	3	1.34E-06	1.34E-06	1
800-HEE0-MOTACT5-ATP-SPO	Actuator spurious op - TEV motor	3	1.34E-06	1.34E-06	1
800-HEE0-MOTACT6-ATP-SPO	Actuator spurious op - TEV motor	3	1.34E-06	1.34E-06	1
800-HEE0-MOTACT7-ATP-SPO	Actuator spurious op - TEV motor	3	1.34E-06	1.34E-06	1
800-HEE0-MOTACT8-ATP-SPO	Actuator spurious op - TEV motor	3	1.34E-06	1.34E-06	1
800-HEE0-MOTACTC-ATP-CCF	CCF - TEV motor actuation	C	6.07E-09	—	—
800-HEE0-MOTOR01-	Motor (electric) fails to	3	5.40E-08	1.35E-08	4

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

Basic Event Name	Basic Event Description	SAPHIRE Calculation Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate[b]	Mission Time (Hours)
MOE-FSO	shut off				
800-HEE0-MOTOR02-MOE-FSO	Motor (electric) fails to shut off	3	5.40E-08	1.35E-08	4
800-HEE0-MOTOR03-MOE-FSO	Motor (electric) fails to shut off	3	5.40E-08	1.35E-08	4
800-HEE0-MOTOR04-MOE-FSO	Motor (electric) fails to shut off	3	5.40E-08	1.35E-08	4
800-HEE0-MOTOR05-MOE-FSO	Motor (electric) fails to shut off	3	5.40E-08	1.35E-08	4
800-HEE0-MOTOR06-MOE-FSO	Motor (Electric) Fails to Shut Off	3	5.40E-08	1.35E-08	4
800-HEE0-MOTOR07-MOE-FSO	Motor (electric) fails to shut off	3	5.40E-08	1.35E-08	4
800-HEE0-MOTOR08-MOE-FSO	Motor (electric) fails to shut off	3	5.40E-08	1.35E-08	4
800-HEE0-PLCDOOR-PLC-SPO	PLC spurious op - TEV doors	3	1.46E-06	3.65E-07	4
800-HEE0-PLCLDR1-PLC-SPO	Drive controller - PLC spurious op	3	1.46E-06	3.65E-07	4
800-HEE0-PLCRETR-PLC-SPO	PLC spurious op - WP retrieval controller	3	3.65E-07	3.65E-07	1
800-HEE0-PLCSPD1-PLC-SPO	Speed controller - PLC spurious op	3	1.46E-06	3.65E-07	4
800-HEE0-ROTARY1-ECP-FOH	TEV position encoder failure - 1	3	7.16E-06	1.79E-06	4
800-HEE0-ROTARY2-ECP-FOH	TEV position encoder failure - 2	3	7.16E-06	1.79E-06	4
800-HEE0-ROTARY3-ECP-FOH	TEV position encoder failure - 3	3	7.16E-06	1.79E-06	4
800-HEE0-ROTARY4-ECP-FOH	TEV position encoder failure - 4	3	7.16E-06	1.79E-06	4
800-HEE0-ROTARY5-ECP-FOH	TEV position encoder failure - 5	3	7.16E-06	1.79E-06	4
800-HEE0-ROTARY6-ECP-FOH	TEV position encoder failure - 6	3	7.16E-06	1.79E-06	4
800-HEE0-ROTARY7-ECP-FOH	TEV position encoder failure - 7	3	7.16E-06	1.79E-06	4
800-HEE0-ROTARY8-ECP-FOH	TEV position encoder failure - 8	3	7.16E-06	1.79E-06	4
800-HEE0-ROTARYC-ECP-CCF	Common-cause failure of 8 rotary encoders	C	3.24E-08	1.60E-08	4
800-HEE0-SHTBLT0-PIN-CCF	Common-cause failure of 2 or more TEV shot bolts	C	<1.00E-09	—	—
800-HEE0-SHTBLT1-PIN-FOH	TEV shot bolt 1 fails	3	3.29E-08	8.23E-09	4

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

Basic Event Name	Basic Event Description	SAPHIRE Calculation Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate[b]	Mission Time (Hours)
800-HEE0-SHTBLT2-PIN-FOH	TEV shot bolt 2 Fails	3	3.29E-08	8.23E-09	4
800-HEE0-SHTBLT3-PIN-FOH	TEV shot bolt 3 Fails	3	3.29E-08	8.23E-09	4
800-HEE0-SHTBLT4-PIN-FOH	TEV shot bolt 4 Fails	3	3.29E-08	8.23E-09	4
800-HEE0-SPSHFC-AXL-CCF	Common-cause failure of spline shaft (8 of 8)	C	3.14E-09	1.40E-01	4
800-SD---SRU001--SRU-FOH	Shield door ultrasonic obstruction sensor fails	3	9.62E-05	9.62E-05	1
800-TEV1-ECP0001-ECP-FOH	Position encoder failure	3	7.16E-06	1.79E-06	4
800-TEV1-ECP0002-ECP-FOH	Position encoder failure	3	7.16E-06	1.79E-06	4
800-TEV1-ECP0003-ECP-FOH	Position encoder failure	3	7.16E-06	1.79E-06	4
800-TEV1-ECP0004-ECP-FOH	Position encoder failure	3	7.16E-06	1.79E-06	4
800-TEV1-ECP0005-ECP-FOH	Position encoder failure	3	7.16E-06	1.79E-06	4
800-TEV1-ECP0006-ECP-FOH	Position encoder failure	3	7.16E-06	1.79E-06	4
800-TEV1-ECP0007-ECP-FOH	Position encoder failure	3	7.16E-06	1.79E-06	4
800-TEV1-ECP0008-ECP-FOH	Position encoder failure	3	7.16E-06	1.79E-06	4
800-TEV1-HNDSWCH-SEL-FOH	Speed selector fails – hand switch included	3	1.66E-05	4.16E-06	4
800-TEV1-SRS0001-SRS-FOH	Over speed sensor fails	3	8.56E-05	2.14E-05	4
800-TEV1-SRS0002-SRS-FOH	Over speed sensor fails	3	8.56E-05	2.14E-05	4
800-TEV1-SRS0003-SRS-FOH	Over speed sensor fails	3	8.56E-05	2.14E-05	4
800-TEV1-SRS0004-SRS-FOH	Over speed sensor fails	3	8.56E-05	2.14E-05	4
800-TEV1-SRS0005-SRS-FOH	Over speed sensor fails	3	8.56E-05	2.14E-05	4
800-TEV1-SRS0006-SRS-FOH	Over speed sensor fails	3	8.56E-05	2.14E-05	4
800-TEV1-SRS0007-SRS-FOH	Over speed sensor fails	3	8.56E-05	2.14E-05	4
800-TEV1-SRS0008-SRS-FOH	Over speed sensor fails	3	8.56E-05	2.14E-05	4

NOTE: [a]The relevant SAPHIRE calculation types are as follows: (1) For failure on demand, the value specified is used

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

Basic Event Name	Basic Event Description	SAPHIRE Calculation Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate[b]	Mission Time (Hours)

directly as the basic event mean failure probability. (3) For failure 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. (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. 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.

AC = alternating current; AHU = air-handling unit; CCF = common-cause failure; CRCF = Canister Receipt and Closure Facility; CTM = canister transfer machine; DG = diesel generator; elec = electrical; exh = exhaust; HEPA = high-efficiency particulate air; ITS = important to safety; MCC = motor control center; PLC = programmable logic controller; rad = radiation; SFP = spent nuclear fuel pool; SPMRC = site prime mover railcar; SPMTT = site prime mover truck trailer; ST = site transporter; WP = waste package; WPTT = waste package transfer trolley; xfer = transfer.

SOURCE: SAPHIRE model results using input from Attachment C, including Sections C3 and 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. 2.2.73), 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, Section D1. The methodology is applicable to all of the waste containers that are processed, 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. 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, Section D1. Loss of containment probability analysis has been evaluated for various containers by three different studies:

- *Seismic and Structural Container Analysis for the PCSA* (Ref. 2.2.39)
- *Structural Analysis Results of the DOE SNF Canisters Subjected to the 23-foot Vertical Repository Drop Event to Support Probabilistic Risk Evaluations* (Ref. 2.2.82) and *Qualitative Analysis of the Standardized DOE SNF Canister for Specific Canister-on-Canister Drop Events at the Repository* (Ref. 2.2.81)
- *Naval Long Waste Package Vertical Impact on Emplacement Pallet and Invert* (Ref.2.2.25).

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.

The failure probability associated with a drop of a waste package is summarized in Table 6.3-2. In calculations involving container failure probabilities due to drops, 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 lift. Lawrence Livermore National Laboratory (LLNL) predicts failure probabilities of $<1.0 \times 10^{-8}$ for most of the events (Ref. 2.2.39). 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 are 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. 2.2.39). 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.

Probability of failure is conservatively calculated by comparing the peak strain to the cumulative distribution function derived from tensile strain to failure test 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

Component	Drop Height (ft)	Failure Probability	Note
Waste package	2	1.0×10^{-5}	BSC FEA, horizontal orientation

NOTE: BSC = Bechtel SAIC Company, LLC; FEA = finite element analysis; ft = feet.

Source: Attachment D, Table D1.4-1

Containment failure probabilities due to other physical impact conditions, equivalent to drops, are listed in Table 6.3-3. These probabilities were modeled by LLNL using FEA, resulting in prediction of failure probabilities of $<1.0 \times 10^{-8}$. 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 $< 1.0 \times 10^{-8}$ 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
Tip over	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: ft/min = feet per minute; 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 miles per hour (mph) or feet per minute (ft/min) is converted to feet per second (ft/sec), then to an equivalent drop height in feet. The drop heights are very small compared with the drop height for the modeled situation 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 that 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.

$$P = \int_{-\infty}^{x} N(t)\,dt \quad and \quad x = \frac{H_d/H_m - 1}{COV} \qquad \text{(Eq. 19)}$$

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.

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 less than 1×10^{-8} are listed, although a value of 1×10^{-5} is conservatively used (as before). The failure probability for the two-blocking drop height of 30 feet for the high level waste canister was determined in Attachment D, Section D1.3. For the multicanister overpack (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 a drop from the height associated with two-blocking is a very low probability event and will have a probability that is no higher than that for a drop during normal operation. The design features that ensure that this probability is achievable include the closure of the slide gate and two levels of shut-off switches if the normal lift height is exceeded, as well as a tension relief device that prevents over-tensioning of the 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.

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

Collision Scenario	Speed	Velocity (ft/sec)	Equivalent Drop Height (ft) [a]	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	N/A	N/A	N/A	N/A
Truck trailer	2.5 (mph)	3.67	0.21	1.00E-08	N/A	N/A	N/A	N/A
Crane	20 (ft/min)	0.33	0.00	1.00E-08	N/A	N/A	N/A	N/A
CTT	10 (ft/min)	0.17	0.00	1.00E-08	1.00E-08	N/A	1.00E-08	1.00E-08
ST	2.5 (mph)	3.67	0.21	N/A	1.00E-08	N/A	1.00E-08	1.00E-08
WPTT	40 (ft/min)	0.67	0.01	N/A	1.00E-08	1.00E-08	1.00E-08	1.00E-08
WP (in TEV)	1.7 (mph)	2.49	0.10	N/A	N/A	1.00E-08	N/A	N/A
CTM	20 (ft/min)	0.33	0.00	N/A	1.00E-08	N/A	1.00E-08	1.00E-08
CTM	40 (ft/min)	0.67	0.01	N/A	1.00E-08	N/A	1.00E-08	1.00E-08
Two-blocking	N/A	N/A	N/A	1.00E-04	1.00E-05	N/A	1.00E+00	1.40E-02

NOTE: [a]Calculated as follows based on constant acceleration due to gravity (no air resistance): $v^2/(2 \times 32.2\ \text{ft/sec}^2)$, where v is the velocity in ft/sec. Values are rounded to the nearest hundredth of a ft.
CTM = canister transfer machine; CTT = cask transfer trolley; ft = feet; MCO = multicanister overpack; min = minutes; mph = miles per hour; N/A = not applicable; sec = second; ST = site transporter; TEV = transport and emplacement vehicle; WP =waste package; WPTT = waste package transfer trolley.

Source: Attachment D

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 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-walled canister in a waste package[a]	3.2×10^{-4}	5.7×10^{-5}
Thick-walled 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-Defense HLW/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.

Source: Attachment D, Table D2.1-8

Note that a failure probability is not provided for a bare canister configuration since the canister is not contained in a waste package or cask for only a short period of 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 is sufficient inflow of air to sustain a large fire that could heat a significant portion of the canister wall. There may be sufficient inflow to sustain a localized fire, but such a fire would not be adequate to heat the canister to failure.

The canister is also outside of a cask, 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 is in this configuration is extremely short, a matter of minutes, so a fire that occurs during this time is extremely unlikely. In addition, because the gap between the top of the 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 is exposed to the fire. Furthermore, this exposure would only be for the short time that the canister was in motion.

For these reasons, failure of a bare canister was not considered credible and is not explicitly modeled in the PCSA.

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. 2.2.12). These calculations consider a range of decay heat levels and a loss of cooling for 30 days. These analyses indicate that the canister temperature would remain well below 500°C (773 K) (Ref. 2.2.12). This temperature is hundreds of degrees below the temperature at which the canister would fail (see Attachment D, Figure D2.1-4). 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 is summarized in Table 6.3-6.

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. Only those items used in the WHF are discussed further.

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 NUREG/CR-6672 (Ref. 2.2.83), 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 also 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.

The PCSA treats the degradation or loss of shielding of an SSC due to a thermal challenge as described in the following paragraphs.

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

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

If the thermal challenge is not sufficiently severe to cause a loss of containment function, it is nevertheless postulated that it will cause shielding loss of the transportation cask, shielded transfer cask, canister transfer machine, or cask transfer trolley affected by the thermal challenge and in which the waste 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 these SSCs is unlikely to be affected by a credible fire. Although credible fires could result in the lead melting in a lead-sandwich transportation cask, there is no way to displace the lead, unless the fire is accompanied by a puncture or rupture of the outer steel wall of the cask. Preliminary calculations were unable to disprove the possibility of hydraulic failure of the steel encasing due to the thermal expansion of molten lead, so loss of gamma shielding for steel-lead-steel transportation casks engulfed in fire is postulated. Conservatively, in the PCSA, transportation casks and shielded transfer casks are postulated to lose their shielding function with a probability of one, regardless of whether or not they use lead for shielding.

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

Table 6.3-6. Probabilities of Degradation or Loss of Shielding

Event	Probability	Note
Sealed transportation cask and shielded transfer casks shielding degradation after structural challenge	1×10^{-5}	Section D, Section D3.4.
Aging overpack shielding loss after structural challenge	5×10^{-6}	Section D, Section D3.4
CTM shielding loss after structural challenge	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.
Shielded loss by fire for aging overpacks and CTM shield bell	0	Type of concrete used for aging overpacks is not sensitive to spallation; Uranium used in CTM shield bell shielding does not lose its shielding function as a result of a fire.

NOTE: CTM = canister transfer machine; STC shielded transfer cask.

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 events were obtained by extrapolation from developed probabilities as described in this section or in Attachment D. The derivation of all passive failure probabilities is described in Attachment D and shown in *PEFA Chart.xls* included in Attachment H.

It is noted that Table 6.3-7 address 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 WHF. The probability of each basic event is based on one of the values presented in Tables 6.3-2 through 6.3-7.

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Table 6.3-7. Summary of Passive Event Failure Probabilities

EVENT: COMPONENT	10 T DROPPED ON CONTAINER	CONTAINER VERTICAL DROP FROM NORMAL OPERATING HEIGHT	CONTAINER 30-FOOT VERTICAL DROP	CONTAINER 45-FOOT VERTICAL DROP	2-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: 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	N/A	No challenge	3.E-04	1.E-04
Loss of shielding: TEV	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: MPH = miles per hour; N/A = not applicable, no scenarios identified; TEV = transport and emplacement vehicle.

Source: Attachment D

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

Basic Event ID	Basic Event	Basic Event Description	Basic Event Value	Basis
SSO-ESD-01-CRCF	WP impact facility shield door (sequence 2)	Failure of waste package due to facility shield door impact	1.00E-08	Table 6.3-7. WP 2.5-mph flat side impact
	TEV shielding (sequences 2, 3, 4, 5, 6)	Loss of gamma shielding	0.00E+00	No challenge to TEV gamma shielding due to physical impact
	Canister containment (sequences 2, 3, 4, 5, 6)	Canister containment fails when WP containment fails	1.00E+00	No credit taken for canister containment when waste package fails, so conditional probability set to 1
	WP impact TEV shield door (sequence 3)	Failure of waste package due to TEV shield door impact	1.00E-08	Table 6.3-7. WP 2.5 mph flat side impact
	WP TEV collision (sequence 4)	Failure of waste package due to TEV collision	1.00E-08	Table 6.3-7. WP 2.5 mph flat side collision
	WP drop (sequence 5)	Failure of waste package due to drop of waste package	1.00E-05	Table 6.3-7. WP horizontal drop
	Heavy load drop on WP (sequence 6)	Failure of waste package due to drop of heavy load onto waste package	1.00E-05	Table 6.3-7. 10 T dropped on WP
SSO-ESD-01 - IHF	WP impact facility shield door (sequence 2)	Failure of waste package due to facility shield door impact	1.00E-08	Table 6.3-7. WP 2.5 mph flat side impact
	TEV shielding (sequences 2, 3, 4, 5, 6)	Loss of gamma shielding for canister	0.00E+00	No challenge to TEV gamma shielding due to physical impact
	Canister containment (sequences 2, 3, 4, 5, 6)	Canister containment fails when TEV containment fails	1.00E+00	No credit taken for canister containment when waste package fails
	WP impact TEV shield door (sequence 3)	Failure of waste package due to TEV shield door impact	1.00E-08	Table 6.3-7. WP 2.5 mph flat side impact
	WP TEV collision (sequence 4)	Failure of waste package due to TEV collision	1.00E-08	Table 6.3-7. WP 2.5 mph flat side collision
	WP drop (sequence 5)	Failure of waste package due to drop of waste package	1.00E-05	Table 6.3-7. WP horizontal drop
	Heavy load drop on WP (sequence 6)	Failure of waste package due to drop of heavy load onto waste package	1.00E-05	Table 6.3-7. 10 T dropped on WP

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

Basic Event ID	Basic Event	Basic Event Description	Basic Event Value	Basis
SSO-ESD-02	TEV impact (sequence 2)	Failure of WP due to TEV impact, collision, or derailment	1.00E-08	Table 6.3-7. WP 2.5 mph flat side collision
	TEV shielding (sequences 2, 3, 4, 5)	Loss of gamma shielding	0.00E+00	No challenge to TEV gamma shielding due to physical impact
	Canister containment (sequences 2, 3, 4, 5)	Canister containment fails when WP containment fails	1.00E+00	No credit taken for canister containment when waste package fails, so conditional probability set to 1
	TEV impact during transit (sequence 3)	Failure of WP due to TEV impact during transit	1.00E-08	Table 6.3-7. WP 2.5 mph flat side collision
	WP drop during transit (sequence 4)	Failure of waste package due to drop of waste package during transit	1.00E-05	Table 6.3-7. WP horizontal drop
	Heavy load drop on TEV (sequence 5)	Failure of waste package due to drop of heavy load onto TEV	1.00E-05	Table 6.3-7. 10 T dropped on WP
SSO-ESD-03	TEV impact (sequence 2)	Failure of WP due to TEV impact, collision, or derailment	1.00E-08	Table 6.3-7. WP 2.5 mph flat side collision
	TEV shielding (sequences 2, 3, 4, 5, 6, 7)	Loss of gamma shielding	0.00E+00	No challenge to TEV gamma shielding due to physical impact
	Canister containment (sequences 2, 3, 4, 5, 6, 7)	Canister containment fails when WP containment fails	1.00E+00	No credit taken for canister containment when waste package fails, so conditional probability set to 1
	Direct impact to WP – collision (sequence 3)	Waste package containment fails due to direct impact during collision	1.00E-08	Table 6.3-7. WP 2.5 mph flat side collision
	Drop or drag of WP (sequence 4)	Waste package fails due to drop or drag	1.00E-05	Table 6.3-7. WP horizontal drop
	Heavy load drop on TEV (sequence 5)	Failure of waste package due to drop of heavy load onto TEV	1.00E-05	Table 6.3-7. 10 T dropped on WP
	WP impact due to TEV doors (sequence 6)	Failure of waste package due to impact by TEV doors	1.00E-08	Table 6.3-7. WP 2.5 mph flat side impact
	Heavy load drop on WP (sequence 7)	Failure of waste package due to drop of heavy load onto WP	1.00E-05	Table 6.3-7. 10 T dropped on WP

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

Basic Event ID	Basic Event	Basic Event Description	Basic Event Value	Basis
SSO-ESD-04	Inadvertent entry No passive equipment failure (sequence 2)	Worker exposure due to inadvertent entry into active drift	—	—
	Prolonged worker proximity No passive equipment failure (sequence 3)	Worker exposure due to prolonged stay in proximity to TEV	—	—
	Inadvertent TEV door opening No passive equipment failure (sequence 4)	Worker exposure due to inadvertent opening of TEV shield door	—	—
	Loss of movement loss of shielding (sequence 5)	Loss of gamma shielding due to loss of TEV movement	0.00E+00	No challenge to TEV gamma shielding due to prolonged exposure to sun (see Section 6.0)
SSO-ESD-05	TEV fire affects WP (sequences 2, 3, 4)	Waste package failure due to fire engulfing TEV in drift	1.00E+00	Canister failure causes WP failure, so conditional probability set to 1
	TEV shielding (sequences 2, 3, 4)	Loss of gamma shielding	0.00E+00	No challenge to TEV gamma shielding due to fire
	Canister containment (sequences 2, 3, 4)	Canister containment fails when WP containment fails	3.20E-04	Thin-walled canister failure due to fire

NOTE: Refer to Attachment D for discussion.
mph = miles per hour; T = ton; TEV = transport and emplacement vehicle; WP = waste package.

Source: Original

6.3.3 Miscellaneous Data

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 Table 6.3-9.

Table 6.3-9. Miscellaneous Data Used In the Reliability Analysis

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	References
No. of WPs	Number of waste packages	12,268	This basic event represents the number of waste packages emplaced during the preclosure period. The value for this basic event is obtained by adding the number of waste packages from the CRCF (11,668) and from the IHF (600) which is documented in the throughput analysis. However the throughput analysis also shows a total number of waste packages of 12,068 assigned for the subsurface operations. The value of 12,268 used here is a conservative estimate.	(Ref. 2.2.31) (Analyzed a value greater than listed in the reference.)
800-TRANSIT-ROCKFALL	Rockfall probability (captured in seismic analysis)	0.00E+00	Rockfall impacting the TEV or WP is analyzed in the seismic analysis, and thus, no further analysis is evaluated in this report. The sequence is screened from further analysis, and the basic event is set to 0.	(Ref. 2.4.4)
ROCKFALL-ON-WP	Rockfall on WP in drift (bound by seismic anal.)	0.00E+00	Rockfall impacting the TEV or WP is analyzed in the seismic analysis, and thus, no further analysis is evaluated in this report. The sequence is screened from further analysis, and the basic event is set to 0.	(Ref. 2.4.4)
ROCKFALL-TEV	Rockfall on TEV subsurface (addressed in seismic)	0.00E+00	Rockfall impacting the TEV or WP is analyzed in the seismic analysis, and thus, no further analysis is evaluated in this report. The sequence is screened from further analysis, and the basic event is set to 0.	(Ref. 2.4.4)
FIRE-IN-DRIFT	Large Fire in the drift (total frequency divided by 3)	3.0E-07	Large fire frequency of 9E-7 (fire/ operations) is equally contributed by a large fire occurring in the three areas where the TEV and the WP might be present. Thus, the large fire frequency in the drift is 1/3 of the total large fire frequency or 3E-7 (fire/operations)	Section 6.5

Table 6.3-9. Miscellaneous Data Used In the Reliability Analysis (continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	References
FIRE-IN-SUBSURFACE	Large fire in subsurface (total fire frequency divided by 3)	3.0E-07	Large fire frequency of 9E-7 (fire/ operations) is equally contributed by a large fire occurring in the three areas where the TEV and the WP might be present. Thus, the large fire frequency in subsurface is 1/3 of the total large fire frequency or 3E-7 (fire/operations)	Section 6.5
FIRE-ON-SURFACE	Large fire on the surface (total fire frequency divided by 3)	3.0E-07	Large fire frequency of 9E-7 (fire/ operations) is equally contributed by a large fire occurring in the three areas where the TEV and the WP might be present. Thus, the large fire frequency on the surface is 1/3 of the total large fire frequency or 3E-7 (fire/operations).	Section 6.5
060-VCTO-DRS0000-DRS-OPN	Vestibule door open during receipt/export	1.60E-04	During receipt of a transportation cask or aging overpack or during the export of a waste package or aging overpack, delta pressure is lost for a period of time not to exceed 7 minutes per event (this is a conservative estimate of the time it will take for the HVAC system to return the vestibule to a negative pressure). This occurs as a direct consequence of opening vestibule doors to allow the site transporter, the site prime mover or the transport and emplacement vehicle.	Attachment B, Section B2

Table 6.3-9. Miscellaneous Data Used In the Reliability Analysis (continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	References
800-TRANSIT-TIME	Transit time from entrance to emplacement drift in yrs	2.20E-04	This basic event represents the transit time between the facility and the drift, which is estimated at 2 hours or 2.2E-4 year. This is based on an average TEV speed of 150 feet per minute and a longest distance of 3.4 miles.	(Ref. 2.2.27) and (Ref. 2.2.24)
26D-#EEY-ITSDG-A-#DG-MTN	ITS DG A OOS maintenance	1.95E-03	Diesel generator A out of service for maintenance.	Attachment B, Section B3
26D-#EEY-ITSDG-B-#DG-MTN	ITS DG B OOS maintenance	1.95E-03	Diesel generator B out of service for maintenance.	Attachment B, Section B3
LOSP	Loss of offsite power	2.99E-03	Frequency of loss of off site power 3.6E-2/yr or 4.1E-6/hr, multiplied by 720 hours (30 days) for diesels in HVAC system.	(Ref. 2.2.48), (Ref. 2.2.33, Attachment B, Sections B7 and B8)
060-VCTO-TRAINB-MAINT	Train B HVAC is off-line for maintenance	4.57E-03	Value based on 40 hr of unavailability due to maintenance per year (8,760 hr).	Attachment B, Section B2
060-EXCESSIVE-WIND-SPEED	Sustained wind exceeds 40 mph & gust to 90 mph	4.70E-03	Sustained wind with speed exceeding 40 mph and gust to 90 mph has an estimated frequency of 5.7E-02 per yr, and with a mission time of 720 hours, the probability of such an occurrence is 4.7E-3.	(Ref. 2.2.30)
060-VCOO-NITS-PWR-FAILS	Non-ITS power failure to CRCF supply fan	3.54E-02	This basic event is the loss of offsite power frequency given in NUREG/CR-6890.	(Ref. 2.2.48)
DSG-MILES	Miles drip shield gantry travels	1.00E-01	This value represents the number of miles that the drip shield gantry will travel in subsurface during normal operations.	Attachment B, Section B1

Table 6.3-9. Miscellaneous Data Used In the Reliability Analysis (continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	References
TEV-CONTROL-MANUAL	TEV is operating in manual mode	1.00E-01	Although the TEV operations are totally conducted remotely and controlled by the DCMIS, there are occasions that manual controls of TEV may be required. Thus, it is conservatively assigned a fraction of 10% of the TEV operations is conducted manually.	Attachment B, Section B1
TEV-DECLINE	TEV on decline	5.00E-01	The longest distance between the entrance and the emplacement drift is 3.4 miles (Ref. 2.2.28) or (3.4 miles × 5,280 ft/mile) about 18,000 ft. Based on Ref. 2.2.95, the incline from the entrance to the end of the incline is about 2,642 m or about 8,700 ft. Thus, the fraction of the incline in relation to the total subsurface distance is (8,700 ft / 18,000 ft) 0.48 or about 0.5	(Ref. 2.2.28) and (Ref. 2.2.24). (Ref.2.2.11, Page 15)
060-VCTO-CONTDOORS-OPEN	Vestibule doors open receipt or export from CRCF	1.00E+00	Set as "TRUE" that the vestibule doors are open during receipt or export of a TC or AO	Attachment B, Section B2
TEV-DERAIL-MILES-SURF	Miles travelled by TEV on surface	2.00E+00	This value represents the number of miles that the TEV will travel on the surface during normal operations.	(Ref. 2.2.32)

Table 6.3-9. Miscellaneous Data Used In the Reliability Analysis (continued)

Basic Event (BE) ID	Basic Event Description	BE Value	Bases	References
TEV-DERAIL-MILES-DRIFT	Miles travelled by TEV in subsurface	4.00E+00	This value represents the number of miles that the TEV will travel in subsurface during normal operations. The distance is 3.4 miles, but it is conservatively rounded up to 4 miles	(Ref. 2.2.28) and (Ref. 2.2.24).
MODERATOR - CRCF	Moderator present	2.10E-05	This value is based on either water or oil being present as a potential moderator while the WP is in the CRCF. Water moderator sources other than inadvertent actuation of the fire suppression system are estimated at 2E-5 for the CRCF. Another water source in the CRCF is the inadvertent actuation of the fire suppression system, which has a calculated probability of 1E-6. The value of Moderator is the sum of these two moderator sources.	Section 6.2.2.8
MODERATOR - IHF	Moderator present	1.50E-03	This value is based on either water or oil being present as a potential moderator while the WP is in the IHF. Water moderator sources other than inadvertent actuation of the fire suppression system are estimated at 1.4E-3 for the IHF. Another water source in the IHF is the inadvertent actuation of the fire suppression system, which has a calculated probability of 9E-7. The value of Moderator is the sum of these two moderator sources.	Section 6.2.2.8
Generic mission time	Generic mission time	720 hrs	Under most all scenarios identified in the reliability analysis for this facility, post accident response time is limited to 720 hours per ISG-03 and NUREG 0800. Thus, all systems that are required to function during post accident period are assigned with a mission time of 720 hours.	(Ref. 2.2.67), (Ref. 2.2.89)

NOTE: BE = basic event; CRCF = Canister Receipt and Closure Facility; DG = diesel generator; HVAC = heating, ventilation, and air conditioning; IHF = Initial Handling Facility; ITS = important to safety; LOSP = loss of offsite power; mph = miles per hour; WP = waste package; TEV = transport and emplacement vehicle.

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 HRA Scope

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

1. HFEs are only considered if they contribute to a scenario that has the potential to result in a release of radioactivity, a criticality event, or a radiation exposure to workers. Such scenarios may include the need for mitigation of radionuclides, 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 surface transportation of empty TEVs when there are no loaded TEVs on the surface).

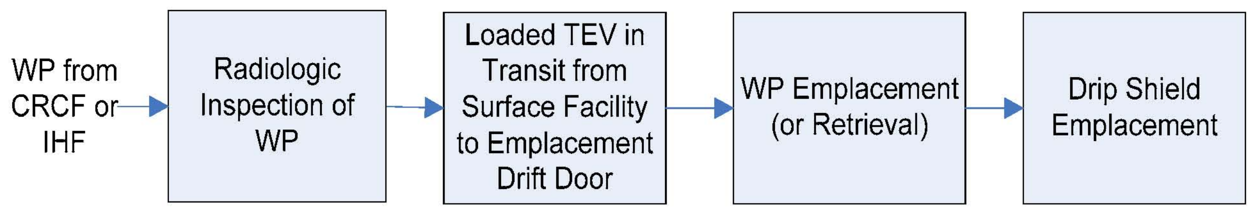
4. The exception to #3 is that system-level HFEs are considered for support systems (e.g., electrical power for confinement HVAC) when those HFEs could result in a loss of a safety function related to the occurrence or consequences associated with the events specified in #1.

5. Post-initiator 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 4.2.10.1 (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 subsurface 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. Subsurface operations are significantly less complicated than a set of facility operations; therefore, the entire set of subsurface operations is analyzed as one group of operations. Figure E6.4-1 below provides an overview of subsurface operations.



NOTE: CRCF = Canister Receipt and Closure Facility; IHF = Initial Handling Facility; TEV = transport and emplacement vehicle; WP = waste package.

Source: Original

Figure 6.4-1. Subsurface Operations

For each block of Figure 6.4-1, a base case scenario is developed and documented. The base case scenario represents the most 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, procedural controls, etc.).

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

[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.

after an initiating event and there are no actions identified that could exacerbate the consequences of an initiating event. This stems from the definitions and modeling of initiating events and subsequent pivotal events as described in Section 6.1 and Attachment A. All initiating events are proximal causes of either radionuclide release or direct exposure to 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 subject matter experts (i.e., from the Engineering and Operations departments) were interviewed in conjunction with examination of the engineering design drawings, concept of operations document and other available documentation. 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.

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.

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

6.4.5 Detailed Analysis

Detailed HRA quantification is performed for those HFEs that were found in dominant event sequences after the initial fault tree or event sequence quantification. The preliminary values were sufficient to demonstrate compliance with the performance objectives of 10 CFR 63.111 (Ref. 2.3.2); therefore no detailed analyses were performed for this HRA.

6.4.6 Human Failure Event Probabilities used in Subsurface Event Sequences Analysis

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

Table 6.4-1. Human Failure Event Probability Summary

Basic Event Name	HFE Description	ESD	Basic Event Mean Probability	Error Factor	Type of Analysis
060-#EEE-LDCNTRA-BUA-ROE	Operator fails to restore load center A post maintenance	1	1.03E−05	10	Preliminary
060-#EEE-LDCNTRB-BUA-ROE	Operator fails to restore load center B post maintenance	1	1.03E−05	10	Preliminary
060-VCTO-DR00001-HFI-NOD	Operators open two or more vestibule doors in CRCF	1	1E−02	3	Preliminary
060-VCTO-HFIA000-HFI-NOM	Human error: exhaust fan switch in wrong position	1	1E−01	3	Preliminary
060-VCTO-HEPALK-HFI-NOD	Operator fails to notice HEPA filter leak in train A	1	1.0	N/A	Preliminary
26D-#EEY-ITSDG-A-#DG-RSS	Operator fails to restore diesel generator A to service	1	1.95E−04	10	Preliminary
26D-#EEY-ITSDG-B-#DG-RSS	Operator fails to restore diesel generator B to service	1	1.95E−04	10	Preliminary

Table 6.4-1. Human Failure Event Probability Summary (Continued)

Basic Event Name	HFE Description	ESD	Basic Event Mean Probability	Error Factor	Type of Analysis
800-HEE0-WKRDRFT-HFI-NOD	Worker enters drift from access main	4	N/A[b]	N/A	Omitted from analysis
800-HEE0-WKRPROX-HFI-NOD	Worker stands too close to TEV for an extended period of time	4	N/A[b]	N/A	Omitted from analysis
800-HEE0-WKRFACD-HFI-NOD	Operator causes collision of TEV with facility doors	1	2.0E−03	5	Preliminary
800-HEE0-SIDEIMP-HFI-NOW	Operator causes collision of TEV with SSC	2	3.0E−04	10	Preliminary
800-HEE0-TEVDOOR-HFI-NOD	Human error causes TEV doors to open during transit	4	1.0E−03	5	Preliminary
800-HEE0-AXSDR00-HFI-NOD	Operator causes collision of TEV with access doors	2, 3	2.0E−03	5	Preliminary
800-HEE0-IMPACT-HFI-NOD	Human error causes TEV to impact WP in the drift	3	1.0E−03	5	Preliminary
Drip shield emplacement	Operator error causes impact to WP during drip shield emplacement	3	N/A[b]	N/A	Omitted from analysis
HFE-RUNAWAY-RESPONSE	Operator fails to stop TEV using manual override during a runaway event	1, 2, 3	N/A[b]	N/A	Omitted from analysis
OP-FAILS-ENDOFRAIL	Operator error causes TEV to run over end of rail	2, 3	1.0E−03	5	Preliminary
TEV derailment	Operator causes TEV to derail as it travels between the facility and the drifts	2, 3	N/A [a, b]	N/A	Historical data

NOTE: [a]HRA value replaced by use of historic data (see Attachment C on active component failure data).
[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.
CRCF = Canister Receipt and Closure Facility; ESD = event sequence diagram; HEPA = high-efficiency particulate air filter; HFE = human failure event; N/A = not applicable; SSC = structure, system, or component; TEV = transport and emplacement vehicle; WP = waste package.

Source: Original

6.5 FIRE INITIATING EVENTS

Attachment F of this document describes the work scope, definitions and terms, method, and results for the fire analysis performed as 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. 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 subsurface operations. 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

Frequency of vehicle fire per operation and the number of movements of waste forms on site are the values that contribute to calculating initiating event frequencies. An uncertainty distribution is applied to the ignition frequency, and contributes to the resulting distribution for fire initiating event frequencies. The uncertainty distribution is determined by using a team judgment process.

6.5.2 Initiating Event Frequencies

The result of the fire initiating event analysis is the fire initiating event frequency and its associated distribution, as presented in Table 6.5-1. The frequency represents the probability, over the length of the pre-closure surface operation period, that a fire will threaten the stated waste form during onsite transportation. Calculations performed to obtain the initiating event frequency are detailed in Section F5.2 of Attachment F.

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

Table 6.5-1. Fire Initiating Event Frequency Distributions

Initiating Event	Mean frequency (per 50 years)	Error Factor	Distribution
Fire Threatens a Waste Form During Onsite Transport	9.0E-07 fires/operation	15	Lognormal

Source: Original

6.6 NOT USED

6.7 EVENT SEQUENCE FREQUENCY RESULTS

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

The section presents a summary of how the quantification is performed by the use of event trees, fault trees, and basic event input parameters. The discussion includes the rationale for truncating low values and analyzing uncertainties.

The results include a summary of all event sequences that are quantified and a table summarizing the results of the final quantification (found in Attachment G).

6.7.1 Process for Event Sequence Quantification

Internal event sequences that are based on the event trees presented in Section 6.1 and fault trees presented in Section 6.2 are quantified as follows. The fault tree quantification was performed using SAPHIRE; the event sequences, on the other hand, are quantified using Excel spreadsheets (Section 4.3). The quantification of an event sequence consists of calculating the number of occurrences over the preclosure period by combining frequencies of each initiating event with the conditional probabilities of pivotal events that comprise the sequence. The quantification results are presented as an expression of the mean number of occurrences of each event sequence over the preclosure period (Attachment G, Table G-1).

The event sequence quantification methodology is presented in Section 4.3.6. An event sequence frequency is the product of several factors, as follows (with examples):

- The number of times the operation or activity that gives rise to the event sequence is performed over the preclosure period, for example, the total number of emplacements of a waste package by a TEV over the preclosure period. In the Excel spreadsheet, this number is entered in the first column of the initiator event tree from which the event sequence arises or in the first event of the system-response event tree if no initiator event tree exists.

- The probability of occurrence of the initiating event for the event sequence considered. Continuing with the previous example, this could be the probability of dropping a waste package during its transfer to the TEV in the CRCF Waste Package Loadout Room, or the probability of occurrence of a fire that could affect the waste package in the drift. The initiating event probability is modeled in SAPHIRE with a fault tree or with a basic event. In an initiator event tree, this probability is assigned on the branch associated with the event sequence as a direct input to the Excel spreadsheet. If no initiator event tree exists, this probability is entered in the second event of the system-response event tree.

- The conditional probability of each of the pivotal events of the event sequence, which appear in the system-response event tree. The pivotal event may represent a passive failure such as the breach of the containment boundary of the waste package or canister or an active system failure such as the unavailability of the HVAC system. If the conditional probability of the pivotal event is represented as a mean value with a probability distribution or a point estimate (such as a passive failure estimate), it is entered directly into the Excel spreadsheet. On the other hand, if the pivotal event is modeled as a fault tree, the fault tree model is solved and the results are input into the spreadsheet.

Uncertainties in input parameters such as throughput rates, equipment failure rates, passive failure probabilities, and human failure events used to calculate basic event probabilities are propagated through the fault tree and event sequence logic to quantify the uncertainty in the event sequence quantification.

To quantify an event sequence, SAPHIRE is used to graphically draw the event tree. Then the event tree logic (i.e., the combination of individual successes and failures of pivotal events after the initiating event) is incorporated into the Excel spreadsheet. Where appropriate, SAPHIRE is then used to solve the fault trees that support the initiating event and the pivotal events and provide results that are used in the event quantification. The frequency for each event sequence is calculated as the product of the initiating event frequency and the pivotal event probabilities.

As an illustration of the above process, the quantification of the event sequences established in the ESD-03 in Table 6.7-1 is as follows: (1) the initiating event (e.g., collision or drop of the waste package) and the number of waste packages handled over the preclosure period, (2) the failure of the waste package, (3) the subsequent failure of the canister, and (4) the potential moderator entry into the canister. This sequence logic is input into the Excel spreadsheet shown in Table 6.7-1. The values associated with each initiating event or pivotal event are then input in the same spreadsheet.

Table 6.7-1. Event Sequence Quantification Example

(Col. 1)	(Col. 2)	(Col. 3)	(Col. 4)			(Col. 5)	(Col. 6)	(Col. 7)	(Col. 8)	(Col. 9)	(Col. 10)	(Col. 11)
Initiating Events (IEs)			IE values			WP Remains Intact	Canister(s) Remain Intact	Moderator excluded from entering canister	Calc'd Mean	Calc'd Median	Calc'd StdDev	End State
	SSO-ESD-03 - SEQ	**No. of WP**	**IE mean** (Col. 4A)	**IE median** (Col. 4B)	**IE Std Dev** (Col. 4C)	**WP**	**CANISTER**	**MODERATOR**	#Waste forms x IE mean x PE Prob			
Pt Values ======>		12,268										
sm. circ1 – TEV impact collision or derail	2-1	12,268	3.02E-03	2.07E-03	3.55E-03	1.00E+00			3.71E+01	2.54E+01	4.35E+01	OK
	2-2					1.00E-08	0.00E+00		0.00E+00	0.00E+00	0.00E+00	OK
	2-3					1.00E-08	1.00E+00	1.00E+00	3.71E-07	2.54E-07	4.35E-07	RRU
	2-4					1.00E-08	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	RRC
sm. circ2 - Direct impact to WP- collision	3-1	12,268	9.90E-04	6.18E-04	1.17E-03	1.00E+00			1.22E+01	7.58E+00	1.43E+01	OK
	3-2					1.00E-08	0.00E+00		0.00E+00	0.00E+00	0.00E+00	OK
	3-3					1.00E-08	1.00E+00	1.00E+00	1.22E-07	7.58E-08	1.43E-07	RRU
	3-4					1.00E-08	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	RRC
sm. circ3 - Drop or drag of WP	4-1	12,268	1.32E-06	4.40E-07	2.51E-06	9.95E-01			1.62E-02	5.40E-03	3.08E-02	OK
	4-2					5.00E-03	0.00E+00		0.00E+00	0.00E+00	0.00E+00	OK
	4-3					5.00E-03	1.00E+00	1.00E+00	1.62E-07	5.40E-08	3.08E-07	RRU
	4-4					5.00E-03	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	RRC
sm. circ4 - Heavy load drop on TEV	5-1	12,268	1.20E-05	8.03E-06	1.31E-05	1.00E+00			0.00E+00	0.00E+00	0.00E+00	OK
	5-2					1.00E-08	0.00E+00		0.00E+00	0.00E+00	0.00E+00	OK
	5-3					1.00E-08	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	RRU
	5-4					1.00E-08	1.00E+00	0.00E+00				RRC
									1.47E-01	9.85E-02	1.61E-01	
sm. circ5 - WP impact due to TEV doors	6-1	12,268	1.20E-05	8.03E-06	1.31E-05	9.95E-01			0.00E+00	0.00E+00	0.00E+00	OK
	6-2					1.00E-08	0.00E+00		1.47E-09	9.85E-10	1.61E-09	OK
	6-3					1.00E-08	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	RRU
	6-4					1.00E-08	1.00E+00	0.00E+00				RRC
									3.40E-04	2.54E-04	3.12E-04	
sm. circ6 - Heavy load drop on WP	7-1	12,268	2.78E-08	2.07E-08	2.55E-08	1.00E+00			0.00E+00	0.00E+00	0.00E+00	OK
	7-2					1.00E-08	0.00E+00		3.40E-09	2.54E-09	3.12E-09	OK
	7-3					1.00E-08	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	RRU
	7-4					1.00E-08	1.00E+00	0.00E+00	1.22E+01	7.58E+00	1.43E+01	RRC

NOTE: Calc'd = calculated; circ = circle; dev = deviation; IE = initiating event; No. = number; OK = okay; Prob = probability; RRC = radiological release, important to criticality; RRU = radiological release, unfiltered; Seq = sequence; sm = small; std = standard; TEV = transport and emplacement vehicle; WP = waste package.
Blank entries in this table are intentional and have been verified as accurate.

Source: Original

INTENTIONALLY LEFT BLANK

Table 6.7-1 provides the following information:

- Column 1: the initiating events depicted as small circles in the ESD and the initiating event tree.

- Column 2: event sequence identification number as "SSO-ESD-03-SEQ-2-1", etc. This identification scheme provides the following information about the event sequence: the ESD it comes from (e.g., SSO-ESD-03) and event sequence from the event tree (e.g., SEQ-2-1), etc.

- Column 3: the number of waste forms during the preclosure period; in this case, the number of waste packages.

- Column 4: values associated with the initiating event which comprise (4a) initiating event mean value, (4b) initiating event median value, (4c) initiating event standard deviation.

- Column 5: the conditional probability of failure accorded to the first pivotal event, "WP", which is defined as "WP remains intact" in the example. The conditional failure probability of "WP" is estimated at 1E-8 for all initiating event, except for the "**sm. bub3** – Drop or drag of WP" initiating event for which the conditional probability of failure of "WP" is estimated at 5E-3.

- Column 6: the conditional probability of failure accorded to the second pivotal event, "CANISTER", which is defined as "Canister(s) remain intact" in this example. The conditional probability of failure for the canister inside the waste package is conservatively estimated at 1, given the waste package failure. If the canister succeeds (not fails) then the end state is OK in Column 11 since there is no radioactive material released.

- Column 7: the conditional probability of failure accorded to the third pivotal event, "MODERATOR", which is defined as "Moderator excluded from entering canister" in this example. The conditional probability of failure for moderator entering the waste package is estimated at 0 since there is no source of moderator available in the proximity of the event sequence location. Given that a canister failure occurs, and no moderator enters the canister, the end state is then labeled as "RRU" in Column 11 for unfiltered radioactive release. However, had there been moderator entering the canister, the end state of the sequence would have been labeled as "RRC" in Column 11 for radioactive release with importance to criticality.

- Column 8: "Calc'd Mean", the mean value of the event sequence estimated by multiplying the number of waste form (value in column 3) by the IE mean value (value in Column 4 – subcolumn A) and by the PE value(s) (value in Column 5, 6 or 7, where appropriate).

- Column 9: "Calc'd Median", the median value of the event sequence estimated by multiplying the number of waste form (value in column 3) by the initiating event median value (value in Column 4 – subcolumn B) and by the pivotal event value(s) (value in Column 5, 6 or 7, where appropriate).

- Column 10: "Calc'd StdDev", the standard deviation value of the event sequence estimated by multiplying the number of waste form (value in column 3) by the initiating event standard deviation value (value in Column 4 – subcolumn C) and by the pivotal event value(s) (value in Column 5, 6 or 7, where appropriate).

- Column 11: "End State" denotes the end state assigned to each event sequence. For example, for event sequence SSO-ESD-03-SEQ-3-3, the assigned end state is RRU, which represents an unfiltered radioactive material release following a failure of waste package(WP), a conditional failure of the canister (CANISTER) due to direct impact to the waste package caused by a collision (initiating event), but no moderator enters the failed canister (/MODERATOR).

As an example, event sequence SSO-ESD-03-SEQ-2-3, which leads to an unfiltered radionuclide release that is not important to criticality, starts with an initiator event tree that depicts the number of waste packages in the TEV in the drift and the initiating events that could occur during the emplacement process over the preclosure period. Based on *Waste Form Throughputs for Preclosure Safety Analysis* (Ref. 2.2.31, Table 4), there are 12,068 such operations; however, to be conservative, 12,268 value was used to match the total number of waste packages from IHF and CRCF. Next, the branch on the initiator event tree that deals with the "TEV impact due to collision or derail" is selected. The fault tree whose top event models the probability of a "TEV impact due to collision or derail" is solved and the results are input into the spreadsheet as Initiating Event mean (Col. 4A), Initiating Event median (Col. 4B) and Initiating Event Std Dev (Col. 4C). Multiplying the number of TEV/waste packages operations in the drift by the probability of a TEV impact per operation yields the number of occurrences, over the preclosure period, of the initiating event for the event sequence considered.

The event quantification continues with the input of event sequence logic from the system-response event tree which provides the basis for quantifying the rest of the event sequence through the use of the pivotal events described in Section 6.1 and Attachment A. First, the breach of the waste package, given an impact to the TEV, is evaluated under the pivotal event called "WP." The analyst ensures that the probability assigned to this pivotal event pertains to the waste form considered in this event sequence – WP; in this example, the passive equipment failure analysis yields a failure probability of 1E-8 for the TEV impact due to collision or derailment. The next pivotal event that appears in the system-response event tree is called "CANISTER." This pivotal event has a probability of one (1), indicating that a canister failure is consider to have occurred if a waste package has failed. Finally, the last pivotal event is called "MODERATOR." This event models moderator intrusion into the breached canister. In the event sequence analyzed, no moderator entry occurs, that is, the success branch is followed. Since there is no ITS air filtering medium available for the drift operations, release of radioactive materials is considered unfiltered, or a "RRU" End State.

The mean event sequence frequency is then obtained by calculating the product of the mean initiating event frequency and the pivotal event probabilities:

(12,268 waste packages/preclosure period) × (3.4E-3 mean impact occurrence/waste packages) × (1E-8 probability of a waste packages failure given a slow speed impact) × (1 canister failure probability given a failure of the waste packages) × (1 probability of no moderator intrusion) = 4.2E-7 occurrence/preclosure period.

As noted, uncertainties in input parameters are propagated through the fault tree and event sequence logic to quantify the uncertainty in the event sequence quantification. The fault tree quantification uncertainty analysis uses the Monte Carlo method that is built into SAPHIRE. The fault tree quantification was analyzed using 10,000 trials. The number of trials is considered sufficient to ensure accurate results for the distribution parameters.

The uncertainty analysis for the event sequence quantification is propagated by multiplying the probability distribution with a series of scalar quantities. For example, the initiating event is normally represented by a probability distribution with a mean, median and standard deviation, where the number of waste packages is a scalar quantity. Thus, for the example above, the event sequence median value is (12,268 × 2.4E-3 × 1E-8 × 1 × 1) = 2.97E-7 with a standard deviation of (12,268 × 3.3E-3 × 1E-8 × 1 × 1) = 4.1E-7.

In the case where the event sequence is comprised of two or more events (initiating or pivotal) that each of them is represented by a probability distribution, the uncertainty propagation for that event sequence is calculated by first, obtaining the uncertainty propagation for the product of the events that have a probability distribution using SAPHIRE software (Section 4.2), and then, multiplying the resulting product (and the calculated probability distribution) with the remaining scalar quantities using the method described above.

6.7.2 Event Sequence Quantification Summary

Table G-1 of Attachment G presents the result of the event sequence quantification. Table G-1 summarizes the results of the event sequence quantification and lists the following elements: (1) the initiating event, (2) the event tree from which the sequence is generated, (3) event sequence designator (ID), (4) event sequence description, (5) event sequence logic, (6) event sequence end state, (7) event sequence mean value, (8) event sequence median value, and (9) event sequence standard deviation value.

6.8 EVENT SEQUENCE GROUPING AND CATEGORIZATION

An aggregation grouping process is applied prior to a categorization of event sequences as was described in Section 4.3.1. It is appropriate for purposes of categorization, to add the frequencies of event sequences that are derived from the same ESD, that elicits the same combination of failure and success of pivotal events, and have the same end state. This is termed final event sequence quantification, discussed in Section 6.8.1, and the results give the final frequency of occurrence. Using the final frequency of occurrence, the event sequences are categorized according to the definition of Category 1 and Category 2 event sequences given in 10 CFR 63.2 (Ref. 2.3.2). Dose consequences for Category 1 and Category 2 event sequences are subject to the performance objectives of 10 CFR 63.111 (Ref. 2.3.2), which is performed in *Preclosure Consequence Analyses* (Ref. 2.2.36). Event sequences with a frequency of occurrence less than one chance in 10,000 of occurring before permanent closure of the repository are designated as Beyond Category 2 event sequences and are not analyzed for dose consequences.

Rather than calculate dose consequences for each Category 2 event sequence identified in the categorization process, dose consequences are performed for a set of bounding events that encompass the end states and material at risk for event sequences. Therefore, dose consequences are determined for a representative set of postulated Category 2 event sequences, identified in Table 6.8-1 (Ref. 2.2.36, Table 2 and Section 7). Once event sequence categorization is complete, Category 2 event sequences are cross referenced with the bounding event number given in Table 6.8-1, thus assuring that Category 2 event sequences have been evaluated for dose consequences and compared to the 10 CFR 63.111 (Ref. 2.3.2) performance objectives.

Table 6.8-1. Bounding Category 2 Event Sequences

Bounding Event Number	Affected Waste Form	Description of End State	Material At Risk
2-01*	LLWF inventory and HEPA filters	Seismic event resulting in LLWF collapse and failure of HEPA filters and ductwork in other facilities.	HEPA filters LLWF inventory
2-02*	HLW canister in transportation cask	Breach of sealed HLW canisters in a sealed transportation cask	5 HLW canisters
2-03*	HLW canister	Breach of sealed HLW canisters in an unsealed waste package	5 HLW canisters
2-04*	HLW canister	Breach of sealed HLW canister during transfer (one drops onto another)	2 HLW canisters
2-05*	Uncanistered commercial SNF in transportation cask	Breach of uncanistered commercial SNF in a sealed truck transportation cask in air	4 PWR or 9 BWR commercial SNF
2-06*	Uncanistered commercial SNF in pool	Breach of uncanistered commercial SNF in an unsealed truck transportation cask in pool	4 PWR or 9 BWR commercial SNF
2-07*	DPC in air	Breach of a sealed DPC in air	36 PWR or 74 BWR commercial SNF
2-08*	DPC in pool	Breach of commercial SNF in unsealed DPC in pool	36 PWR or 74 BWR commercial SNF
2-09*	TAD canister in air	Breach of a sealed TAD canister in air within facility	21 PWR or 44 BWR commercial SNF
2-10*	TAD canister in pool	Breach of commercial SNF in unsealed TAD canister in pool	21 PWR or 44 BWR commercial SNF
2-11*	Uncanistered commercial SNF	Breach of uncanistered commercial SNF assembly in pool (one drops onto another)	2 PWR or 2 BWR commercial SNF
2-12*	Uncanistered commercial SNF	Breach of uncanistered commercial SNF in pool	1 PWR or 1 BWR commercial SNF
2-13*	Combustible and non combustible LLW	Fire involving LLWF inventory	Combustible and non combustible LLW
2-14*	Uncanistered commercial SNF in truck transportation cask	Breach of a sealed truck transportation cask due to a fire	4 PWR or 9 BWR commercial SNF

NOTE: Items marked with an asterisk (*) are not applicable to the Subsurface Operations.
BWR = boiling water reactor; DPC = dual-purpose canister; HEPA = high-efficiency particulate air; HLW = high-level radioactive waste; LLWF = Low-Level Waste Facility; PWR = pressurized water reactor; SNF = spent nuclear fuel; TAD = transportation, aging and disposal.

Source: Ref. 2.2.36, Table 2

6.8.1 Event Sequence Grouping and Final Quantification

Event sequences are modeled to represent the GROA operations and SSCs. Accordingly, an event sequence is unique to a given operational activity in a given operational area, which is depicted in an event sequence diagram. When more than one initiating event (for example, the drop, collision, or other structural challenges that could affect the canister) share the same ESD (and therefore elicit the same pivotal events and the same end states), it may be necessary to quantify the event sequence for each initiating event individually because the conditional probabilities of the pivotal events depend on the specific initiating event. In such cases, the frequencies of event sequences that are represented in the same ESD and have the same end state are added together, thus comprising an event sequence grouping.

By contrast, some ESDs indicate a single initiating event. Such initiating events may be composites of several individual initiating events, but because the conditional probabilities of pivotal events and the end states are the same for each of the constituents, the initiators are grouped before the event sequence quantification.

In the PCSA, this grouping is performed for a given waste form configuration at the event ESD level. Note that the subsurface operations only consider one waste form, which is the waste package.

The grouping of event sequences is carried out by summing "like" event sequences listed in the Excel spreadsheet for each ESD. The event sequence frequencies from this step comprise the final event sequence quantification. Continuing the example listed in Table 6.7-1, the grouping of event sequences is as follows.

Table 6.7-1 listed 6 different initiating events, with each initiating event having 4 event sequences. The end states assigned to the event sequences 1, 2, 3, and 4 for each initiating event are "OK", "OK", "RRU", and "RRC", respectively. Since the end states of the event sequences are the same for each IE, the event sequences are then grouped as follows:

- Event sequence 1 of all initiating events are summed together.
- The summed event sequence, which represents the final event sequence, is then labeled with an event sequence number denoting the ESD where it is originated from (SSO03), the waste form (waste package), the summed sequence number (SEQ1) and the end state given to the original event sequence (OK). For this example, the final event sequence is labeled as SSO03-WP-SEQ1-OK.
- The mean, median and standard deviation values are derived as shown in Section 4.3.1.1. The mean value of the final event sequence is calculated as the sum of the mean value of all event sequences bearing the same end state. The standard deviation value of the final event sequence is calculated as the square root of the sum of the squares of the standard deviation values of all event sequences bearing the same end state. Because the event sequence probability distribution approximates a lognormal, the median is derived from the mean.

The above information is then compiled and listed in Table 6.8-2 below.

Table 6.8-2. Event Sequence Grouping and Quantification Example

End State	Total WP Sequence ID	Mean	Median	Std Dev
OK	SSO03-WP-SEQ1-OK	2.02E+02	3.51E+01	1.71E+02
OK	SSO03-WP-SEQ2-OK	0.00E+00	0.00E+00	0.00E+00
RRU	SSO03-WP-SEQ3-RRU	2.04E-06	4.64E-07	1.71E-06
RRC	SSO03-WP-SEQ4-RRC	0.00E+00	0.00E+00	0.00E+00

NOTE: ID = identification; Std = standard; Dev = deviation; WP = waste package.

Source: Original

6.8.2 Event Sequence Categorization

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

Some event sequences are not directly dependent on the duration of the preclosure period. For example, the expected number of occurrences of waste package drops in subsurface operations over the preclosure period is essentially controlled, among other things, by the number of waste packages and the number of times these waste packages are transported. The duration of the preclosure period is not directly relevant for this event sequence, but implicitly built into the operations. In contrast, for other event sequences, time is a direct input. For example, seismically induced event sequences are evaluated over a period of time. In such cases, event sequences are evaluated and categorized for the time during which they are relevant. Seismically induced event sequences for a surface facility are evaluated over a period of 50 years, because surface facilities are expected to operate for no longer than 50 years (Ref. 2.2.15, Section 2.2.2.7). Seismically induced event sequences for the emplacement drifts are evaluated over the entire preclosure period, which is 100 years (Ref. 2.2.15, Section 2.2.2.7).

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

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

- Other event sequences that have at least one chance in 10,000 of occurring before permanent closure are referred to as Category 2 event sequences (Ref. 2.3.2). Thus, a value of *m* less than one but greater than or equal to 10^{-4}, means the event sequence is a Category 2 event sequence.

- A measure of the probability of occurrence of the event sequence over the preclosure period is given by a Poisson distribution that has a parameter taken equal to *m*. The probability, P, that the event sequence occurs at least one time before permanent closure is the complement to one that the event sequence occurs exactly zero times during the preclosure period. Using the Poisson distribution, $P = 1 - \exp(-m)$ (Ref. 2.2.9, p. A-13). A value of P greater than or equal to 10^{-4} implies the value of m is greater than or equal to $-\ln(1 - P) = -\ln(1 - 10^{-4})$, which is approximately equal to 10^{-4}. Thus, a value of m greater than or equal to 10^{-4}, but less than one, implies the corresponding event sequence is a Category 2 event sequence.

- Event sequences that have a value of m less than 10^{-4} are designated as Beyond Category 2.

An uncertainty analysis is performed on m to determine the main characteristics of its associated probability distribution, specifically the 50th percentile (i.e., the median), and the standard deviation. The uncertainty analysis is performed as described in Section 4.3.6.2.

The calculations carried out to quantify an event sequence are performed using the full precision of the individual probability estimates that are used in the event sequence. However, the categorization of event sequences is based upon the expected number of occurrences over the preclosure period with one significant digit.

6.8.3 Final Event Sequence Quantification Summary

Initially, the results of the event sequence gathering and quantification process are reported in a single table of all event sequences for the subsurface operations (Attachment G, Table G-2). Following the final categorization, the event sequences for the respective Category 2 (Table 6.8-4) and Beyond Category 2 (Attachment G, Table G-3) are tabulated separately. There are no Category 1 (Table 6.8-3) events for the CRCF. As desired, other sorting may be performed. For example, event sequences that have end states important to criticality are tabulated separately (Attachment G, Table G-4).The format of the table headings and content are the same for each table as follows:

1. Event sequence group ID –assigned during the grouping process

2. End state – taken from the event tree

3. Event sequence description – narrative to describe the initiating event(s) and pivotal events that are involved

4. Material at risk – describes the quantity and type of waste form involved

5. Mean event sequence frequency (number of occurrences over the preclosure period)

6. Median event sequence frequency (number of occurrences over the preclosure period)

7. Standard deviation of the event sequence frequency (number of occurrences over the preclosure period)

8. Event sequence category – declaration of Category 1, Category 2, or Beyond Category 2

9. Basis for categorization (e.g., categorization by mean frequency, or from sensitivity study for mean frequencies near a threshold as described in Section 4.3.6.2)

10. Consequence analysis – cross-reference to the bounding event number in the dose consequence analysis (Table 6.8-1) (Ref. 2.2.36, Table 2 and Section 7).

Table 6.8-3. Category 1 Final Event Sequences Summary

Event Sequence Group ID	End State	Description	Material-At-Risk	Mean	Median	Standard Deviation	Event Sequence Categorization	Basis for Categorization	Consequence Analysis
None	—	—	—	—	—	—	—	—	—

NOTE: ID = identification.

Source: Original

Table 6.8-4. Category 2 Final Event Sequences Summary

Event Sequence Group ID	End State	Description	Material-At-Risk	Mean[3]	Median[3]	Std. Dev[3]	Event Sequence Category	Basis for Categorization	Consequence Analysis[1]
SSO05-WP-SEQ3-DEL	Direct exposure, loss of shielding	This event sequence represents a thermal challenge to a canister inside a waste package, due to a fire, resulting in a direct exposure from loss of shielding. In this sequence, the waste package fails, and the canister remains intact.	1 waste package with canister(s) inside	1.E-02	7.E-03	1.E-02	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[2]
SSO04-WP-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a direct exposure due to inadvertent TEV door opening or prolonged immobilization of the TEV in the heat causing a loss of shielding. In this sequence there are no pivotal events.	1 waste package with canister(s) inside	1.E-03	1.E-04	1.E-02	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[2]

NOTE: [1]The bounding event number provided in this column identifies the bounding Category 2 event sequence identified in Table 6.8-1 from *Preclosure Consequence Analyses* (Ref. 2.2.36, Table 2) that results in dose consequences that bound the event sequence under consideration.
[2]Because of the great distances to the locations of the offsite receptors, doses to members of the public from direct radiation after a Category 2 event sequence are reduced by more than 13 orders of magnitude to insignificant levels (Ref. 2.2.22).
[3]The mean, median, and standard deviation displayed are for the number of occurrences, over the preclosure period, of the event sequence under consideration.
N/A = not applicable; TEV = transport and emplacement vehicle.

Source: Original

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

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

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

Section 6.9.1 describes the process for the identification of ITS SSCs; Section 6.9.2 describes the process for the identification of procedural safety controls.

6.9.1 Important to Safety Structures, Systems, and Components

Important to safety is defined in 10 CFR 63.2 (Ref. 2.3.2) as:

> "*Important to safety*, with reference to structures, systems, and components, means those engineered features of the geologic repository operations area whose function is:
>
> (1) To provide reasonable assurance that high-level waste can be received, handled, packaged, stored, emplaced, and retrieved without exceeding the requirements of § 63.111(b)(1) for Category 1 event sequences; or
>
> (2) To prevent or mitigate Category 2 event sequences that could result in radiological exposures exceeding the values specified at § 63.111(b)(2) to any individual located on or beyond any point on the boundary of the site."

Implementation of this regulatory definition of ITS has produced the following specific criteria in the preclosure safety analysis to classify SSCs:

> An SSC is classified as ITS if it appears in an event sequence and at least one of the following criteria apply:
>
> - The SSC is relied upon to reduce the frequency of an event sequence from Category 1 to Category 2
> - The SSC is relied upon to reduce the frequency of an event sequence from Category 2 to Beyond Category 2
> - The SSC is relied upon to reduce the aggregated dose of Category 1 event sequences to levels within the limits specified in 10 CFR 63.111(b)(1) (Ref. 2.3.2)
> - The SSC is relied upon to reduce the frequency or consequences for a Category 2 event sequence to ensure that the risk-based dose is within the limits specified in 10 CFR 63.111(b)(2) (Ref. 2.3.2)
> - The SSC is relied upon to perform a criticality control function.

An SSC is classified as non-ITS if the preceding criteria do not apply. In addition, an SSC is classified as non-ITS if at least one of the following criteria apply:

> - The SSC is relied upon to exclusively perform only the normal operational functions of the repository
> - The SSC performs a defense-in-depth function for which another SSC provides an ITS function.

The classification process involves the selection of the SSCs in the identified event sequences (including event sequences that involve nuclear criticality) that are relied upon to perform the identified safety functions such that the preclosure performance objectives of 10 CFR Part 63 (Ref. 2.3.2) are not exceeded. The ITS classification extends only to the attributes of the SSC involved in providing the ITS function. If one or more components of a system are determined to be ITS, the system is identified as ITS, even though only a portion of the system may actually be relied upon to perform a nuclear safety function. The SSCs classified as ITS for subsurface operations are included in Table 6.9-1.

Design bases are established for the ITS SSCs as described in 10 CFR 63.2 (Ref. 2.3.2):

> "Design bases means that information that identifies the specific functions to be performed by a structure, system, or component of a facility and the specific values or ranges of values chosen for controlling parameters as reference bounds for design. These values may be constraints derived from generally accepted "state-of-the-art" practices for achieving functional goals or requirements derived

> from analysis (based on calculation or experiments) of the effects of a postulated event under which a structure, system, or component must meet its functional goals..."

The safety functions and controlling parameters and values (which together are referred to as the nuclear safety design bases in the PCSA) are developed from the applicable Category 1 and Category 2 event sequences (as applicable) for the SSCs that have been classified as ITS. In general, the controlling parameters and values can be grouped in, but are not limited to, the following categories:

1. Mean frequency of SSC failure: It is demonstrated by analysis that the ITS SSC has a mean frequency of failure of the safety function, with consideration of uncertainties, less than or equal to the stated criterion value.

2. Specific design features (e.g., a designed-in speed limit for ITS equipment).

3. Mean unavailability over time period: It is demonstrated by analysis that the ITS SSC or SSCs (e.g., HVAC and ITS electrical power) will have a mean unavailability over a period of a specified number of days, with consideration of uncertainties, of less than or equal to the criterion value.

These controlling parameters and values and reliability and availability goals ensure that the ITS SSCs perform their identified safety functions such that the 10 CFR Part 63 (Ref. 2.3.2) performance objectives are met. Frequencies and probabilities associated with the controlling parameters and values provide a direct link from the design to the 10 CFR Part 63 (Ref. 2.3.2) requirement for the categorization of event sequences. The parameters and values in Table 6.9-1 are derived from the event sequence analysis for subsurface operations. These values provide reasonable assurance, in some cases with considerable conservatism, that the categorization of event sequences is realized.