6.6 NOT USED

6.7 EVENT SEQUENCE FREQUENCY RESULTS

This section discusses the results of the event sequence quantification as produced from the SAPHIRE (Ref. 2.2.70) analyses. Quantification of an event sequence consists of calculating its number of occurrences over the preclosure period by combining the frequency of a single initiating event with the conditional probabilities of pivotal events that comprise the sequence. The quantification results are presented as an expression of the mean and median number of occurrences of each event sequence over the preclosure period, and the standard deviation as a measure of uncertainty. Section 6.8 describes the process for aggregation of similar event sequences to permit categorization as Category 1, Category 2, or Beyond Category 2 event sequences.

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

The results include a summary of all event sequences that are quantified and four tables summarizing the results of the final quantification (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 using SAPHIRE (Section 4.2) (Ref. 2.2.70). In SAPHIRE, the quantification of an event sequence is always labeled as a "frequency" in the output formats. The quantification also includes the results of the uncertainty analysis of the number of occurrences.

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 transfers of a naval SNF canister by a CTM in the IHF over the preclosure period. In SAPHIRE, this number is entered in the first event 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 naval SNF canister during its transfer by the CTM in the IHF, or the probability of occurrence of a fire that could affect the canister during its transfer by the CTM. 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 that initiating event, through the use of SAPHIRE rules (i.e., textual logic instructions that determine which fault tree or basic event is to be used). 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 canister or an active system failure such as the unavailability of the HVAC system. The conditional event probabilities of pivotal events are linked to the event sequence in SAPHIRE through the linkage to basic events in a fault tree that represents the pivotal event. The selection of pivotal event models and the associated basic event values may be determined by SAPHIRE rules.

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 (Ref. 2.2.70) first establishes the logic of the event sequence (i.e., the combination of individual successes and failures of pivotal events after the initiating event). SAPHIRE then links together the fault trees that support the initiating event and the pivotal events and uses Boolean logic to identify dependencies between the initiating event and the pivotal events and between pivotal events. SAPHIRE finally develops minimal cut sets for the event sequence considered. A minimal cut set for an event sequence is a Boolean reduced combination of a set of basic events that, if it occurs, will cause the event sequence to occur. The event sequence frequency is calculated as the sum of frequencies of the cut sets. For computational efficiency, minimal cut sets that have a frequency less than a cutoff value of 10^{-12} are not calculated by SAPHIRE. Such minimal cut sets are insignificant contributors to the number of occurrences of the event sequence over the preclosure period. This value is considered sufficient to ensure that all significant contributors are identified because it would require the sum of 1×10^{8} cut sets with a probability of occurrence of 1×10^{-12} over the preclosure period to reach the Category 2 threshold frequency of 1×10^{-4} over the preclosure period.

As an illustration of the above process, the quantification of the event sequence initiated by a drop of a HLW canister during a transfer in the IHF, followed by the breach of the canister, the subsequent failure of the HVAC confinement to perform its confinement and filtering function over its mission time, but no moderator entry into the canister, is outlined in the following paragraphs. For IHF, the HVAC system is not required as an ITS system, and is modeled with a failure probability of 1.0.

The event sequence, which leads to an unfiltered radionuclide release that is not important to criticality, starts with an initiator event tree that depicts the number of HLW canisters that are transferred by the CTM in the IHF over the preclosure period. Based on *Waste Form Throughputs for Preclosure Safety Analysis* (Ref. 2.2.26, Table 4), there are 1,000 such transfers. Next, the branch on the initiator event tree that deals with the drop of a canister is selected. In practice, this is done by SAPHIRE through the use of rules, which are assigned to the pivotal event called "INIT-EVENT," the fault tree whose top event models the probability of a HLW canister drop. Multiplying the number of HLW canister transfers by the probability of a drop yields the number of occurrences, over the preclosure period, of the initiating event for the event sequence considered.

SAPHIRE (Ref. 2.2.70) continues the construction of event sequence logic via a transfer to 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 B. First, the breach of the canister, given its drop, is evaluated under the pivotal event called "CANISTER." SAPHIRE rules are used to ensure that the probability assigned to this pivotal event pertains to the waste form considered in this event sequence–a HLW canister. The next event that appears in the system-response event tree is called "SHIELDING." This pivotal event has a probability of one, indicating that a loss of shielding is considered to occur if the canister breaches. This modeling conforms to the approach taken in the PCSA, where event sequences that lead to a radionuclide release also embed direct exposure of personnel to radiation that could result from a loss of shielding. The next pivotal event is called "CONFINEMENT." This event models the failure of HVAC to maintain confinement and perform filtering of the radionuclide release. This pivotal event is quantified with a fault tree. The mission time for the system is 720 hrs (i.e., 30 days). 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.

The SAPHIRE event sequence quantification report includes the number of occurrences of each cut set that contributes to an event sequence and the summation over the cut set to yield a number of occurrences of the event sequence over the preclosure period. The internal processes of SAPHIRE provide quantification of cut sets that represent combinations of basic events from respective initiating event trees and pivotal event tress. The summation over such cut sets represents the cumulative frequency of an initiating event (e.g., drop), containment (e.g., canister) breach, confinement unavailability, and moderator availability.

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 uncertainty analysis uses the Monte Carlo method that is built into SAPHIRE (Ref. 2.2.70). Each event sequence was analyzed using 10,000 trials. The number of trials is considered sufficient to ensure accurate results for the distribution parameters.

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 final quantification and lists the following elements: (1) event tree from which the sequence is generated, (2) SAPHIRE event sequence designator (ID), (3) initiating event description, (4) event sequence logic, (5) event sequence end state, (6) event sequence mean value, (7) event sequence median value, and (8) standard deviation (i.e., event sequence variance).

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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. 2.2.31). Event sequences with a frequency of occurrence less than one chance in 10,000 of occurring before permanent closure of the repository are designated 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 that may occur anywhere within the GROA (Ref. 2.2.31, Table 2 and Section 7). Therefore, dose consequences are determined for a bounding set of postulated Category 2 event sequences, as shown in Table 6.8-1. Because all waste form types and configurations that are applicable to the repository are included in Table 6.8-1, some of the bounding event sequences do not apply to the present analysis. 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 ensuring 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 noncombustible LLW	Fire involving LLWF inventory	Combustible and noncombustible inventory
2-14*	Uncanistered commercial SNF in truck transportation cask	Breach of a sealed truck transportation cask due to a fire	4 PWR or 9 BWR commercial SNF

NOTE: BWR = boiling water reactor; DAW = dry active waste; 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 canister. Items marked with an asterisk (*) are not applicable to the IHF.

Source: *Preclosure Consequence Analyses* (Ref. 2.2.31, Table 2)

6.8.1 Event Sequence Grouping and Final Quantification

Event sequences are modeled to represent the GROA operations and SSCs. Accordingly, an event sequence is unique to a given operational activity in a given operational area, which is depicted in an ESD. When more than one initiating event (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, having the same path through the event tree, and have the same end state are added together, thus comprising an event sequence grouping.

For example, an ESD may show event sequences that could occur during the transfer of a canister from one container to another by the CTM in the IHF. More than one initiating event (for example, the drop, collision, or other structural challenges that could affect the canister) may share the same ESD (and therefore elicit the same pivotal events and the same end states), but give rise to event sequences that are quantified for each initiating event because the conditional probabilities of their pivotal events depend on the specific initiating event.

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

In the PCSA, event sequence grouping is performed for a given waste form configuration at the ESD level. The waste container configurations considered for the IHF are as follows.

- Waste package
- Naval SNF canister, by itself or in a transportation cask
- HLW canister, by itself or in a transportation cask.

In SAPHIRE (Ref. 2.2.70), the grouping of event sequences is carried out using textual instructions, designated as partitioning rules. Partitioning rules gather into a single end state the minimal cut sets from the relevant individual event sequences that need to be grouped together, and further apply a Boolean reduction to ensure that non-minimal cut sets are removed. The event sequence frequencies from this step comprise the final event sequence quantification.

An illustration of the grouping of event sequences is described in the following. The potential structural challenges to a given canister during its transfer by the CTM in the IHF are partitioned among seven different initiating events such as canister drop, collision, drop of a heavy load on the canister, etc. The event sequences involving the canister are quantified separately seven times, once for each initiating event. After an initiating event, the event sequences that elicit the same system-response and lead to the same end state (i.e., those event sequences that follow the same path on the system-response event tree) are grouped together for purposes of categorization. Thus, the seven individual event sequences initiated by a HLW canister drop, collision, etc., that eventually result in a specific end state, for example a filtered (i.e., mitigated) radionuclide release, are grouped together for the purposes of categorization as a single aggregated event sequence with a unique name termed the “event sequence group ID”. Since there are five different end states that can lead to exposure of personnel to radiation (i.e., result in an end state other than “OK”), there are five aggregated event sequences involving the HLW canister, each having a unique name. The frequency of each of the five aggregated event sequences represents the sum of frequencies of the seven individual event sequences.

The uncertainties in the grouped event sequences are generated by SAPHIRE as described in Section 6.7. The logic of the grouped event sequences is applied to recalculate the output probability distribution from the input parameters such as throughput rates, equipment failure rates, passive failure probabilities, and HFEs used to calculate basic event probabilities. These probability distributions are propagated through the fault tree and event sequence logic to quantify the uncertainty in the event sequence quantification.

6.8.2 Event Sequence Categorization

Based on the calculated 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 frequency or 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 HLW canister drops in the IHF over the preclosure period is essentially controlled, among other things, by the number of HLW canisters and the number of lifts of these canisters. The duration of the preclosure period is not directly relevant for this event sequence, but is 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.

Using the parameter *m* to represent the frequency or expected number of occurrences of a given event sequence over the preclosure period, 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. 2.2.10, p. A-3). 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 mean 50th percentile (i.e., the median), and the standard deviation. The uncertainty analysis is performed in SAPHIRE, using the Monte Carlo technique with 10,000 samples 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 the event sequence is based upon the expected number of occurrences over the preclosure period given with one significant digit.

6.8.3 Final Event Sequence Quantification Summary

Initially, the results of the SAPHIRE event sequence gathering and quantification process are reported in a single table of all event sequences for the IHF (Attachment G, Table G-2). Following the final categorization, the event sequences for the respective Category 2 (Table 6.8-3) and Beyond Category 2 (Attachment G, Table G-3) are tabulated separately. There are no Category 1 (Table 6.8-2) event sequences for the IHF. 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 in SAPHIRE.

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. 2.2.31, Table 2 and Section 7).

Table 6.8-2. Category 1 Final Event Sequences Summary

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

Source: Original

Table 6.8-3. Category 2 Final Event Sequences Summary

Event Sequence Group ID	End State	Description	Material-At-Risk[3]	Mean[4]	Median[4]	Std. Dev[4]	Event Sequence Category	Basis for Categorization	Consequence Analysis[1]
ESD12B-NVL-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a direct exposure during preparation activities of a transportation cask containing a naval SNF canister, or during assembly and closure of a waste package containing a naval SNF canister. In this sequence there are no pivotal events.	1 naval SNF canister	2.E-01	1.E-01	1.E-01	Category 2	Mean of distribution for number of occurrences of event sequence near a category threshold. Categorization confirmed by alternative distribution	N/A[2]
ESD13-NVL-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a thermal challenge to a naval SNF canister inside a transportation cask, due to a fire, resulting in a direct exposure from loss of shielding. In this sequence the canister remains intact, and the shielding fails.	1 naval SNF canister	3.E-02	3.E-02	1.E-02	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[2]
ESD12B-HLW-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a direct exposure during assembly and closure of a waste package containing HLW canisters. In this sequence there are no pivotal events.	5 HLW canisters	2.E-02	2.E-02	2.E-04	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[2]

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

Event Sequence Group ID	End State	Description	Material-At-Risk[3]	Mean[4]	Median[4]	Std. Dev[4]	Event Sequence Category	Basis for Categorization	Consequence Analysis[1]
ESD12C-NVL-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a direct exposure during export of a waste package containing a naval SNF canister. In this sequence there are no pivotal events.	1 naval SNF canister	1.E-02	4.E-03	2.E-02	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[2]
ESD07-HLW-SEQ5-RRU	Radionuclide release, unfiltered	This event sequence represents a structural challenge to an HLW canister, during canister transfer by the CTM, resulting in an unfiltered radionuclide release. In this sequence the canister fails, the confinement boundary is not relied upon, and moderator is excluded from entering the canister.	2 HLW canisters	7.E-03	5.E-03	7.E-03	Category 2	Mean of distribution for number of occurrences of event sequence	2-04
ESD12C-HLW-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a direct exposure during export of a waste package containing HLW canisters. In this sequence there are no pivotal events.	5 HLW canisters	6.E-03	2.E-03	1.E-02	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[2]
ESD12A-HLW-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a temporary loss of shielding during CTM operations, while an HLW canister is being transferred. In this sequence there are no pivotal events.	5 HLW canisters	2.E-03	9.E-04	4.E-03	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[2]

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

Event Sequence Group ID	End State	Description	Material-At-Risk[3]	Mean[4]	Median[4]	Std. Dev[4]	Event Sequence Category	Basis for Categorization	Consequence Analysis[1]
ESD12A-NVL-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a temporary loss of shielding during CTM operations, while a naval SNF canister is being transferred. In this sequence there are no pivotal events.	1 naval SNF canister	7.E-04	3.E-04	1.E-03	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[2]
ESD13-HLW-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a thermal challenge to an HLW canister inside a transportation cask, due to a fire, resulting in a direct exposure from loss of shielding. In this sequence the canister remains intact, and the shielding fails.	5 HLW canisters	7.E-04	6.E-04	3.E-04	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[2]

NOTES:
[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. 2.2.31, 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 (*GROA External Dose Rate Calculation* (Ref. 2.2.18)).
[3] The material at risk is, as relevant, based upon the nominal capacity of the waste form container involved in the event sequence under consideration, or accounts for the specific operation covered by the event sequence.
[4] The mean, median, and standard deviation displayed are for the number of occurrences, over the preclosure period, of the event sequence under consideration.

CTM = canister transfer machine; CTT = cask transfer trolley; DOE = U.S. Department of Energy; DPC = dual-purpose canister; DSTD = DOE standardized canister; HLW = high-level radioactive waste; MCO = multicanister overpack; RHS = remote handling system; ST = site transporter; TC = transportation cask; WP = waste package; WPTT = waste package transport trolley.

Source: Original

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

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

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

Section 6.9.1 identifies ITS SSCs and Section 6.9.2 identifies the procedural safety controls. The first three columns identify the ITS system or facility, subsystem and component. The fourth column identifies the safety function relied upon in the event sequence analysis. The fifth column provides the characteristics of the safety function (i.e., controlling parameter or value) that is demonstrated to occur or exist in the design. The sixth column provides an event sequence in which the safety function and the characteristic is relied upon. The seventh column provides the source, usually a fault tree, for the controlling parameter or value.

6.9.1 Important to Safety Structures, Systems, and Components

Table 6.9-1 contains the nuclear safety design bases for the IHF ITS SSCs. The event sequence column identifies a representative event sequence that is affiliated with each ITS SSC. The seventh column provides the source for the controlling parameter or value. It is either a fault tree or basic event. If it is a fault tree, it can be found in the reliability model provided in Attachments A and B. If it is a basic event, it can be traced to Section 6.3 of this report.

6.9.2 Procedural Safety Controls

PSCs are the controls that are relied upon to limit or prevent potential event sequences or mitigate their consequences. For this analysis, all PSCs were derived to reduce the initiating event sequence to an acceptable level.

Table 6.9-2 lists the PSCs that are required to support the event sequence analysis and categorization. The event sequence column identifies a representative event sequence that relies upon the PSC.

Table 6.9-1 Preclosure Nuclear Safety Design Bases for the IHF ITS SSCs

System or Facility (System Code)	Subsystem (As Applicable)	Component	Nuclear Safety Design Bases		Representative Event Sequence (Sequence Number)	Source
			Safety Function	Controlling Parameters and Values		
DOE And Commercial Waste Package System	DOE and commercial waste package	Entire	Provide containment	1. The mean conditional probability of breach of a sealed waste package resulting from a side impact shall be less than or equal to 1E-08 per impact.	IHF-ESD-11-HLW (Seq. 4-6)	51A-HLW-IMPACT-WP
				2. The mean conditional probability of breach of a sealed waste package resulting from a drop of a load onto the waste package shall be less than or equal to 1E-05 per drop.	IHF-ESD-11-HLW (Seq. 3-6)	51A-HLW-WP-FAILS-DROPON
				3. The mean conditional probability of breach of a sealed waste package resulting from an end-on impact or collision shall be less than or equal to 1E-05 per impact.	IHF-ESD-11-HLW (Seq. 5-6)	51A-HLW-WPTT-IMPACT-TEV
	HLW	HLW canister	Provide containment	4. The mean conditional probability of breach of an HLW canister resulting from a drop of the canister shall be less than or equal to 3E-02 per drop.	IHF-ESD-07-HLW (Seq. 4-5)	51A-HLW-CAN-FAIL-DROP
				5. The mean conditional probability of breach of an HLW canister resulting from a side impact or collision shall be less than or equal to 1E-08 per impact.	IHF-ESD-07-HLW (Seq. 7-5)	51A-HLW-CAN-FAIL-COLL
				6. The mean conditional probability of breach of an HLW canister contained within a waste package resulting from the spectrum of fires[d] shall be less than or equal to 3E-04 per fire event.	IHF-ESD-13-HLW-WP (Seq. 5-5)	51A-HLW-CAN-FAIL-IN-WP

Table 6.9-1 Preclosure Nuclear Safety Design Bases for the IHF ITS SSCs (Continued)

System or Facility (System Code)	Subsystem (As Applicable)	Component	Nuclear Safety Design Bases		Representative Event Sequence (Sequence Number)	Source
			Safety Function	**Controlling Parameters and Values**		
(Cont.)	**(Cont.)**	**(Cont.)**	**(Cont.)**	7. The mean conditional probability of breach of an HLW canister contained within a cask resulting from the spectrum of fires shall be less than or equal to 2E-06 per fire event.	IHF-ESD-13-HLW-WP (Seq. 5-5)	51A-PMRC-FAIL-CAN-DIESEL
				8. The mean conditional probability of breach of an HLW canister located within the CTM shield bell resulting from the spectrum of fires shall be less than or equal to 1E-04 per fire event.	IHF-ESD-13-HLW-WP (Seq. 5-5)	51A-HLW-CAN-CONT-CTM-FIR
				9. The mean conditional probability of breach of an HLW canister, given the drop of another HLW canister onto the first canister, shall be less than or equal to 3E-02 per drop.	IHF-ESD-07-HLW (Seq. 2-5)	51A-HLW-CAN-FAIL-DROP
Initial Handling Facility	Initial Handling Facility	Shield doors (including anchorages)	Protect against[a] direct exposure of personnel	10. Equipment and personnel shield doors shall have a mean probability of inadvertent opening of less than or equal to 1E-06 per transfer.	IHF-ESD-12A-HLW (Seq. 2)	51A-SHLD-DR-DIRCT-EXP
			Preclude collapse onto waste containers	11. An equipment shield door falling onto a waste container as a result of an impact from a conveyance shall be precluded.	Initiating event does not require further analysis.[c]	Table 6.0-2
		Cask Port Slide Gate (51A-HTC0-HTCH-00001)	Protect against dropping a canister due to spurious closure of the slide gate	12. The mean probability of a canister drop resulting from a spurious closure of the slide gate shall be less than or equal to 2E-06 per transfer.	IHF-ESD-07-HLW (Seq. 4-5)	GATE-36-109 of 51A-CTM-DROP

Table 6.9-1 Preclosure Nuclear Safety Design Bases for the IHF ITS SSCs (Continued)

System or Facility (System Code)	Subsystem (As Applicable)	Component	Nuclear Safety Design Bases: Safety Function	Nuclear Safety Design Bases: Controlling Parameters and Values	Representative Event Sequence (Sequence Number)	Source
(Cont.)	**(Cont.)**	**(Cont.)**	Protect against direct exposure to personnel	13. The mean probability of inadvertent opening of a slide gate shall be less than or equal to 1E-09[b] per transfer.	IHF-ESD-12A-HLW (Seq. 2)	51A-SLIDE-GATE-DIR-EX
			Preclude canister breach	14. Closure of the slide gate shall be incapable of breaching a canister.	Initiating event does not require further analysis.[c]	Table 6.0-2
		Waste Package Port Slide Gate (51A-HTC0-HTCH-00002)	Protect against dropping a canister due to a spurious closure of the slide gate	15. The mean probability of a canister drop resulting from a spurious closure of the port slide gate shall be less than or equal to 9E-09 per transfer.	IHF-ESD-07-HLW (Seq. 4-5)	GATE-36-61 of 51A-CTM-DROP
			Protect against direct exposure to personnel	16. The mean probability of inadvertent opening of a slide gate shall be less than or equal to 2E-06 per transfer.	IHF-ESD-12A-HLW (Seq. 2)	ESD12A-HLW-SHLD
			Preclude canister breach	17. Closure of the slide gate shall be incapable of breaching a canister.	Initiating event does not require further analysis.[c]	Table 6.0-2
			Preclude canister drop onto the floor	18. The waste package port slide gate shall be incapable of opening without a waste package transfer trolley with waste package in position to receive a canister.	Initiating event does not require further analysis.[c]	Table 6.0-2
Mechanical handling system	Cask handling	Transportation cask (analyzed as a representative transportation cask)	Provide containment	19. The mean conditional probability of breach of a canister in a sealed cask resulting from a cask drop shall be less than or equal to 1E-05 per drop.	IHF-ESD-01-NVL (Seq. 3-6)	51A-NVL-TC-FAIL-DROP

Table 6.9-1 Preclosure Nuclear Safety Design Bases for the IHF ITS SSCs (Continued)

System or Facility (System Code)	Subsystem (As Applicable)	Component	Nuclear Safety Design Bases: Safety Function	Nuclear Safety Design Bases: Controlling Parameters and Values	Representative Event Sequence (Sequence Number)	Source
(Cont.)	**(Cont.)**	**(Cont.)**	**(Cont.)**	20. The mean conditional probability of breach of a canister in a sealed cask resulting from a drop of a load onto the cask shall be less than or equal to 1E-05 per drop.	IHF-ESD-01-NVL (Seq. 2-6)	51A-NVL-TC-FAIL-DROPON
				21. The mean conditional probability of breach of a canister contained within a sealed cask resulting from a side impact or collision shall be less than or equal to 1E-08 per impact.	IHF-ESD-04-NVL (Seq. 7-5)	51A-NVL-CAN-FAIL-SIMP
			Preclude lid contact with canisters	22. The geometry of the casks that carry HLW canisters shall preclude lid contact with canisters following a drop of a cask lid.	Initiating event does not require further analysis.[c]	Table 6.0-2
			Protect against direct exposure to personnel	23. The mean conditional probability of loss of cask gamma shielding resulting from a drop of a cask shall be less than or equal to 1E-05 per drop.	IHF-ESD-02-HLW (Seq. 2-3)	HLW-SHIELDING-FAILS5
				24. The mean conditional probability of loss of cask gamma shielding resulting from a collision or side impact to a cask shall be less than or equal to 1E-08 per impact.	IHF-ESD-02-HLW (Seq. 5-3)	HLW-SHIELDING-FAILS8
				25. The mean conditional probability of loss of cask gamma shielding resulting from drop of a load onto a cask shall be less than or equal to 1E-05 per impact.	IHF-ESD-02-HLW (Seq. 6-3)	HLW-SHIELDING-FAILS5

Table 6.9-1 Preclosure Nuclear Safety Design Bases for the IHF ITS SSCs (Continued)

System or Facility (System Code)	Subsystem (As Applicable)	Component	Nuclear Safety Design Bases: Safety Function	Nuclear Safety Design Bases: Controlling Parameters and Values	Representative Event Sequence (Sequence Number)	Source
(Cont.)	**(Cont.)**	Site Prime Mover	Limit speed	26. The speed of the site prime mover shall be limited to 9 mi/hr.	IHF-ESD-01-HLW (Seq. 4-6)	This parameter limits the conditional probability of cask breach given a collision to the appropriate value from Table 6.3-7.
			Preclude fuel tank explosion	27. The fuel tank of a site prime mover that enters the facility shall preclude fuel tank explosions.	Initiating event does not require further analysis.[c]	Table 6.0-2
		Cask Handling Yoke (51A-HM00-BEAM-00001)	Protect against drop	28. The cask handling yoke is an integral part of the load-bearing path. See Cask Handling Crane requirements.	See Cask Handling Crane requirements	See Cask Handling Crane requirements
		Cask Handling Crane; 300-ton (51A-HM00-CRN-00001)	Protect against drop	29. The mean probability of dropping a loaded transportation cask from less than two-block height resulting from the failure of a piece of equipment in the load-bearing path shall be less than or equal to 3E-05 per transfer.	IHF-ESD-02-HLW (Seq. 2-6)	51A-CRN3-DROPHLW-CRN-DRP
			Protect against drop	30. The mean probability of dropping a loaded cask from the two-block height resulting from the failure of a piece of equipment in the load-bearing path shall be less than or equal to 4E-07 per transfer.	IHF-ESD-02-HLW (Seq. 3-6)	51A-CRN3-2-BLOCK-CRN-TBK
			Limit drop height	31. The two-block drop height shall not exceed 40 ft from the bottom of the shortest cask to the floor.	IHF-ESD-02-HLW (Seq. 3-6)	This parameter limits the conditional probability of cask breach given a collision to the appropriate value from Table 6.3-7.

Table 6.9-1 Preclosure Nuclear Safety Design Bases for the IHF ITS SSCs (Continued)

System or Facility (System Code)	Subsystem (As Applicable)	Component	Nuclear Safety Design Bases: Safety Function	Nuclear Safety Design Bases: Controlling Parameters and Values	Representative Event Sequence (Sequence Number)	Source
(Cont.)	**(Cont.)**	**(Cont.)**	Protect against drop of a load onto a cask	32. The mean probability of dropping a load onto a loaded cask or its contents shall be less than or equal to 3E-05 per cask handled.	IHF-ESD-02-HLW (Seq. 6-6)	51A-CRN3-DROPON-CRN-DRP
			Limit speed	33. The speed of the trolley and bridge shall be limited to 20 ft/min.	IHF-ESD-02-HLW (Seq. 5-6)	This parameter limits the conditional probability of cask breach given a collision to the appropriate value from Table 6.3-7. (2.5 mi/hr, from Table 6.3-7, equals 220 ft/min, which bounds 20 ft/min.)
		Cask transfer trolley (and pedestals) Trolley (51A-HM00-TRLY-00001) Cask Pedestals (51A-HM00-PED-00001-2) Naval Cask Pedestal (51A-HM00-PED-00003)	Limit speed	34. The speed of the CTT shall be limited to 2.5 mi/hr.	IHF-ESD-05-HLW (Seq. 3-5)	This parameter limits the conditional probability of canister breach given a collision to the appropriate value from Table 6.3-7.
			Protect against spurious movement	35. The mean probability of spurious movement of the CTT while a canister is being lifted by the CTM shall be less than or equal to 1E-09[b] per transfer.	IHF-ESD-07-NVL (Seq. 3-5)	51A-7-CTT-SPURMOVE
		Cask preparation crane; 30-ton (51A-HM00-CRN-00002)	Protect against drop	36. The mean probability of a drop of a load onto a loaded cask shall be less than or equal to 3E-05 per transfer.	IHF-ESD-04-NVL (Seq. 4-5)	51A-CRN3-DROPON--CRN-DRP

Table 6.9-1 Preclosure Nuclear Safety Design Bases for the IHF ITS SSCs (Continued)

System or Facility (System Code)	Subsystem (As Applicable)	Component	Nuclear Safety Design Bases		Representative Event Sequence (Sequence Number)	Source
			Safety Function	Controlling Parameters and Values		
(Cont.)	Cask Handling/ Cask Receipt	Naval cask lift bail (51A-HMC0-BEAM-00001)	Protect against drop	37. The naval cask lift bail is an integral part of the load-bearing path. See Cask Handling Crane requirements.	See Cask Handling Crane requirements	See Cask Handling Crane requirements
		Naval cask lift plate (51A-HMC0-HEQ-00005)	Protect against drop	38. The naval cask lift plate is an integral part of the load-bearing path. See Cask Handling Crane requirements.	See Cask Handling Crane requirements	See Cask Handling Crane requirements
	Cask Handling / Cask Preparation	Rail Cask Lid Adapters (51A-HMH0-HEQ-00002)	Protect against drop	39. The rail cask lid adapter is integral to the load-bearing path for the HLW rail cask lid. See Cask Handling Crane requirements.	See Cask Handling Crane requirements	See Cask Handling Crane requirements
	Waste Transfer/ Canister Transfer	Canister Transfer Machine (51A-HTC0-FHM-00001)	Protect against drop	40. The mean probability of drop of a canister from below the two-block height due to the failure of a piece of equipment in the load-bearing path shall be less than or equal to 2E-04 per transfer.	IHF-ESD-07-HLW (Seq. 4-5)	51A-CTM-DROP
			Protect against drop	41. The mean probability of drop of a canister from the two-block height due to the failure of a piece of equipment in the load-bearing path shall be less than or equal to 3E-08 per transfer.	IHF-ESD-07-HLW (Seq. 5-5)	CTM-2-BLOCK
			Limit drop height	42. The two-block drop height shall not exceed 40 ft from the bottom of a canister to the cavity floor of the transportation cask or waste package.	IHF-ESD-07-HLW (Seq. 5-5)	This parameter limits the conditional probability of canister breach given a two-block drop to the appropriate value from Table 6.3-7.

Table 6.9-1 Preclosure Nuclear Safety Design Bases for the IHF ITS SSCs (Continued)

System or Facility (System Code)	Subsystem (As Applicable)	Component	Nuclear Safety Design Bases		Representative Event Sequence (Sequence Number)	Source
			Safety Function	Controlling Parameters and Values		
(Cont.)	**(Cont.)**	**(Cont.)**	Protect against drop of a load onto a canister	43. The mean probability of dropping a load onto a canister shall be less than or equal to 1E-05 per transfer.	IHF-ESD-07-HLW (Seq. 2-5)	51A-CTM-HLW-DROPON
			Protect against spurious movement	44. The mean probability of spurious movement of the CTM while a canister is being lifted or lowered shall be less than or equal to 7E-09 per transfer.	IHF-ESD-07-HLW (Seq. 3-5)	CTM-SHEAR
			Preclude canister breach	45. Closure of the CTM slide gate shall be incapable of breaching a canister.	Initiating event does not require further analysis.[c]	Table 6.0-2
			Preclude non-flat-bottom drop of a naval SNF canister	46. The CTM shall preclude non-flat-bottom drops of naval canisters.	Initiating event does not require further analysis.[c]	Table 6.0-2

Table 6.9-1 Preclosure Nuclear Safety Design Bases for the IHF ITS SSCs (Continued)

System or Facility (System Code)	Subsystem (As Applicable)	Component	Nuclear Safety Design Bases: Safety Function	Nuclear Safety Design Bases: Controlling Parameters and Values	Representative Event Sequence (Sequence Number)	Source
(Cont.)	**(Cont.)**	**(Cont.)**	Protect against direct exposure of personnel	47. The mean probability of inadvertent radiation streaming due to the inadvertent opening of the CTM slide gate, the inadvertent raising of the CTM shield skirt, or an inadvertent motion of the CTM away from an open port shall be less than or equal to 1E-04 per transfer.	IHF-ESD-12B-HLW (Seq. 2)	ESD12B-HLW-SHLD-RING
			Limit speed	48. The speed of the CTM trolley and bridge shall be limited to 20 ft/min.	IHF-ESD-07-HLW (Seq. 7-5)	This parameter limits the conditional probability of canister breach given a collision to the appropriate value from Table 6.3-7. (2.5 mi/hr, from Table 6.3-7, equals 220 ft/min, which bounds 20 ft/min.)
			Protect against drop	49. The mean frequency of drop by the CTM of the naval SNF canister resulting in breach of the canister shall be less than or equal to 2E-05 over the preclosure period.[f]	IHF-ESD-07-NVL (Seq. 4-5)	IHF-ESD-07-NVL (Seq. 4-5)
		CTM Grapple (51A-HTC0-HEQ-00001) Canister grapples (51A-HTC0-HEQ-00003, 51A-HTC0-HEQ-00004)	Protect against drop	50. Grapples are an integral part of the load-bearing path. See Canister Transfer Machine requirements.	See Canister Transfer Machine requirements.	See Canister Transfer Machine requirements.

Table 6.9-1 Preclosure Nuclear Safety Design Bases for the IHF ITS SSCs (Continued)

System or Facility (System Code)	Subsystem (As Applicable)	Component	Nuclear Safety Design Bases		Representative Event Sequence (Sequence Number)	Source
			Safety Function	Controlling Parameters and Values		
(Cont.)	**(Cont.)**	**(Cont.)**	Protect against drop of a load onto a canister	51. The grapples are an integral part of the load-bearing path. See Canister Transfer Machine requirements.	See Canister Transfer Machine requirements.	See Canister Transfer Machine requirements.
		Naval Canister Lifting Adapter (51A-HTC0-HEQ-00005)	Protect against drop of a canister	52. The naval canister lifting adapter is an integral part of the load-bearing path of the CTM. See Canister Transfer Machine requirements.	See Canister Transfer Machine requirements.	See Canister Transfer Machine requirements.
		DOE Waste Package Inner Lid Grapple (51A-HTC0-HEQ-00007)	Protect against the drop of a load onto a canister	53. The lid grapple is an integral part of the load-bearing path of the CTM. See Canister Transfer Machine requirements.	See Canister Transfer Machine requirements.	See Canister Transfer Machine requirements.
		Naval Waste Package Inner Lid Grapple (51A-HTC0-HEQ-00008)	Protect against the drop of a load onto a canister	54. The lid grapple is an integral part of the load-bearing path of the CTM. See Canister Transfer Machine requirements.	See Canister Transfer Machine requirements.	See Canister Transfer Machine requirements.
	Waste Package Loadout	Waste Package Transfer Trolley (including Pedestals, Seismic Rail Restraints, and Rails) (Trolley: 51A-HL00-TRLY-00001) (Pedestals: 51A-HL00-PED-00001-4)	Preclude rapid tilt-down	55. The WPTT shall be incapable of rapid tilt-down.	Initiating event does not require further analysis.[c]	Table 6.0-2

Table 6.9-1 Preclosure Nuclear Safety Design Bases for the IHF ITS SSCs (Continued)

System or Facility (System Code)	Subsystem (As Applicable)	Component	Nuclear Safety Design Bases: Safety Function	Nuclear Safety Design Bases: Controlling Parameters and Values	Representative Event Sequence (Sequence Number)	Source
(Cont.)	**(Cont.)**	**(Cont.)**	Limit speed	56. The speed of the WPTT shall be limited to 2.5 mi/hr.	IHF-ESD-08-NVL (Seq. 2-5)	This parameter limits the conditional probability of canister breach given a collision to the appropriate value from Table 6.3-7.
			Protect against spurious movement	57. The mean probability of spurious movement of the WPTT while a canister is being lowered by the CTM shall be less than or equal to 1E-09[b] per transfer.	IHF-ESD-07-NVL (Seq. 3-5)	51A-7-WPTT-SPURMOVE
Naval SNF Waste Package System	Naval SNF Waste Package	Entire	Provide containment	58. The mean conditional probability of breach of a sealed waste package resulting from a side impact shall be less than or equal to 1E-08 per impact.	IHF-ESD-11-NVL (Seq. 4-6)	51A-WP-FAIL-EXPORT
				59. The mean conditional probability of breach of a sealed waste package resulting from a drop of a load onto the waste package shall be less than or equal to 1E-05[e] per drop.	IHF-ESD-11-NVL (Seq. 3-6)	51A-WP-FAIL-EXPORT[e]
				60. The mean conditional probability of breach of a sealed waste package resulting from an end-on impact or collision shall be less than or equal to 1E-05 per impact.	IHF-ESD-11-NVL (Seq. 5-6)	51A-NVL-WPTT-COLLIDE-TEV
	Naval SNF Canister	Naval SNF canister (analyzed as a representative canister)	Provide containment	61. The mean frequency of drop by the CTM of the naval SNF canister resulting in breach of the canister shall be less than or equal to 2E-05 over the preclosure period.[f]	IHF-ESD-07-NVL (Seq. 4-5)	IHF-ESD-07-NVL (Seq. 4-5)

Table 6.9-1 Preclosure Nuclear Safety Design Bases for the IHF ITS SSCs (Continued)

System or Facility (System Code)	Subsystem (As Applicable)	Component	Nuclear Safety Design Bases		Representative Event Sequence (Sequence Number)	Source
			Safety Function	Controlling Parameters and Values		
(Cont.)	**(Cont.)**	**(Cont.)**	**(Cont.)**	62. The mean conditional probability of breach of a canister resulting from a drop of a load onto the canister shall be less than or equal to 1E-05 per drop.	IHF-ESD-07-NVL (Seq. 2-5)	51A-NVL-CAN-FAIL-DROPON
				63. The mean conditional probability of breach of a canister resulting from a side impact or collision shall be less than or equal to 1E-08 per impact.	IHF-ESD-07-NVL (Seq. 6-5)	51A-NVL-CAN-FAIL-COLL
				64. The mean conditional probability of breach of a canister contained within a cask resulting from the spectrum of fires shall be less than or equal to 1E-06 per fire event.	IHF-ESD-13-NVL (Seq. 8-6)	51A-NVL-FAIL-CAN-DIESEL
				65. The mean conditional probability of breach of a canister located within the CTM shield bell resulting from the spectrum of fires shall be less than or equal to 1E-04 per fire event.	IHF-ESD-13-NVL (Seq. 8-6)	51A-NVL-CAN-CONT-CTM-FIR

Table 6.9-1 Preclosure Nuclear Safety Design Bases for the IHF ITS SSCs (Continued)

System or Facility (System Code)	Subsystem (As Applicable)	Component	Nuclear Safety Design Bases: Safety Function	Nuclear Safety Design Bases: Controlling Parameters and Values	Representative Event Sequence (Sequence Number)	Source
(Cont.)	(Cont.)	(Cont.)	(Cont.)	66. The mean conditional probability of breach of a canister contained within a waste package resulting from the spectrum of fires shall be less than or equal to 1E-04 per fire event.	IHF-ESD-13-NVL (Seq. 8-6)	51A-NVL-CAN-CONT-LR-FIRE

NOTES: [a] Protect against' in this table means either 'reduce the probability of' or 'reduce the frequency of'.

[b] Extremely low probabilities are reported in this table as 1E-09. Increasing the source probability to 1E-09 does not impact the categorization of event sequences.

[c] Design requirement is applied to reduce the frequency of any event sequence that could result in damage to a waste container to Beyond Category 2.

[d] The term "spectrum of fires" refers to the variations in the intensity and duration of the fire that are considered along with conditions that control the rate of heat transfer to the container (Attachment D, Section D2.1).

[e] In this instance, a value of 1E-08 was used for the calculation. This probability bounds the estimated probability, as discussed in Attachment D, Section D1.4.4. The probability given in the nuclear safety design basis is higher, 1E-05. The stated nuclear safety design basis is supported by the analysis because the frequencies of the affected event sequences are below the Category 2 threshold by more than three orders of magnitude (the difference between the value used and the value stated in the nuclear safety design basis).

[f] The failure probability of the naval canister given a drop from the CTM and the drop frequency of the CTM as it pertains to the naval canister are combined for the purpose of stating the nuclear safety design bases for the CTM and the naval canister. Thus, the corresponding controlling parameters and values place a limit on the event sequence involving drop and breach of the naval canister. This is done to allow flexibility in meeting the NSDB by trading off a reduction in the CTM drop probability for an increase in the canister failure probability.

CTM = canister transfer machine; CTT = cask transfer trolley; DOE = U.S. Department of Energy; HLW = high-level radioactive waste; SNF = spent nuclear fuel; WPTT = waste package transfer trolley.

Source: Original

Table 6.9-2. Summary of Procedural Safety Controls for the IHF Facility

Item	SSC	Procedural Safety Control	Basis for Selection	Representative Event Sequence
1	CTT	The CTT is deflated during loading of cask onto trolley, cask preparation activities, and during canister unloading or loading activities.	This control limits the probability of spurious movement of the CTT and resulting canister impact.	IHF-ESD-04-NVL (Seq. 3-5)
2	Site Prime Mover	The site prime mover is disconnected or secured to prevent motion before waste handling operations begin.	This control limits the probability of spurious movement of the site prime mover and resulting collision or tipover.	IHF-ESD-01-HLW (Seq. 4-6)
3	WPTT	Personnel are verified to be outside of the WP Positioning Room and the WP Loadout Room prior to movement of a loaded WP into the WP Positioning Room or the WP Loadout Room.	This control limits the probability of operators receiving a direct exposure during the loading of a WP into the TEV.	IHF-ESD-12C-NVL (Seq. 2)
4	CTM Naval SNF canister	Verify that the naval canister lifting adapter is fully detached from the naval SNF canister before using the CTM to remove the naval canister lifting adapter and shield ring.	HRA quantification is based on this PSC being in place. This control protects the canister from a drop by the CTM during the removal of the naval canister lifting adapter and shield ring.	IHF-ESD-07-NVL (Seq. 2-5)
5	ITS SSCs	The amount of time that a waste form spends in each process area or in a given process operation, including total residence time in a facility, is periodically compared against the average exposure times used in the PCSA. Additionally, component failures per demand and component failures per time period are compared against the PCSA. Significant deviations will be analyzed for risk significance.	PCSA uses exposure/residence times and reliability data to calculate the probability of an initiating event, or the probability of seismic induced failures that lead to an event sequence. This control ensures that the average exposure times and reliability data are maintained consistent with those analyzed in the PCSA.	Applies to all event sequence and fault tree quantification that uses data from Attachment C. Also applies to fire analysis per Section 4.3 and Attachment E.
6	Cask Preparation Platform	Transportation cask lid bolts are independently verified to have been removed prior to moving the cask from the cask preparation area to the unloading room.	This control prevents the CTM from attempting to remove the cask lid with bolts still in place resulting in failure of the bolts and possible drop of the lid or cask.	IHF-ESD-07-HLW (Seq. 9-5)

Table 6.9-2. Summary of Procedural Safety Controls for the IHF Facility (Continued)

Item	SSC	Procedural Safety Control	Basis for Selection	Representative Event Sequence
7	CTM Port Slide Gates	At completion of a canister transfer operation, the port slide gates are verified to be closed.	While the CTM is being used to perform transfer operations, the Operational Radiation Protection Program provides the necessary controls to ensure that workers are not present with the slide gates open. This control limits the probability of workers receiving a direct exposure by entering the transfer room with the CTM away from a port with a waste form present and the slide gate open.	IHF-ESD-12A-NVL (Seq. 2)
8	CTM	Prior to lifting or lowering a naval canister, the CTM guide sleeve is to be verified to have been lowered.	This control limits the probability that a naval canister is not in a vertical orientation during transfer such that any potential drops would be flat bottom drops.	IHF-ESD-07-NVL (Seq. 4-5)
9	HLW	The individual radionuclide inventories per HLW canister are limited to the values presented in consequence analysis.	This control is to ensure that the dose consequences from Category 2 event sequences involving HLW are within the values presented in the consequence analysis.	Applies to all event sequence end states that result in release of radioactivity from HLW.

NOTE: CTM = canister transfer machine; CTT = cask transfer trolley; HRA = human reliability analysis; ITS = important to safety; PCSA = preclosure safety analysis; SSC = structures, systems, and components; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

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7. RESULTS AND CONCLUSIONS

This analysis report on the IHF and its predecessor companion report, the *Initial Handling Facility Event Sequence Development Analysis* (Ref. 2.2.28), are part of the PCSA for the GROA that supports the license application. In combination, these documents identify, evaluate, quantify, and categorize event sequences for the GROA facilities and operations. They are part of a collection of analysis reports that encompass all waste handling activities and facilities at the GROA from initial operations to the end of the preclosure period. Probabilistic risk assessment techniques derived from both nuclear power plant and aerospace methods are used to perform the analyses to comply with the risk-informed aspects of 10 CFR 63.111 and 63.112 (Ref. 2.3.2) and to be responsive to the acceptance criteria articulated in the *Yucca Mountain Review Plan* (Ref. 2.2.64). The identification and development of the event sequences is limited to those that might lead to the direct radiation exposure of workers or onsite members of the public, radiological releases that may affect the workers or public (onsite and offsite), and nuclear criticality.

The results of the analysis are discussed and presented in the logical progression through Section 6 of this document and are not reiterated here. Instead, only key points are highlighted. For the ungrouped event sequence results and the complete grouped event sequence summaries, electronic files are provided due to the large size of hard copy versions (refer to Attachments G and H). In addition, although the results from the SAPHIRE model are used and presented in Section 6 and Attachment B, the model itself is difficult to completely represent in paper form. Therefore, these outputs are also provided electronically (refer to Attachment H). Table 7-1 describes the results and indicates the location within this analysis for each result provided.

Table 7-1. Key to Results

Result	Description	Cross Reference
Grouping of event sequences	Grouping of event sequences and description of event sequence groups	Table G-1
Quantification of event sequences	Calculation of probability distributions for the numbers of occurrences of internal event sequence groups over the preclosure period	Table G-2
Categorization of event sequences	Assignment of frequency categories Category 1, Category 2, or Beyond Category 2 to internal event sequence groups based on mean numbers of occurrences	Table 6.8-2 Table 6.8-3 Table G-3
Designation of structures, systems, and components as important to safety	Identification of SSCs that are relied on in the quantification of internal event sequences for prevention or mitigation	Table 6.9-1
Statement of nuclear safety design bases	List of nuclear safety design bases for SSCs that are relied on in the quantification of internal event sequences for prevention or mitigation	Table 6.9-1
Statement of procedural safety controls	List of procedural safety controls that are relied on in the quantification of internal event sequences for prevention or mitigation	Table 6.9-2

NOTE: ITS = important to safety; SSCs = structures, systems, and components.

Source: Original

Summary of Event Sequences

The analysis concludes that there are no Category 1 event sequences and 9 Category 2 event sequences. Table 7-2 gives the number of Category 2 event sequences by end state for each waste form.

Table 7-2. Summary of Category 2 Event Sequences

End State	Description	Waste Forms	
		HLW	Naval
DE-SHIELD-DEGRADE	Direct exposure due to degradation of shielding	None	None
DE-SHIELD-LOSS	Direct exposure due to loss of shielding	4	4
RR-UNFILTERED	Radionuclide release, unfiltered	1	None
RR-FILTERED	Radionuclide release, filtered	None	None
RR-UNFILTERED-ITC	Radionuclide release, unfiltered, also important to criticality	None	None
RR-FILTERED-ITC	Radionuclide release, filtered, also important to criticality	None	None
ITC	Important to criticality	None	None

Source: Original

Summary of Conservatisms

It should be noted that the event sequence identification and categorization were conducted with conservatisms that increase confidence in the results. These conservatisms include those listed below.

1. Fire frequency and damage analyses are performed without relying on fire suppression. This increases the calculated frequency of large fires and also increases the duration and peak temperature of fires, thereby significantly increasing the calculated probability of waste container failure.

2. If a fire is calculated to propagate out of the initiating location fire zone, the entire building is considered to be involved in the fire.

3. In the PEFA for thermal and fire scenarios, conservatism is built into the boundary conditions, which consider the fire as occurring next to the waste containers instead of only a fraction of the fire occurrence being near the waste form. A fire closer to the target will lead to a higher target failure probability than a fire located further away. By considering all fires to be next to the waste forms, the thermal PEFA yields higher waste form failure probabilities than is likely.

4. For event sequences in which a cask containing a canister is subjected to a drop, slapdown, or in which a load is dropped onto the cask, the calculated containment failure probability pertains to the canister inside without regard to the integrity of the cask. That is, cask containment is not relied upon to reduce probability of containment failure.

5. The structural PEFA uses a conservative failure probability of 1E-5, whereas the actual PEFA assessment indicates values of less than 1E-8 failure probabilities (Table D1.2-7 of Attachment D). This conservatism provides event sequence quantification results orders of magnitude higher than what they would be if the actual PEFA assessment values are used.

6. The event sequence development for shielding degradation of transportation casks caused by an impact event considers all casks as if they contained lead gamma shielding that could slump. However, not all transportation casks received at the GROA will be leaded casks. Because non-leaded casks are not affected by this degraded shielding condition, the introduction of this conservatism increases the event sequence quantification value.

7. The structural analyses for drops and collisions of canisters or casks model a rigid, unyielding surface as the target.

8. The structural analysis for drops of loads onto casks or canisters uses a rigid unyielding object for the dropped load.

9. The probabilities of event sequences involving drops of casks and canisters represent a drop height of up to 40 feet for casks and 45 feet for bare canisters. This is much higher than the normal operational lift height but is applied for all lower drop heights. Lower drop heights would result in less structural challenge to casks and canisters.

10. When a canister is inside a waste package, failure of the waste package is considered to fail containment; i.e., the canister is not relied upon to reduce the probability of containment failure.

11. Transportation casks are analyzed without impact limiters even for those event sequences in which impact limiters would be attached.

12. The speed limitation of crane and conveyances within facilities to 20 ft/min and 2.5 mph, respectively, is set to ensure no breach of casks or canisters. The probability of breach at such speeds is calculated to be less than 1E-08 per impact. Speeds could be considerably larger without changing the categorizations of event sequences.

13. The HVAC system that provides confinement of radioactive material releases following a waste form drop is not relied upon and is modeled with a failure probability of 1.0. This conservative consideration leads to unfiltered event sequence frequencies higher than are realistically expected.

14. The human reliability analysis screening values used for human failure events are typically one or more orders of magnitude higher than values that would be obtained through detailed analysis.

15. The probability of failure associated with the structural analysis of mechanical impact loads to casks and canisters is conservatively based on the maximum effective plastic strain of any brick (i.e., finite element mesh) in the modeled structure rather than relying on evidence of through-wall cracking.

16. Categorization of event sequences is based on the highest category after application of a conservative adjustment to account for the uncertainty in the calculated uncertainties.

17. To preserve flexibility in the conduct of operations, the throughput analysis (Ref. 2.2.26) embeds multiple and bounding waste handling scenarios in the throughput numbers. For example, it considers that a certain number of HLW canisters are handled in IHF without subtracting that number from the number considered to be handled in the CRCF, which is the total number received at the repository. As a result, the allocated numbers, especially for the IHF, are higher than is realistically expected. This conservatism applies especially to the IHF because, although the IHF is designed to handle HLW canisters, it is preferable to handle virtually all of them in the CRCF where they can be loaded into codisposal waste packages along with DOE SNF. Including this conservatism in the analysis yields calculated event sequence frequencies that are higher than is realistically expected.

ATTACHMENT A
EVENT TREES

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CONTENTS

Page

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FIGURES

Page

FIGURES (Continued)

Page

TABLES

TABLES (Continued)

TABLES (Continued)

Page

TABLES (Continued)

Page

ATTACHMENT A
EVENT TREES

A1 INTRODUCTION

This attachment presents event trees that are derived from the ESDs in Attachment F of the *Initial Handling Facility Event Sequence Development Analysis* (Ref. 2.2.28). All initiator event trees and system response event trees are located at the end of this attachment. Refer to Table A5-1 for the figure locations of specific event and response trees. The event trees are presented in Figures A5-2 through A5-39 according to the "hierarchy ordering" rules in SAPHIRE. The first rule is that event trees are presented in alphabetical order (which is also ESD order). For example, the event trees associated with IHF-ESD-01 appear first, and those associated with IHF-ESD-02 appear after that, and so on. The second rule is that the first initiator event tree associated with the ESD appears first and the corresponding system response event tree is placed immediately following the first initiator event tree, followed by the remaining initiator event trees for the ESD. For example, the first initiator event tree (IHF-ESD-01-HLW) associated with the first ESD (IHF-ESD-01) is the first event tree figure. Then the system response event tree (IHF-RESP-TC1) appears, followed by the remaining initiator event trees for the ESD (IHF-ESD-01-NVL). The same kind of ordering is done for each group in turn.

A2 READER'S GUIDE TO THE EVENT TREE DESCRIPTIONS

The following sections are organized by ESD. The event trees that correspond to each ESD are presented as follows:

1. The event trees for the waste forms covered are briefly described and listed (initiator and system-response event trees or self contained event trees, as applicable).

2. The initiating events are described and listed. The listing is provided as a table that includes the assignments of fault trees or basic events to the initiating events. The assignments are made in SAPHIRE using basic rules or by fault-tree construction. The goal of the initiating event table is to provide a link to the underlying system fault tree (covered in Section 6.2 and Attachment B) or basic event (covered in Section 6.3 and Attachment C). In a few cases, the assignment is not straightforward and a supplemental fault tree provides a link to the system fault tree or basic event level (covered in Attachment B). Note that the initiating event frequencies are defined on a per-unit-handled basis. Thus, when the initiating event frequencies are multiplied by the number of units handled over the preclosure period, the result is an initiating event frequency over the preclosure period.

3. The system-response event tree that corresponds to the initiator event tree or the system response for a self-contained event tree is covered as follows. Each pivotal event used in an event tree is listed in the event tree description section and summarized in Section A3. Each pivotal event is accompanied by a table that provides a link between the name given to the pivotal event in the event tree and the associated system fault tree or basic event. The goal of the pivotal event table is to provide a link to the underlying system fault tree (covered in Section 6.2) or basic event (covered in Section 6.3). In a few cases, the assignment is not straightforward and a supplemental fault tree provides a link to the system fault tree or basic event level.

A3 SUMMARY OF THE MAJOR PIVOTAL EVENT TYPES

A self-contained event tree or a system response event tree may include pivotal events of following types:

CELL-DOOR. This pivotal event represents the success or failure of the shield door to not fail and damage waste forms.

WP. This pivotal event represents the success or failure of the waste package to contain radioactive material after the impact caused by the initiating event. The failure of this pivotal event leads to loss of the waste package's containment function. The failure probability for this pivotal event depends on the selection of initiating event and is determined by PEFA, and is given in Table 6.3-4 in Section 6.3.2.2.

TRANSCASK. This pivotal event represents the success or failure of the transportation cask to contain radioactive material after the impact caused by the initiating event. The failure of this pivotal event leads to the loss of the cask's containment function. The failure probability for this pivotal event is determined by PEFA, and is given in Table 6.3-4 in Section 6.3.2. In accordance with a simplifying approximation, the same failure probability is used for all casks for the various initiating events.

CANISTER. This pivotal event represents the success or failure of the canister to contain radioactive material after the impact caused by the initiating event. Failure of a containment pivotal event means that a release could occur if the canister containment barrier is breached (along with the cask or waste-package containment, as applicable). In accordance with a simplifying approximation, the conditional probability of canister breach given cask breach is taken to be 1.

SHIELDING. Failure of a shielding pivotal event means that a direct exposure could occur. Casks, some canisters, and the cask transfer machine shield bell, which include integral shields that could be pierced or degraded in some impact events. In addition, a breach of a container's seal can also result in a loss of shielding. Thus, this pivotal event represents the success or failure of the shielding function of the cask, canister, or aging overpack after the impact caused by the initiating event. Failure of shielding in this instance refers to an unspecified degree of shielding degradation due to the impact.

CONFINEMENT. This pivotal event represents the success or failure of the HVAC system in continuing to provide HEPA filtration (radiological confinement) after the initiating event. Success of the pivotal event requires the facility structural integrity as well as the functioning of equipment associated with the HVAC system. Failure results in a potential airborne release that is not mitigated by the HEPA filtration system.

MODERATOR. This pivotal event represents the conditional probability of introducing liquid moderator (water or crane gearbox lubricating oil) into a breached canister, given that a breached canister is present. The conditional probability of failure (introduction of liquid moderator) is the same for all waste forms and all initiating events. Failure of a moderator pivotal event results in an end state that may be susceptible to nuclear criticality. The opportunity for criticality also depends on other pivotal events (e.g., loss of containment, which may allow liquid moderator into a breached canister) and the physical properties of the waste form. HLW is not subject to the possibility of criticality; therefore, all moderator trees pertaining to criticality sequences for HLW are set to "0.00E+00."

Each of the specific failure events included in a self-contained or system-response event tree may be linked to a basic event or to the top event of a fault tree that represents equipment failure modes and human failure events that can initiate the specific event. The fault tree models are, in turn, linked to basic events that provide the failure frequencies. Some of the pivotal events represent failure of equipment whose failure probabilities are linked to a separately developed basic event and not to a fault tree.

A4 EVENT TREE DESCRIPTIONS

A4.1 EVENT TREES FOR IHF-ESD-01

IHF-ESD-01 covers event sequences associated with receipt of a truck trailer or railcar carrying a transportation cask (Ref. 2.2.28, Figure F-1). This ESD covers two types of transportation casks naval and HLW. Corresponding to each type of cask is an initiator event tree (Table A4.1-1). Although the initiator event trees transfer to the same system-response event tree, it is customized within SAPHIRE for each initiator event tree by the use of basic rules. The rules instruct SAPHIRE where to look for the fault tree that models each pivotal event. The assignments made in the rules files are indicated in this section.

Table A4.1-1. Summary of Event Trees for IHF-ESD-01

Waste Form Unit	Associated Event Trees	Number of Waste Form Units
Transportation cask containing HLW canisters	Initiator: IHF-ESD-01-HLW Response: IHF-RESP-TC1	600
Transportation cask containing a naval canister	Initiator: IHF-ESD-01-NVL Response: IHF-RESP-TC1	400

Source: *Waste Form Throughputs for Preclosure Safety Analysis* (Ref. 2.2.26, Table 4)

A4.1.1 Initiating Events for IHF-ESD-01

The following initiating events are associated with IHF-ESD-01. The assignments made within SAPHIRE for quantification of these initiating events are indicated in Table A4.1-2. In this ESD, some of the initiating events apply to both naval SNF and HLW. Others apply only to HLW or to naval SNF. The differences are due to the fact that naval casks do not arrive by truck and naval casks are lifted from the railcar with impact limiters attached whereas HLW casks are lifted after removal of the impact limiters.

Table A4.1-2. Initiating Event Assignments for IHF-ESD-01

Initiating Event Description	Initiator Event Tree	SAPHIRE Assignment by Basic Rules	SAPHIRE Assignment at Fault Tree Level[a]
Railcar derailment	IHF-ESD-01-HLW	ESD01-HLW-SPMRC DERAIL	51A-%-HLW-ON-SPMRC ***AND*** 51A-SPMRC-DERAIL-DER-FOM ***AND*** 51A-SPMRC-MILES-IN-IHF
	IHF-ESD-01-NVL	ESD01-NVL-SPMRC DERAIL	51A-SPMRC-DERAIL-DER-FOM ***AND*** 51A-SPMRC-MILES-IN-IHF
Truck trailer rollover	IHF-ESD-01-HLW	ESD01-HLW-SPMTTROLL	Screened out (Section 6.0.3)
Railcar or truck trailer collision	IHF-ESD-01-HLW	ESD01-HLW-COLLIDE	[(51A-%-HLW-ON-SPMRC) ***AND*** (51A-SPMRC-COLLISION)] ***OR*** [(51A-%-HLW ON SPMTT) ***AND*** (51A-SPMTT-COLLISION)]
	IHF-ESD-01-NVL	ESD01-NVL-COLLIDE	[(51A-% NVL ON SPMRC) ***AND*** (51A-SPMRC-COLLISION)] ***OR*** [(51A-% NVL ON SPMTT) ***AND*** (51A-SPMTT-COLLISION)]
Crane drops object on cask	IHF-ESD-01-NVL	ESD01-NVL-DROPON	ESD01-NVL-DROPON
Crane drops cask (ordinary)		ESD01-NVL-DRP-CSK	(51A-CRN3-DROPNVL-CRN-DRP) ***AND*** (51A-TRANSNSCTTLIFTNUMBER)
Crane drops cask (two-block)		ESD01-NVL-2BLK-CSK	51A-CRN3-2-BLOCK-CRN-TBK ***AND*** 51A-TRANSNSCTTLIFTNUMBER
Collision of suspended cask		ESD01-NVL-COL-CSK	51A-TC-IMPACT-SPM
Tipover of cask		ESD01-NVL-TIPOVER	51A-OPTIPOVER001-HFI-NOD

NOTE: [a] This column may contain fault trees and basic events logically connected as noted. See Attachment B for fault trees and Attachment C for basic events.

Source: Original

The following initiating events apply to both waste forms.

Railcar Derailment. This initiating event accounts for the potential impact to the transportation cask on the railcar due to a derailment.

Conveyance Collision. This initiating event covers the potential impact to the transportation cask on the conveyance due to a collision with another vehicle.