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

Basic Event ID	Basic Event Description	Basic Event Value	Bases	References
050-CRWT-TRCT-STEER-FAIL	Tractor steering system failure	1.84E-05	Probability of failure used for horizontal cask transfer trolley	Attachment B, Table B9.4-1
050-CRWT-TRLR-STEER-FAIL	Trailer steering system failure	1.84E-05	Probability of failure used for horizontal cask transfer trolley	Attachment B, Table B9.4-1
050-CTMOBJLIFTNUMBERD	Number of objects dropped on canister	1.00E+00	During canister transfer from a DPC or TAD canister, the CTM lifts a lid over the transportation cask. Therefore, a value of 1 is assigned to this basic event.	N/A
050-DPCPREPLIFTNUMBER	Number of object lifts for DPC prep	3.00E+00	There are three crane lifts associated with the preparation of the DPC in the Cask Preparation Area. Therefore, a value of 3 is assigned to this basic event.	N/A
050-DPCPREP-OBJ-MOVE	Number of object moves during DPC prep	2.00E+00	There are two crane lifts associated with the preparation of the DPC in the Cask Preparation Area. Therefore, a value of 2 is assigned to this basic event.	N/A
050-FIRE-CSNF-PREP	Prep area fire affects CSNF	5.40E-06	Frequency of a localized fire involving uncanistered SNF in transportation casks in the preparation area.	Table 6.5-4
050-FIRE-CSNF-VEST	Fire threatens CSNF in entrance vestibule	3.00E-06	Frequency of a localized fire involving uncanistered SNF in transportation casks in the entrance vestibule.	Table 6.5-4
050-FIRE-DPC-CTM	Fire affects DPC in the CTM	8.30E-08	Frequency of a localized fire involving a DPC in the CTM.	Table 6.5-4
050-FIRE-DPC-DPCCUT	Fire affects DPC at DPC cutting station	1.70E-05	Frequency of a localized fire involving a DPC at the DPC cutting station.	Table 6.5-4
050-FIRE-DPC-LARGE	Large fire affects DPC in facility	1.00E-04	Frequency of a large fire involving a DPC at the DPC cutting station.	Table 6.5-4
050-FIRE-DPC-PREP	Fire affects DPC in prep area	8.90E-06	Frequency of a localized fire involving a DPC in the preparation area.	Table 6.5-4
050-FIRE-DPC-UNLOAD	Fire affects DPC in unload room	4.90E-07	Frequency of a localized fire involving a DPC in the unloading room.	Table 6.5-4
050-FIRE-DPC-VEST	Fire affects DPC in entrance vestibule	1.20E-05	Frequency of a localized fire involving DPCs in the entrance vestibule.	Table 6.5-4

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

Basic Event ID	Basic Event Description	Basic Event Value	Bases	References
050-FIRE-LARGE-CSNF	Large fire affects CSNF	1.10E-05	Frequency of a large fire involving uncanistered SNF in the facility.	Table 6.5-4
050-FIRE-TAD-CLOSE	Fire affects TAD canister in closure area	2.30E-05	Frequency of a localized fire involving a TAD canister at the TAD canister closure station.	Table 6.5-4
050-FIRE-TAD-CTM	Fire affects TAD canister in CTM	6.90E-08	Frequency of a localized fire involving a TAD canister in the CTM.	Table 6.5-4
050-FIRE-TAD-LARGE	Large fire affects TAD canister in WHF	6.70E-05	Frequency of a large fire involving a TAD canister in the facility.	Table 6.5-4
050-FIRE-TAD-LOAD	Fire affects TAD canister in loading room	2.90E-07	Frequency of a localized fire involving a TAD canister in the loading room.	Table 6.5-4
050-FIRE-TAD-UNLOAD	Fire affects TAD canister in unload room	3.30E-07	Frequency of a localized fire involving a TAD canister in the unloading room.	Table 6.5-4
050-FIRE-TAD-VEST	Fire affects TAD canister in entrance vestibule (bolting)	3.50E-07	Frequency of a localized fire involving a TAD canister in the entrance vestibule.	Table 6.5-4
050-LIFTS-PER-DPC-CAN	Number of lifts per DPC canister	1.00E+00	There is one CTM lift associated with the transfer of the DPC. Therefore, a value of 1 is assigned to this basic event.	N/A
050-LIFTS-PER-TAD-CAN	Number lifts of TAD canister	1.00E+00	There is one CTM lift associated with the transfer of the TAD canister. Therefore, a value of 1 is assigned to this basic event.	N/A
050-OBJLIFT-DPC-CUT-TRAN	Number of object lifts during DPC cutting station transfer	1.00E+00	There is one object lift associated with DPC cutting. Therefore, a value of 1 is assigned to this basic event.	N/A
050-OBJLIFT-POOL-FLOOR	Number of object moves during pool floor transfer	1.00E+00	There is one object lift associated with the movement of a DPC to the pool floor. Therefore, a value of 1 is assigned to this basic event.	N/A
050-OBJLIFT-POOL-TRANS	Number of object lifts during transfer to pool	1.00E+00	There is one object lift associated with the movement of a DPC or TAD canister to or from the pool ledge. Therefore, a value of 1 is assigned to this basic event.	N/A
050-OBJLIFT-TAD-CLOSE	Number of object moves during TAD canister closure	2.00E+00	There are three crane lifts associated with the closure of the TAD canister at the TAD canister closure station. Therefore, a value of 2 is assigned to this basic event.	N/A

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

Basic Event ID	Basic Event Description	Basic Event Value	Bases	References
050-OBJLIFT-TAD-EXPORT	Number of object moves during TAD canister export	2.00E+00	There are two crane lifts associated with the export of the TAD canister from TAD canister closure station to CTT. Therefore, a value of 2 is assigned to this basic event.	N/A
050-OIL-MODERATOR	Oil moderator sources in WHF (gear boxes)	9.00E-05	Crane gearbox leaks oil during normal WHF operations (no fire) that could potentially create a moderator source.	Section 6.2.2.10.2
050-OTHER-WATER	Water moderator from other sources	1.50E-05	The WHF pool contains 1.4 million gal of water with the minimum required concentration of soluble boron in the pool is 2500 mg/L of boron enriched to 90 atom % ^{10}B. For all normal WHF pool operations, subcriticality is maintained crediting no more than 15% of this minimum required soluble boron concentration. Boron concentration is sampled regularly and ^{10}B is added as required. For boron concentration to reach the critical 15% level would require multiple human error events in failing to sample the boron concentration when required. In addition, 0.85 x 1.4 million = 1.2 million gal of water would have to added to dilute the ^{10}B concentration to 15%. The first human error of failing to sample is based upon a human performance limiting value of 1.0 x 10^{-5}/d from NARA (Attachment E) for a single team. In addition, it is physically impossible to displace and add 1.2 million gal of water. Hence a probability estimate of 1.0 x 10^{-6} for failure to maintain boron concentration is conservative.	Attachment E
050-SPMRC-MILES-IN-WHF	Miles traveled in WHF	4.00E-02	(Site) prime mover travel distance on rails inside the WHF.	Section 6.2.2.1 and (Ref. 2.2.27)
050-PWR-LOSS	Loss of site power	5.70E-06	Commercial power reliability requirement	N/A
050-PWR-LOSS-2	Loss of site power	5.70E-06	Commercial power reliability requirement	N/A
050-ST-#-OF-SHIELD-DOORS	Number of shield doors the site transporter passes through	2.00E+00	Site transporter goes through rooms 1023 (Site Transporter Vestibule) and 1007 (Loading Room). In this movement, it passes through two doors: an overhead door and a shield door.	Section 6.2.2.6.4 and (Ref. 2.2.27)
050-TRANSCTTLIFTNUMBER	Number of crane lifts	3.00E+00	Total number of crane lifts.	

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

Basic Event ID	Basic Event Description	Basic Event Value	Bases	References
050-TRANSSTANDLIFTNUMBER	Crane lifts with sling lift	2.00E+00	Number of lifts performed by sling lift	Section 6.4
050-UPENDOBJLIFTNUMBER	Number of object lifts	3.00E+00	Number of crane lifts performed during upending transportation cask in Cask Preparation Area	Section 6.4
050-VCTO-TRAINB-MAINT	Train B unavailable due to maintenance	4.570E-03	Estimated time that Train will be out of service due to maintenance	Section B7.4.1.5
AO-DPC-NUMB	Number of aging overpacks/ dual-purpose canisters processed over the WHF life	3.46E+02	Throughput analysis	(Ref. 2.2.26)
BORON-SYSTEM-FAILS	Boron system fails	1.00E-06	The WHF pool contains 1.4 million gal of water with the minimum required concentration of soluble boron in the pool is 2500 mg/L of boron enriched to 90 atom % ^{10}B. For all normal WHF pool operations, subcriticality is maintained crediting no more than 15% of this minimum required soluble boron concentration. Boron concentration is sampled regularly and ^{10}B is added as required. For boron concentration to reach the critical 15% level would require multiple human error events in failing to sample the boron concentration when required. In addition, 0.85 x 1.4 million = 1.2 million gal of water would have to added to dilute the ^{10}B concentration to 15%. The first human error of failing to sample is based upon a human performance limiting value of 1.0 x 10^{-5}/d from *A User Manual for the Nuclear Action Reliability Assessment (NARA) Human Error Quantification Technique* (Ref. 2.2.41) or a single team. In addition, it is physically impossible to displace and add 1.2 million gallon of water. Hence a probability estimate of 1.0 x 10^{-6} for failure to maintain boron concentration is conservative.	Attachment E
CSNF-NUMB	Number of transportation casks containing CSNF processed over the WHF life	3.78E+03	Throughput analysis	(Ref. 2.2.26)
DPC-NUMB	Number of DPCs processed through the WHF during preclosure period	3.46E+02	Total number of DPCs received at WHF over preclosure period.	(Ref. 2.2.26)
FILTER-NUMBER	Number of LLW pool filters processed	1.80E+03	Total number of filters changed out during WHF facility life.	(Ref. 2.2.28)

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

Basic Event ID	Basic Event Description	Basic Event Value	Bases	References
FUEL-NUMB	Number of fuel assemblies processed over facility life	6.62E+04	Throughput analysis	(Ref. 2.2.26)
HVAC	HVAC failure probability	3.57E-02	Quantified mean failure probability of HVAC fault tree for handling activities other than cask cooling	Attachment B.
HVAC-FAILS-DURING-PREP	HVAC fails during cask cooling or drying	9.97 E-04	Quantified mean failure probability of HVAC fault tree for cask cooling activities	Attachment B.
LOSP	Loss of offsite power	2.99E-03	Commercial power reliability requirement	N/A
LOSP-4	Failure of off site power	4.10E-06	Commercial power reliability requirement	N/A
RC-DPC-NUMB	Number of rail casks containing DPC processed over the WHF life	3.46E+02	Throughput analysis; number of DPCs arriving by rail car	(Ref. 2.2.26)
TAD-NUMB	Number of TAD canisters processed through the WHF during preclosure period	1.17E+03	Total number of TAD canisters received at WHF over preclosure period	(Ref. 2.2.26)
TIME-OVER-FLOOR-TO-CLOSE	Fraction of time over floor for movement to closure	2.00E-01	Time and motion study	Attachment F, (Ref. F2.6)
TIME-OVER-FLOOR-TO-POOL	Fraction of time over floor for movement into pool	6.00E-01	Time and motion study	Attachment F, (Ref. F2.6)
TIME-OVER-POOL-TO-CLOSE	Fraction of time over pool for movement to closure	8.00E-01	Time and motion study	Attachment F, (Ref. F2.6)
TIME-OVER-POOL-TO-POOL	Fraction of time over pool for movement into pool	4.00E-01	Time and motion study	Attachment F, (Ref. F2.6)

NOTE: CTM = canister transfer machine; CTT = cask transfer trolley; CRCF = Canister Receipt and Closure Facility; CSNF = commercial spent nuclear fuel; DPC = dual-purpose canister; HVAC = heating, ventilation and air conditioning, LLW = low-level radioactive waste; NARA = Nuclear Action Reliability Assessment; TAD = transportation, aging, and disposal; WHF = Wet Handling Facility.

Source: Original

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6.4 HUMAN RELIABILITY ANALYSIS

The PCSA has emphasized HRA because the waste handling processes include substantial interactions between equipment and operating personnel. If there are human interactions that are typically associated with the operation, test, calibration, or maintenance of a certain type of SSC (e.g., drops from a crane when using slings) and this SSC has been treated using industry-wide data per Attachment C, then 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 methodology applied is provided in Section 4.3.4, and the detailed description of the HRA is presented in Attachment E.

6.4.1 HRA Scope

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

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

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

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

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

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

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

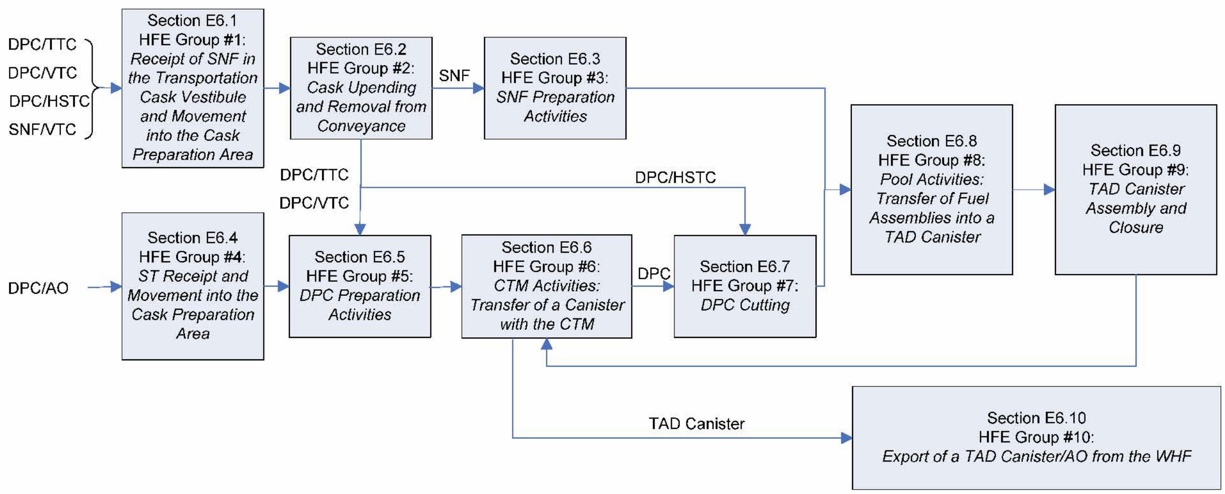
4. The exception to #3 is that system-level HFEs are considered for support systems (e.g., electrical power for confinement HVAC) when those HFEs could result in a loss of a safety function related to the occurrence or consequences associated with the events specified in #1.

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

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

6.4.2 Base Case Scenarios

The first step in this analysis is to describe the WHF operations in sufficient detail such that the human reliability analysts can identify specific deviations that would lead to a radiation release, a direct exposure, or a criticality event. To do this, the WHF operations were broken into ten separate operational steps, as depicted in Figure 6.4-1.



NOTE: AO = aging overpack; CTM = canister transfer machine; DPC = dual-purpose canister; HFE = human failure event; HSTC = cask tractor and cask transfer trailer; SNF = spent nuclear fuel; ST = site transporter; TAD = transportation, aging, and disposal; TTC = a transportation cask that is upended using a tilt frame; VTC = a transportation cask that is upended on a railcar; WHF = Wet Handling Facility.

Source: Original

Figure 6.4-1. WHF Operations

The base case scenario for each HFE group represents a realistic description of expected facility, equipment, and operator behavior for the selected operation. These scenarios are created from discussions between the human reliability analysts, other PCSA analysts, and personnel from engineering and operations. In addition to a detailed description of the operation itself, these base case scenarios include a brief description of the initial conditions and relevant equipment features (e.g., interlocks). The relationship between these HFE groups and the corresponding PFD nodes and ESDs are mapped in Attachment E, Table E6.0-1.

6.4.3 Identification of Human Failure Events

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

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

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

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

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

modeling, and it culminated in the preliminary analysis and incorporation of HFEs into the model. Included in this process is an extensive information collection process where industry data for potential vulnerabilities and HFE scenarios are reviewed. The following sources were examined:

- A Survey of Crane Operating Experience at U.S. Nuclear Power Plants from 1968 – 2002. NUREG-1774 (Ref. 2.2.55)

- Control of Heavy Loads at Nuclear Power Plants. NUREG-0612 (Ref. 2.2.65)

- Naval Facilities Engineering Command Internet web site, Navy Crane Center ("DOE Occurrence Reporting and Processing System (ORPS) Website and Naval Facilities Engineering Command (NAVFAC) Navy Crane Center Website." The database includes the following information:

  - NCC Quarterly Reports ("Crane Corner") 2001 through 2007
  - NCC Fiscal Year 2006 Crane Safety Reports (covers fiscal year 2001 through 2006)
  - NCC Fiscal Year 2006 Audit Report

- DOE Occurrence Reporting and Processing System (ORPS) Internet web site, Operational Experience Summaries (2002 through 2007) (http://www.hss.energy.gov/CSA/analysis/orps/orps.html)

- Institute of Nuclear Power Operations database (https://www.inpo.org). The Institute of Nuclear Power Operations database contains the following information:

  - Licensee event reports
  - Equipment Performance and Information Exchange System
  - Nuclear Plant Reliability Data System.

- Savannah River Site Human Error Data Base Development for Nonreactor Nuclear Facilities (U) (Ref. 2.2.11)

- All SCIENTECH/Licensing Information Service (LIS) data on Independent Spent Fuel Storage Installation events (1994 through 2007) SCIENTECH and Dry Storage Information Forum (New Orleans, LA, May 2-3, 2001): This database includes the following information:

  - Inspection reports
  - Trip reports
  - Letters, etc.

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

The result of this identification process is a list of HFEs and a description of each HFE scenario, including system and equipment conditions and any resident or triggered human factor concerns (e.g., PSFs). This combination of conditions and human 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, that sequence is above Category 1 or Category 2 according to 10 CFR 63.111 (Ref. 2.3.2) performance objectives.

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

6.4.5 Detailed Analysis

Once preliminary values have been assigned, the model is run, and HFEs are identified for a detailed analysis if (1) the HFE is a risk-driver for a dominant sequence, and (2) using the preliminary values, that sequence is Category 1 or Category 2. A dominant sequence is one that does not meet the performance objectives according to the performance objectives in 10 CFR 63.111 (Ref. 2.3.2). The objective of a detailed analysis is to develop a more realistic HRA and identify design features to be added that will provide compliance with the aforementioned regulation. Many of the ITS features of Section 6.9 were identified during the HRA. The remaining HFEs retain their assigned preliminary values. For the preliminary analysis, many of the HFEs are modeled in a simplified form in the event trees and fault trees; although, for the preliminary analysis, each action is separated as much as possible for the detailed analysis. This separation is done to ensure that the detailed analysis is thorough and that the relationship between the system functionality and operations crew is transparent. First an HFE is broken down into the various scenarios that lead to the failure. Then, each scenario is further broken down into specific required actions and their applicable procedures, along with the systems and components that must be operated during performance of each action. Each action in each scenario has its own unique context, dependencies, and set of PSFs, and each is quantified independently. The failure probabilities for these unsafe actions are quantified by the HRA method appropriate to the HFE, its classification (e.g., errors of commission, errors of omission, observation error, execution error), and the context. For this analysis, several HRA methods were considered, and the following four methods were selected (Appendix E.IV of Attachment E provides a discussion of the selection process):

- CREAM (*Cognitive Reliability and Error Analysis Method, CR*EAM (Ref. 2.2.54))
- HEART ("HEART - A Proposed Method for Assessing and Reducing Human Error"

9th Advances in Reliability Technology Symposium – 1986 (Ref. 2.2.88)/NARA (*A User Manual for the Nuclear Action Reliability Assessment (NARA) Human Error Quantification Technique* (Ref. 2.2.41))

- THERP with some modifications (*Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications Final Report.* NUREG/CR-1278 (Ref. 2.2.84))

- ATHEANA's expert elicitation approach (*Technical Basis and Implementation Guidelines for a Technique for Human Event Analysis (ATHEANA).* NUREG-1624 (Ref. 2.2.70)).

For the preliminary analysis, HFEs are modeled at a high level where several subtasks are combined into a single task so that explicit consideration of dependencies between subtasks is eliminated. For a detailed assessment, where the various actions that constitute an HFE are explicitly quantified, dependencies are also explicitly addressed using the basic formulae in Table 6.4-1 from the THERP method (Ref. 2.2.84), where N is the independently derived HEP.

Table 6.4-1.Formulae for Addressing HFE Dependencies

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

Source: Modified from Ref. 2.2.84, Table 20-17, p. 20–33

After estimates for HFE probabilities are generated, these results are reviewed by the HRA team and, in some cases, by knowledgeable operations personnel, as a "sanity check." Principally, such checks are used, for example, to compare the probabilities of different HFEs and determine whether or not these probabilities are consistent with the judgment of experts regarding the associated operator actions. A review of this type is particularly important for HFE probabilities that are generated using data from the THERP method (Ref. 2.2.84) since it is difficult to identify all important PSFs that are appropriate for repository operations. In addition, the HFE probability estimates are reviewed to ensure that they do not exceed the lower limit of credible human performance as defined by NARA (Ref. E2.2.41). HFE probabilities produced in this HRA are mean values; uncertainties are accounted for by applying an error factor to the mean value of the overall HFE according to the guidelines presented in Section E3.4 of Attachment E.

6.4.6 Human Failure Event Probabilities used in WHF Event Sequences Analysis

The results of the HRA are the HFE probabilities used in the event tree and fault tree quantification process, which are listed in Table 6.4-2.

Table 6.4-2. Human Failure Event Probability Summary

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
050-#EEE-LDCNTRA-BUA-ROE	Operator Fails to Restore Load Center (Train A) Post Maintenance	Electrical	OA (Pre-Initiator)	1.03E−05	10	Preliminary
050-#EEE-LDCNTRB-BUA-ROE	Operator Fails to Restore Load Center (Train B) Post Maintenance	Electrical	OA (Pre-Initiator)	1.03E−05	10	Preliminary
050-Liddisplace1-HFI-NOD	Operator Inadvertently Displaces Lid	29	3, 5, 7, 10	N/A[a]	N/A	Omitted from Analysis
050-LLW-Cleanup	Operator Exposed during LLW cleanup	23	OA	N/A[a]	N/A	Omitted from Analysis
050-LLW-Collision	Operator Causes Collision with LLW Container	23	OA	N/A[a]	N/A	Omitted from Analysis
050-LLW-Decon-Fail	Operator Improperly Performs Decontamination Procedures	23	OA	N/A[a]	N/A	Omitted from Analysis
050-OpCaskDrop01-HFI-NOD	Operator Drops Cask during Preparation Activities	7, 8, 9	3, 5	N/A[a]	N/A	Omitted from Analysis
050-OpClCTMGate1-HFI-NOD	Operator Inappropriately Closes Slide or Port Gate during Vertical Canister Movement and Continues Lifting	13	6	1.00E−03	5	Preliminary
050-OpCollide001-HFI-NOD	Operator Causes Low-speed Collision with RC, TT, HCTT, CTT or TTC	5, 6	2	3.00E−03	5	Preliminary
050-OpCTCollide1-HFI-NOD	Operator Causes Low-speed Collision of Auxiliary Vehicle with Cask, CTT or ST	7, 8, 9, 11, 25	3, 5, 9, 10	3.00E−03	5	Preliminary
050-OpCTCollide2-HFI-NOD	Operator Causes Low-speed Collision of the CTT during Transfer between the Preparation Station to the Cask Unloading Room	10, 14	5, 7, 9	1.00E−03	5	Preliminary
050-OpCTMDirExp1-HFI-NOD	Operator Causes Direct Exposure during CTM Activities (Second Floor, All CTM Movements)	29	6	8.00E−06	10	Detailed
050-OpCTMDrInt01-HFI-COD	Operator Lifts Canister too High with CTM	13	6	1.0	N/A	Preliminary
050-OpCTMdrop001-HFI-COD	Operator Drops Object onto Canister during CTM Operations	13	6	4.00E−07	10	Detailed
050-OpCTMdrop002-HFI-COD	Operator Causes Drop of Canister during CTM Operations	13	6	5.00E−07	10	Detailed

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

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
050-OpCTMImpact1-HFI-COD	Operator Moves the CTM while Canister or Object is below or between Levels	13	6	4.00E−08	10	Detailed
050-OpCTMImpact2-HFI-COD	Operator Causes Canister Impact with Lid during CTM Operations [AO, STC]	13	6	N/A[a]	N/A	Omitted from Analysis
050-OpCTMImpact5-HFI-COD	Operator Causes Canister Impact with SSC during CTM Operations (All)	13	6	1.0	N/A	Preliminary
050-OpCTTImpact1-HFI-NOD	Operator Causes an Impact between an SSC and a Loaded CTT/ST due to Crane Operations	7, 9	5	3.00E−03	5	Preliminary
050-OpDirExpose1-HFI-NOD	Operator Causes Direct Exposure during CTM Activities (First Floor, All CTM Movements)	29	6	1.00E−01	3	Preliminary
050-OpDirExpose2-HFI-NOD	Operator Causes Direct Exposure During CTM Activities	29	6	1.00E−04	10	Preliminary
050-OpDPC-OVP01-HFI-NOW	Operator Causes DPC Overpressurization	17	7	7.00E−08	10	Detailed
050-OpDPCShield1-HFI-NOW	Operator Fails to Properly Shield DPC while Installing Canister Lift Fixture, Leading to Direct Exposure (TC/DPC only)	29	5	4.00E−04	10	Detailed
050-OpDPCShield2-HFI-NOW	Operator Causes Loss of Shielding During DPC Cutting	29	7	2.00E−04	10	Detailed
050-OpDPCShield3-HFI-NOW	Operator Causes Loss of Shielding While Removing DPC Lift Fixture (TC/DPC only)	29	7	4.00E−04	10	Detailed
050-OpExpose-Decon	Operator Exposed During Decontamination	23	OA	N/A[a]	N/A	Omitted from Analysis
050-OpExpose-Splash	Operator Exposed Due to Pool Splash	30	7	1.0	N/A	Preliminary
050-OpFailRstInt-HFI-NOM	Operator Fails to Restore Interlock after Maintenance	29	6	1.00E−02	3	Preliminary
050-OpFailSG-HFI-NOD	Operator Fails to Close the CTM Slide Gate before Moving the CTM with the Canister inside the Bell	29	6	1.00E−03	5	Preliminary
050-OpFailStop-HFI-NOD	Operator Fails to Stop the ST if the Tread Fails	3, 11	4, 5, 10	1.0	N/A	Preliminary
050-Op-Filter-Expose	Operator Exposed During Filter Change out	23	OA	N/A[a]	N/A	Omitted from Analysis

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

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
050-OpFLCollide1-HFI-NOD	Operator Causes High-speed Collision of Loaded Conveyance or Cask with Auxiliary Vehicle	5, 6, 7, 8, 9, 11, 25	2, 3, 5, 9, 10	1.0	N/A	Preliminary
050-OpFLCollide2-HFI-NOD	Operator Causes Collision of Auxiliary Vehicle with Cask at DPC Cutting Station	15	7	N/A[a]	N/A	Omitted from Analysis
050-OpFuelImpact-HFI-NOD	Operator Impacts Fuel Assembly During Transfer	22	8	N/A[a]	N/A	Omitted from Analysis
050-OpHTCollide1-HFI-NOD	Operator Causes Low-speed Collision between HCTT and facility SSC	4	1	3.00E−03	5	Preliminary
050-OpHTIntCol01-HFI-NOD	Operator Causes High-speed Collision between HCTT and facility SSC	4	1	1.0	N/A	Preliminary
050-OpImpact0000-HFI-NOD	Operator Causes Impact of Cask during Transfer from the Platform to Loading/Unloading Room	10, 11, 14	5, 7, 10	N/A[a]	N/A	Omitted from Analysis
050-OpLoadDrop-HFI-NOD	Operator Causes ST to Drop the AO	3, 11	4, 10	N/A[a]	N/A	Omitted from Analysis
050-OpNoDiscoAir-HFI-NOD	Operator Causes Spurious Movement of CTT while Canister is Being Loaded	13	6	1.00E−03	5	Preliminary
050-OpNoUnBolt00-HFI-NOD	Operator Fails to remove Lid Bolts, Resulting in Impact, Drop, or Tipover (AO or STC)	13	6	1.00E−03	5	Preliminary
050-OpNoUnBoltDP-HFI-NOD	Operator Fails to remove Lid Bolts, Resulting in Impact, Drop, or Tipover (TC/DPC)	13	6	N/A[b]	N/A	Omitted from Analysis
050-OpNoUnplugST-HFI-NOD	Operator Causes Spurious Movement of the ST while Canister is Being Loaded	13	6	1.00E−03	5	Preliminary
050-OpRCCollide1-HFI-NOD	Operator Causes Low-speed Collision between RC and facility SSC	2	1	3.00E−03	5	Preliminary
050-OpRCIntCol01-HFI-NOD	Operator Causes High-speed Collision between RC and facility SSC	2	1	1.0	N/A	Preliminary
050-OpRCIntCol02-HFI-NOD	Operator Causes the Mobile Access Platform to Collide into a RC	2	1	1.0	N/A	Preliminary
050-OpSampleRel2-HFI-NOD	Operator Improperly Performs Gas Sampling of Canister or Cask with Bare SNF	16, 17	3, 7	5.00E−03	5	Preliminary
050-OpSDClose001-HFI-NOD	Operator Closes Shield Door on Conveyance	12	OA (5, 7, 9, 10)	1.0	N/A	Preliminary

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

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
050-OpSpurMove01-HFI-NOD	Operator Causes Spurious Movement of the CTT in the Preparation Area or ST in the ST Vestibule	6, 7, 9, 11	2, 5, 10	1.00E−04	10	Preliminary
050-OpSTCollide3-HFI-NOD	Operator Causes Low-speed Collision of ST with an SSC while Moving to the ST Vestibule or Loading Room	3, 11	4, 5, 10	3.00E−03	5	Preliminary
050-OpSTCollide4-HFI-NOD	Operator Causes Low-Speed Collision of ST with SSC while Exporting the ST	11	10	3.00E−03	5	Preliminary
050-OpSTCShield1-HFI-COD	Operator Causes a Direct Exposure Due to Failure to Properly Install the STC Shield Ring	29	9	6.00E−05	10	Detailed
050-OpTCImpact01-HFI-NOD	Operator Causes an Impact Between Cask and SSC (Preparation Area)	5, 6, 8, 11, 15, 28	2, 3, 7, 9, 10	3.00E−03	5	Preliminary
050-OpTCImpact06-HFI-NOD	Operator Causes an Impact between the Cask and an SSC during Movement between the Pool Ledge and the Outside of the Pool	19, 20, 24	8	3.00E−03	5	Preliminary
050-OpTCImpact07-HFI-COD	Operator Causes an Impact Between Cask and SSC during Cask Movement between Pool Shelf and Pool Bottom	21	8	6.00E−03	5	Preliminary
050-OpTCImpact10-HFI-NOD	Operator Causes an Impact between a Cask and an SSC during TAD Canister Closure	25	9	6.00E−03	5	Preliminary
050-OpTipover001-HFI-NOD	Operator Causes Cask to Tip Over (Preparation Area)	5, 6, 7, 8, 15, 28	2, 3, 5, 7, 9	1.00E−04	10	Preliminary
050-OpTipOver002-HFI-NOD	Operator Causes Cask to Tip Over during Movement between Pool Ledge and Outside the Pool	19, 20, 24	8	3.00E−03	5	Preliminary
050-OpTipOver004-HFI-COD	Operator Causes Cask to Tip Over during Cask Movement between Pool Shelf and Pool Bottom	21	8	6.00E−03	5	Preliminary
050-OpTipOver3-HFI-NOD	Operator Causes a Tipover of CTT during Movement to the Cask Unloading Room or Tipover of ST with Jib Crane	10, 11	5, 10	N/A[a]	N/A	Omitted from Analysis
050-OpTTCollide1-HFI-NOD	Operator Causes Low-speed Collision between TT and facility SSC	1	1	3.00E−03	5	Preliminary

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

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
050-OpTTIntCol01-HFI-NOD	Operator Causes High-speed Collision between TT and facility SSC	1	1	1.0	N/A	Preliminary
050-OpTTIntCol02-HFI-NOD	Operator Causes the Mobile Access Platform to Collide into a TT	1	1	1.0	N/A	Preliminary
050-OpTTRollover-HFI-NOD	Operator Causes a TT or HCTT to Rollover as the Conveyance Moves into the Cask Preparation Area	1, 4	1	N/A[a]	N/A	Omitted from Analysis
050-TadDry-Fail	Operator Leaves Water in the TAD Canister	26	9	N/A[a]	N/A	Omitted from Analysis
050-VCSO-DR00001-HFI-NOD	Operators Open Two or More Vestibule Doors in WHF	HVAC	OA (Pre-initiator)	1.00E−02	3	Preliminary
050-VCSO-HEPALK-HFI-NOD	Operator Fails to Notice HEPA Filter Leak in Train A	HVAC	OA (Pre-initiator)	1.0	N/A	Preliminary
050-VCSO-HFIA000-HFI-NOM	Human Error Exhaust Fan Switch Wrong Position	HVAC	OA (Pre-initiator)	1.00E−01	3	Preliminary
050-WeldDetect-Fail	Operator Causes Defective Weld or Fails to Detect a Bad Weld	27	9	N/A[a]	N/A	Omitted from Analysis
26D-#EEY-ITSDG-A-#DG-RSS	Operator Fails to Restore Diesel Generator to Service (Train A)	Electrical	OA (Pre-initiator)	1.95E−04	10	Preliminary
26D-#EEY-ITSDG-B-#DG-RSS	Operator Fails to Restore Diesel Generator to Service (Train B)	Electrical	OA (Pre-initiator)	1.95-04	10	Preliminary
Crane Drops	Operator Causes Drop of Cask or Drop of Object onto Cask	OA (5-9, 15, 17-24, 30)	OA (2, 3, 5, 7, 8)	N/A [b]	N/A	Historical Data
Drop from SNF Transfer Machine	Operator Causes Drop of Fuel Assembly	22	8	N/A [b]	N/A	Historical Data
Fuel Transpose	Operator Misloads TAD Canister	N/A	8	N/A[a]	N/A	Omitted from Analysis
Gas Sampling	Operator Improperly Performs Gas Sampling of Cask with Canister	29	5	N/A[a]	N/A	Omitted from Analysis
Improper Boration	Operator Fails to Maintain Proper Boron Concentration	N/A	8	N/A[a]	N/A	Omitted from Analysis
Load too Heavy	Operator attempts to lift load which is greater than crane rating	OA	OA	N/A[a]	N/A	Omitted from Analysis

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

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
Moderator	Operator Introduces Moderator Source in to Moderator-Controlled Areas of the WHF	OA	OA	N/A[a]	N/A	Omitted from Analysis
RC Derailment	Operator Causes RC to Derail as the RC travels into the Cask Preparation Area	1	1	N/A [b]	N/A	Historical Data
Spurious Movement of CTT or ST during CTM Activities	Operator Causes Spurious Movement of CTT or ST while Canister is Being Loaded	13	6	N/A[a]	N/A	Omitted from Analysis
ST Rollover	Operator Causes the ST to Rollover in the ST Vestibule	3, 11	4, 10	N/A[a]	N/A	Omitted from Analysis

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

AO = aging overpack; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; ESD = event sequence diagram; HCTT = cask tractor and cask transfer trailer; HFE = human failure event; HSTC = horizontal shielded transfer cask; LLW = low-level radioactive waste; N/A = not applicable; OA = over arching (applies to multiple HFE groups, Section E6.0.2); RC = railcar; SNF = spent nuclear fuel; ST = site transporter; SSC = structure, system, or component; SSCs = structures, systems, and components; STC = shielded transfer cask; TAD = transportation, aging, and disposal; TC = transportation cask; TT = truck trailer; TTC = a transportation cask that is upended using a tilt frame; VTC = a transportation cask that is upended on a railcar; WHF = Wet Handling Facility.

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

6.5 FIRE INITIATING EVENTS

Attachment F of this document describes the work scope, methodology, and results for the fire analysis performed as a part of the PCSA. The internal events of the PCSA model are evaluated with respect to fire initiating events and modified as necessary to address fire-induced failures that lead to exposures. The list of fire-induced failures included in the model are evaluated as to fire vulnerability, and fragility analyses are conducted as needed (Section 6.3.2 and Attachment D, Section D2.1.5).

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

6.5.1 Input to Initiating Events

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

Room dimensions (Section F5.2.1 of Attachment F) are utilized to determine individual room areas, and the total building area. The area of the WHF is utilized to evaluate the building ignition frequency. From methodology and equations presented in Section F4.3.1 of Attachment F, over the 50-year facility operation period the building ignition frequency of 2.96 is obtained for the WHF. The results of this portion of the analysis are summarized in Table 6.5-1.

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

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

Table 6.5-1. Room Areas and Total Ignition Frequency

Room	Area(sq-m)	Room	Area(sq-m)	Room	Area(sq-m)	Room	Area(sq-m)
B001	69	1018B	14	1044B	25	2002	216
B002	65	1019	186	1044C	25	2003	134
B003	38	1020	30	1045A	33	2004	1017
B004	68	1021	216	1045B	33	2005A	142
B005	35	1022	6	1045C	100	2005B	90
B006	3	1023	434	1045D	99	2006	136
B007	7	1024	20	1046	158	2007A	52
B008	62	1025	29	1201	8	2007B	197
B009	65	1026	31	1202	21	2008	522
1001	1630	1027	31	1203	34	2010	216
1002	186	1028	56	1204	40	2011A	95
1003	30	1029	28	1205	44	2011B	120
1004	216	1030	17	1206	12	2012	241
1005	9	1031	31	1207	51	2013	14
1006	160	1032	27	1208	9	2024	18
1007	182	1032A	22	1209	39	2025	45
1008	133	1033	32	1210	22	2026	31
1009	228	1034	29	1211	12	2027	31
1010	38	1035	17	1212	21	2029	17
1011A	51	1036	17	1213	15	2030	14
1011B	137	1037	7	1214	15	2032	9
1012A	49	1038	7	1215	70	2033	12
1012B	100	1039	7	1216	25	2034	29
1013	315	1042A	19	1217	25	2201	19
1014	18	1042B	19	1218A	60	2202	30
1015	6	1042C	19	1218B	30	2203	52
1016	4097	1043A	30	1218C	58	2204	12
1017	269	1043B	30	M001	474	2205	13
1018	21	1043C	30	2001	140	2206	8
1018A	14	1044A	25	2001A	46		

Total Area (sq-m)	15046
Ignition Frequency (per sq-m/yr)	3.94E-06
Ignition Frequency (per yr)	5.93E-02

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

Source: Table F5.2-1 of Attachment F

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

- Motor control centers, load centers, and equipment racks contribute an ignition source for each active vertical cabinet

- An ignition source is counted for each motor over 5 hp for all equipment with motors
- A welding ignition source is counted for each hour of operation expected per year
- The ignition sources for mobile equipment are split between the rooms the equipment occupies in proportion to the amount of time the equipment will spend in each room
- An ignition source is counted for every square meter in the room for the no equipment involved category.

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

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

Room	Electrical	HVAC	Mechanical Equipment	Torches, Welders, Burners	Internal Combustion Engines	Office/ Kitchen Equipment	Portable Equipment
B002	—	—	2	—	—	—	—
P001	—	—	—	—	—	—	—
1001	—	4	3	10	22	—	—
1002	22	2	—	5	—	—	4
1003	1	4	—	—	—	—	—
1004	—	4	—	5	—	—	4
1006	—	6	—	—	—	—	4
1007	—	—	—	—	61	—	—
1008	—	—	0.03	—	—	—	2
1009	—	—	—	5	—	—	—
1013	—	—	1	5	—	—	—
1016	—	—	36.97	365	78	—	8
1017	5	—	4	—	—	—	—
1018	—	2	—	400	—	—	—
1019	23	2	—	5	—	—	4
1020	1	4	—	—	—	—	—
1021	—	4	—	—	—	—	4
1023	—	3	4	—	39	—	—
1028	—	—	1	—	—	—	—
1036	—	—	1	—	—	—	—
1042A	—	—	1	—	—	—	—
1042B	—	—	1	—	—	—	—
1042C	—	—	1	—	—	—	—

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

Room	Electrical	HVAC	Mechanical Equipment	Torches, Welders, Burners	Internal Combustion Engines	Office/ Kitchen Equipment	Portable Equipment
1045C	—	—	1	—	—	—	—
1046	92	—	—	—	—	—	—
1202	—	—	—	—	—	1	—
1205	—	—	—	—	—	1	—
1209	—	—	—	—	—	1	—
1210	—	—	—	—	—	1	—
1211	—	—	—	—	—	1	—
1212	—	—	—	—	—	1	—
1215	—	—	—	—	—	1	—
1216	—	—	—	—	—	1	—
1217	—	—	—	—	—	1	—
M001	—	3	—	—	—	—	4
2001	66	—	—	—	—	—	4
2001A	1	4	—	—	—	—	
2002	—	2	—	—	—	—	4
2003	—	1	—	—	—	—	4
2004	—	—	7	5	—	—	2
2008	—	—	—	5	—	—	—
2010	—	4	—	—	—	—	4
2011A	—	—	—	—	—	2	—
2011B	—	—	—	—	—	2	—
2012	6	—	—	—	—	2	—
2201	—	—	—	—	—	1	—
2202	—	—	—	—	—	1	—
2203	—	—	—	—	—	3	—
TOTAL	**217**	**49**	**64**	**810**	**200**	**20**	**52**

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

Source: Table F5.5-1 of Attachment F

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

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

Table 6.5-3. Residence Fractions

Initiating Event	Residence Fraction
TC/SNF or TC/DPC (including TTC) on Railcar/Trailer in Receipt Area with Tractor (Diesel Present)	
TC/SNF or TC/DPC (including TTC) on Railcar/Trailer in Receipt Area with Tractor (Diesel)	1.7E-06
Waste Form on Railcar/Trailer in Receipt Area without Tractor/SPM (No Diesel Present)	
TC/SNF on Truck Trailer in Receipt Area without Tractor (No Diesel)	1.0E-05
TC/DPC (TTC) on Railcar/Trailer in Receipt Area without Tractor/SPM (No Diesel)	3.1E-05
TC/DPC on Truck Trailer in Receipt Area without Tractor (No Diesel)	1.6E-05
TC/SNF in the Preparation Area	
TC/SNF (Dry Cavity) in the Preparation Station in the Preparation Area	3.9E-06
TC/SNF (Wet Cavity) in the Preparation Station in the Preparation Area	7.7E-06
TC/DPC or STC/DPC on CTT in the Preparation Station	
TC/DPC (all) on CTT in the Preparation Station in the Preparation Area	2.4E-05
STC/DPC (all) on CTT in the Preparation Station in the Preparation Area	3.1E-05
Waste Form on CTT in the Unloading Room	
TC/DPC (all) on CTT in the Unloading Room	2.0E-06
STC/DPC (all) on CTT in the Unloading Room	5.0E-06
STC/TAD Canister on CTT in the Unloading Room	4.3E-06
DPC or TAD Canister in the Transfer Room	
DPC (all) in the Transfer Room	1.1E-06
TAD Canister in the Transfer Room	9.1E-07
STC/DPC in DPC Cutting Station in the Preparation Area	
STC/DPC in DPC Cutting Station (Dry Cavity, Dry Annulus) in the Preparation Area	6.1E-06
STC/DPC in DPC Cutting Station (Dry Cavity, Wet Annulus) in the Preparation Area	4.2E-05
STC/DPC in DPC Cutting Station (Wet Cavity, Wet Annulus) in the Preparation Area	3.4E-05
STC/TAD Canister in TAD Closure Station in the Preparation Area	
STC/TAD in TAD Closure Station (Dry Cavity, Dry Annulus) in the Preparation Area	1.6E-05
STC/TAD in TAD Closure Station (Dry Cavity, Wet Annulus) in the Preparation Area	7.0E-05
STC/TAD in TAD Closure Station (Wet Cavity, Wet Annulus) in the Preparation Area	4.1E-05
TAD Canister in Aging Overpack in Loading Room	
TAD in Aging Overpack in Loading Room	3.7E-06
TAD Canister in Aging Overpack in Site Transporter Vestibule	
TAD in Aging Overpack in Site Transporter Vestibule	9.7E-06
TC/SNF or TC/DPC (all) (Diesel Present)	1.7E-06
TC/SNF (No Diesel)	1.4E-05
TC/DPC (TTC) (No Diesel)	5.6E-05
TC/DPC (No Diesel)	3.9E-05
DPC (all) in CTM	1.1E-06
STC/DPC (all)	4.1E-05

Table 6.5-3. Residence Fractions (Continued)

Initiating Event	Residence Fraction
STC/DPC (all) (Dry Cavity, Wet Annulus)	4.2E-05
STC/DPC (all) (Wet Cavity, Wet Annulus)	3.4E-05
TC/SNF (Wet Cavity)	7.7E-06
STC/TAD Canister (Wet Cavity, Wet Annulus)	4.1E-05
STC/TAD Canister (Dry Cavity, Wet Annulus)	7.0E-05
STC/TAD Canister (Dry Cavity, Dry Annulus)	1.9E-05
TAD Canister in CTM	9.1E-07
TAD Canister in Aging Overpack	1.3E-05

NOTE: CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; SNF = spent nuclear fuel; SPM = site prime mover; STC = shielded transfer cask; TAD = transportation, aging, and disposal; TC = transportation cask; TTC= transportation cask in the tilted position.

Source: Attachment F, Table F5.7-1

6.5.2 Initiating Event Frequencies

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

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

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

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

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

Initiating Event	Equipment	Mean	Median	97.5% Value	Error Factor	Type
Localized Fire Threatens TC/SNF or TC/DPC (including TTC) on Railcar/Trailer in Receipt Area with Tractor (Diesel Present)						
Localized Fire Threatens TC/SNF or TC/DPC (including TTC) on Railcar/Trailer in Receipt Area with Tractor (Diesel Present)	Railcar/Truck	4.7E-07	4.2E-07	1.1E-06	2.2E+00	Lognormal
Localized Fire Threatens Waste Form on Railcar/Trailer in Receipt Area without Tractor/SPM (No Diesel Present)						
Localized Fire Threatens TC/SNF on Truck Trailer in Receipt Area without Tractor (No Diesel Present)	Railcar/Truck	2.5E-06	2.3E-06	5.7E-06	2.2E+00	Lognormal
Localized Fire Threatens TC/DPC (TTC) on Railcar/Trailer in Receipt Area without Tractor/SPM (No Diesel Present)	Railcar/Truck	7.6E-06	6.8E-06	1.7E-05	2.2E+00	Lognormal
Localized Fire Threatens TC/DPC on Truck Trailer in Receipt Area without Tractor (No Diesel Present)	Railcar/Truck	4.0E-06	3.6E-06	9.0E-06	2.2E+00	Lognormal
Localized Fire Threatens TC/SNF in the Preparation Area						
Localized Fire Threatens TC/SNF (Dry Cavity) in the Preparation Station in the Preparation Area	Preparation Station	1.9E-06	1.7E-06	4.2E-06	2.1E+00	Lognormal
Localized Fire Threatens TC/SNF (Wet Cavity) in the Preparation Station in the Preparation Area	Preparation Station	3.6E-06	3.3E-06	8.2E-06	2.1E+00	Lognormal
Localized Fire Threatens TC/DPC or STC/DPC on CTT in the Preparation Station						
Localized Fire Threatens TC/DPC (all) on CTT in the Preparation Station in the Preparation Area	Cask Transfer Trolley	4.2E-06	3.8E-06	9.8E-06	2.2E+00	Lognormal
Localized Fire Threatens STC/DPC (all) on CTT in the Preparation Station in the Preparation Area	Cask Transfer Trolley	5.4E-06	4.8E-06	1.3E-05	2.2E+00	Lognormal
Localized Fire Threatens Waste Form on CTT in the Unloading Room						
Localized Fire Threatens TC/DPC (all) on CTT in the Unloading Room	Cask Transfer Trolley	1.5E-07	1.4E-07	3.5E-07	2.2E+00	Lognormal
Localized Fire Threatens STC/DPC (all) on CTT in the Unloading Room	Cask Transfer Trolley	3.9E-07	3.5E-07	8.9E-07	2.2E+00	Lognormal

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

Initiating Event	Equipment	Mean	Median	97.5% Value	Error Factor	Type
Localized Fire Threatens STC/TAD Canister on CTT in the Unloading Room	Cask Transfer Trolley	3.3E-07	3.0E-07	7.6E-07	2.2E+00	Lognormal
Localized Fire Threatens DPC or TAD Canister in the Transfer Room						
Localized Fire Threatens DPC (all) in the Transfer Room	Canister Transfer Machine	8.3E-08	7.4E-08	1.9E-07	2.2E+00	Lognormal
Localized Fire Threatens TAD Canister in the Transfer Room	Canister Transfer Machine	6.9E-08	6.2E-08	1.6E-07	2.2E+00	Lognormal
Localized Fire Threatens STC/DPC in DPC Cutting Station in the Preparation Area						
Localized Fire Threatens STC/DPC (all) in DPC Cutting Station (Dry Cavity, Dry Annulus) in the Preparation Area	DPC Cutting Station	1.2E-06	1.1E-06	2.8E-06	2.2E+00	Lognormal
Localized Fire Threatens STC/DPC (all) in DPC Cutting Station (Dry Cavity, Wet Annulus) in the Preparation Area	DPC	8.3E-06	7.4E-06	1.9E-05	2.2E+00	Lognormal
Localized Fire Threatens STC/DPC (all) in DPC Cutting Station (Wet Cavity, Wet Annulus) in the Preparation Area	DPC	6.8E-06	6.0E-06	1.5E-05	2.2E+00	Lognormal
Localized Fire Threatens STC/TAD Canister in TAD Closure Station in the Preparation Area						
Localized Fire Threatens STC/TAD in TAD Closure Station (Dry Cavity, Dry Annulus) in the Preparation Area	TAD Closure Station	7.5E-06	6.8E-06	1.7E-05	2.1E+00	Lognormal
Localized Fire Threatens STC/TAD Canister in TAD Closure Station (Dry Cavity, Wet Annulus) in the Preparation Area	TAD Closure Station	8.6E-06	7.6E-06	2.0E-05	2.2E+00	Lognormal
Localized Fire Threatens STC/TAD Canister in TAD Closure Station (Wet Cavity, Wet Annulus) in the Preparation Area	TAD Closure Station	6.8E-06	6.1E-06	1.6E-05	2.2E+00	Lognormal
Localized Fire Threatens TAD Canister in Aging Overpack in Loading Room						
Localized Fire Threatens TAD Canister in Aging Overpack in Loading Room	Site Transporter	2.9E-07	2.6E-07	6.8E-07	2.2E+00	Lognormal
Localized Fire Threatens TAD Canister in Aging Overpack in Site Transporter Vestibule						
Localized Fire Threatens TAD Canister in Aging Overpack in Site Transporter Vestibule	Site Transporter	3.5E-07	3.1E-07	8.3E-07	2.2E+00	Lognormal
Large Fire Threatens TC/SNF or TC/DPC (all) (Diesel Present)		7.9E-07	7.0E-07	1.8E-06	2.2E+00	Lognormal

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

Initiating Event	Equipment	Mean	Median	97.5% Value	Error Factor	Type
Large Fire Threatens TC/SNF (No Diesel)		6.7E-06	5.9E-06	1.6E-05	2.2E+00	Lognormal
Large Fire Threatens TC/DPC (TTC) (No Diesel)		2.6E-05	2.3E-05	6.1E-05	2.2E+00	Lognormal
Large Fire Threatens TC/DPC (No Diesel)		1.8E-05	1.6E-05	4.3E-05	2.2E+00	Lognormal
Large Fire Threatens DPC (all) in CTM		5.2E-07	4.6E-07	1.2E-06	2.3E+00	Lognormal
Large Fire Threatens STC/DPC (all)		1.9E-05	1.7E-05	4.5E-05	2.1E+00	Lognormal
Large Fire Threatens STC/DPC (all) (Dry Cavity, Wet Annulus)		2.0E-05	1.7E-05	4.6E-05	2.4E+00	Lognormal
Large Fire Threatens STC/DPC (all) (Wet Cavity, Wet Annulus)		1.6E-05	1.4E-05	3.7E-05	2.3E+00	Lognormal
Large Fire Threatens TC/SNF (Wet Cavity)		3.6E-06	3.2E-06	8.4E-06	2.2E+00	Lognormal
Large Fire Threatens STC/TAD Canister (Wet Cavity, Wet Annulus)		1.9E-05	1.7E-05	4.4E-05	2.2E+00	Lognormal
Large Fire Threatens STC/TAD Canister (Dry Cavity, Wet Annulus)		3.3E-05	2.9E-05	7.7E-05	2.2E+00	Lognormal
Large Fire Threatens STC/TAD Canister (Dry Cavity, Dry Annulus)		8.8E-06	7.8E-06	2.1E-05	2.2E+00	Lognormal
Large Fire Threatens TAD Canister in CTM		4.3E-07	3.8E-07	1.0E-06	2.2E+00	Lognormal
Large Fire Threatens TAD Canister in Aging Overpack		5.9E-06	5.3E-06	1.4E-05	2.2E+00	Lognormal

NOTE: CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; SPM = site prime mover; SNF = spent nuclear fuel; STC = shielded transfer cask; TAD = transportation, aging, and disposal; TC = transportation cask; TTC=transportation cask in tilting position.

Source: Table F5.7-5 of Attachment F

For use in the model, some fire initiating event results were summed, and are illustrated in Table 6.5-5. These are sums of distributions, and were therefore performed using Crystal Ball. Table 6.5-6 provides the fire analysis data for the basic events in this model.

Table 6.5-5 Basic Events Data Associated with Fire Analysis

Fire Initiating Events	Mean
Localized Fire Threatens TC/DPC (TTC) on Railcar/Trailer in Receipt Area without Tractor/SPM (No Diesel Present)	7.6E-06
Localized Fire Threatens TC/DPC on Truck Trailer in Receipt Area without Tractor (No Diesel Present)	4.0E-06
Localized Fire Threatens TC/SNF or TC/DPC (including TTC) on Railcar/Trailer in Receipt Area with /Tractor (Diesel Present)	4.7E-07
Total	**1.2E-05**
Localized Fire Threatens TC/SNF or TC/DPC (including TTC) on Railcar/Trailer in Receipt Area with Tractor (Diesel Present)	4.7E-07
Localized Fire Threatens TC/SNF on Truck Trailer in Receipt Area without Tractor (No Diesel Present)	2.5E-06
Total	**3.0E-06**
Localized Fire Threatens TC/SNF (Dry Cavity) in the Preparation Station in the Cask Preparation Area	1.9E-06

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

Fire Initiating Events	Mean
Localized Fire Threatens TC/SNF (Wet Cavity) in the Preparation Station in the Cask Preparation Area	3.6E-06
Total	**5.4E-06**
Localized Fire Threatens TC/DPC (all) on CTT in the Preparation Station in the Cask Preparation Area	4.2E-06
Localized Fire Threatens STC/DPC (all) on CTT in the Preparation Station in the Cask Preparation Area	5.4E-06
Total	**8.9E-06**
Localized Fire Threatens TC/DPC (all) on CTT in the Cask Unloading Room	1.5E-07
Localized Fire Threatens STC/DPC (all) on CTT in the Cask Unloading Room	3.9E-07
Total	**4.9E-07**
Localized Fire Threatens STC/DPC (all) in DPC Cutting Station (Dry Cavity, Dry Annulus) in the Cask Preparation Area	1.2E-06
Localized Fire Threatens STC/DPC (all) in DPC Cutting Station (Dry Cavity, Wet Annulus) in the Cask Preparation Area	8.3E-06
Localized Fire Threatens STC/DPC (all) in DPC Cutting Station (Wet Cavity, Wet Annulus) in the Cask Preparation Area	6.8E-06
Total	**1.7E-05**
Localized Fire Threatens STC/TAD Canister in TAD Closure Station (Dry Cavity, Dry Annulus) in the Cask Preparation Area	7.5E-06
Localized Fire Threatens STC/TAD Canister in TAD Closure Station (Dry Cavity, Wet Annulus) in the Cask Preparation Area	8.6E-06
Localized Fire Threatens STC/TAD Canister in TAD Closure Station (Wet Cavity, Wet Annulus) in the Cask Preparation Area	6.8E-06
Total	**2.3E-05**
Large Fire Threatens TC/SNF or TC/DPC (all) (Diesel Present)	7.9E-07
Large Fire Threatens TC/SNF (No Diesel)	6.7E-06
Large Fire Threatens TC/SNF (Wet Cavity)	3.6E-06
Total	**1.1E-05**
Fire Initiating Events	**Mean**
Large Fire Threatens TC/DPC (TTC) (No Diesel)	2.6E-05
Large Fire Threatens TC/DPC (No Diesel)	1.8E-05
Large Fire Threatens DPC (all) in CTM	5.2E-07
Large Fire Threatens STC/DPC (all)	1.9E-05
Large Fire Threatens STC/DPC (all) (Dry Cavity, Wet Annulus)	2.0E-05
Large Fire Threatens STC/DPC (all) (Wet Cavity, Wet Annulus)	1.6E-05
Total	**1.0E-04**
Large Fire Threatens STC/TAD Canister (Wet Cavity, Wet Annulus)	1.9E-05
Large Fire Threatens STC/TAD Canister (Dry Cavity, Wet Annulus)	3.3E-05
Large Fire Threatens STC/TAD Canister (Dry Cavity, Dry Annulus)	8.8E-06
Large Fire Threatens TAD Canister in CTM	4.3E-07
Large Fire Threatens TAD Canister in Aging Overpack	5.9E-06
Total	**6.7E-05**

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

NOTE: CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; SNF = spent nuclear fuel; SPM = site prime mover; STC = shielded transportation cask; TAD = transportation, aging, and disposal; TC= transportation cask; TTC = a transportation cask that is upended using a tilt frame.

Source: Original

Table 6.5-6. Basic Events Data Associated with Fire Analysis

Basic Event Name	Basic Event Description	BE Value	Bases	References
050-FIRE-CSNF-PREP	Cask Preparation Area fire affects CSNF	5.4E-06	Localized fire threatens a TC containing CSNF (dry or wet cavity) at the preparation station in the Cask Preparation Area (no diesel).	Table 6.5-5
050-FIRE-CSNF-VEST	Fire threatens CSNF in Transportation Cask Vestibule	3.0E-06	Localized fire threatens a TC containing CSNF on the railcar/trailer in the receipt area/ Transportation Cask Vestibule.	Table 6.5-5
050-FIRE-DPC-CTM	Fire affects DPC in the CTM	8.3E-08	Localized fire threatens DPC in the Canister Transfer Room.	Table 6.5-4
050-FIRE-DPC-DPCCUT	Fire affects DPC at DPC cutting station	1.7E-05	Localized fire threatens a DPC (dry or wet cavity/annulus) at the DPC cutting station in the Cask Preparation Area.	Table 6.5-5
050-FIRE-DPC-LARGE	Large fire affects DPC	1.0E-04	Large fire threatens DPC anywhere in the WHF.	Table 6.5-5
050-FIRE-DPC-PREP	Fire affects DPC in Cask Preparation Area	8.9E-06	Localized fire threatens a TC or STC containing a DPC on the CTT at the preparation station in the Cask Preparation Area.	Table 6.5-5
050-FIRE-DPC-UNLOAD	Fire affects DPC in Cask Unloading Room	4.9E-07	Localized fire threatens a TC or STC containing a DPC on the CTT in the Cask Unloading Room.	Table 6.5-5
050-FIRE-DPC-VEST	Fire affects DPC in Transportation Cask Vestibule	1.2E-05	Localized fire threatens a TC containing a DPC on a railcar/trailer in the receipt area/ Transportation Cask Vestibule.	Table 6.5-5
050-FIRE-LARGE-CSNF	Large fire affects CSNF	1.1E-05	Large fire threatens CSNF anywhere in the WHF.	Table 6.5-5
050-FIRE-TAD-CLOSE	Fire affects TAD canister in closure area	2.3E-05	Localized fire threatens an STC containing a TAD canister (dry or wet cavity/annulus) at the closure station in the Cask Preparation Area.	Table 6.5-5
050-FIRE-TAD-CTM	Fire affects TAD canister in CTM	6.9E-08	Localized fire threatens TAD canister on the CTM in the Canister Transfer Room.	Table 6.5-4
050-FIRE-TAD-LARGE	Large fire affects TAD canister	6.7E-06	Large fire threatens a TAD canister anywhere in the WHF.	Table 6.5-5

Table 6.5-6. Basic Events Data Associated with Fire Analysis (Continued)

Basic Event Name	Basic Event Description	BE Value	Bases	References
050-FIRE-TAD-LOAD	Fire affects TAD canister in Loading Room	2.9E-07	Localized fire threatens TAD canister in aging overpack in the Loading Room.	Table 6.5-4
050-FIRE-TAD-UNLOAD	Fire affects TAD Canister in Cask Unloading Room	3.3E-07	Localized fire threatens STC containing TAD canister on the CTT in the Cask Unloading Room.	Table 6.5-4
050-FIRE-TAD-VEST	Fire affects TAD in Site Transporter Vestibule	3.5E-07	Localized fire threatens TAD canister in aging overpack in the Site Transporter Vestibule.	Table 6.5-4

NOTE: CSNF = commercial spent nuclear fuel; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; STC = shielded transportation cask; TAD = transportation, aging, and disposal; TC= transportation cask.

Source: Original

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6.7 EVENT SEQUENCE FREQUENCY RESULTS

This section provides the results of the event sequence quantification as produced from the SAPHIRE (Ref. 2.2.77) 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 a table 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). In SAPHIRE, the quantification of an event sequence is always labeled as a "frequency" in the output formats.

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 TAD canister by a CTM in the WHF 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 TAD canister during its transfer by the CTM in the WHF, or the probability of occurrence of a fire that could affect the TAD 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 TAD 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 HFEs 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 (Section 4.2) 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 they occur, will cause the event sequence to occur. The event sequence frequency is calculated as the sum of frequencies of the cut sets. No cutoff probability was used to ensure that event sequences are grouped properly.

As an illustration of the above process, the quantification of the event sequence initiated by a drop of a TAD canister during a transfer in the WHF, 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.

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. 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) event sequence variance.

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. 2.2.33). 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. 2.2.33, 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 in pool	Breach of uncanistered commercial SNF assembly in pool (one drops onto another)	2 PWR or 2 BWR commercial SNF
2-12	Uncanistered commercial SNF in pool	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 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: Items marked with an asterisk (*) are not applicable to the WHF.
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; LLW = low-level radioactive waste; TAD = transportation, aging and disposal.

Source: Ref. 2.2.33, 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 WHF. 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 are as follows.

- TAD canister, by itself, in a transportation cask, or in an aging overpack
- DPC, by itself, in a transportation cask, or an aging overpack
- Transportation cask containing bare SNF assemblies
- SNF assembly (handled in the pool of the WHF)
- Low-level waste.

In SAPHIRE (Section 4.2), 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 nonminimal 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 into the WHF are partitioned among seven different initiating events such as canister drop, collision, and drop of a heavy load on the canister. Refer to the IETs in Figures A5-22 and A5-23 and the SRET in Figure A5-7. 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 TAD 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 TAD 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 re-calculate 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 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 TAD canister drops in the WHF over the preclosure period is essentially controlled, among other things, by the number of TAD 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* 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 (10 CFR 63.2 (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 (10 CFR 63.2 (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 Monte Carlo 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 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 SAPHIRE event sequence gathering and quantification process are reported in a single table of all event sequences for the WHF (Attachment G, Table G-2). Following the final categorization, the event sequences for the respective Category 2 (see Table 6.8-3) and Beyond Category 2 (Attachment G, Table G-3) are tabulated separately. There are no Category 1 (Table 6.8-2) events for the WHF. 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. It is composed of the event tree name (less the facility identifier, WHF, a sequence identifier such as SEQ2 (which indicates the associated branch of the response tree), and an abbreviated end-state designator (as explained in Section 4.3-8 and in the end state column of the table).

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. 2.2.33, 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	Std Dev	Event Sequence. Cat.	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[1]	Mean[2]	Median[2]	Std Dev[2]	Event Sequence Category	Basis for Categorization	Consequence Analysis[3]
ESD29-DPC-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a direct exposure during operations involving a DPC (transportation cask preparation, transfer by CTM, DPC cutting). In this sequence there are no pivotal events.	1 DPC	3.E-01	3.E-01	2.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[4]
ESD22-FUEL-SEQP-GRRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to SNF assemblies during fuel transfer activities, resulting in an unfiltered radionuclide release in the pool. In this sequence an adequate boron concentration is maintained. This sequence occurs inside the pool.	2 SNF assemblies	3.E-01	3.E-01	2.E-01	Category 2	Mean of distribution for number of occurrences of event sequence near a category threshold. Categorization confirmed by alternative distribution	2-11
ESD31-TAD-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a thermal challenge to a TAD canister inside an STC due to a fire, resulting in a direct exposure from loss of shielding. In this sequence the canister remains intact, and the shielding fails.	1 TAD canister	1.E-01	1.E-01	4.E-02	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[4]

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

Event Sequence Group ID	End State	Description	Material-At-Risk[1]	Mean[2]	Median[2]	Std Dev[2]	Event Sequence Category	Basis for Categorization	Consequence Analysis[3]
ESD16-CSNF-SEQ1-RRF	Filtered radionuclide release	This event sequence represents a structural challenge to a transportation cask with uncanistered SNF assemblies during preparation activities (sampling, gas cooling, water filling), resulting in a filtered radionuclide release. In this sequence the confinement boundary remains intact, and no condition important to criticality occurs.	1 transportation cask with uncanistered SNF assemblies	1.E-01	5.E-02	2.E-01	Category 2	Mean of distribution for number of occurrences of event sequence	2-05
ESD29-TAD-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a direct exposure during operations involving a TAD canister (assembly and closure, transfer by CTM). In this sequence there are no pivotal events.	1 TAD canister	9.E-02	5.E-02	2.E-01	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[4]
ESD31-CSNF-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a thermal challenge to a transportation cask with uncanistered SNF assemblies due to a fire, resulting in a direct exposure from loss of shielding. In this sequence the transportation cask containment function remains intact, and the shielding fails.	1 transportation cask with uncanistered SNF assemblies	7.E-02	7.E-02	2.E-02	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[4]

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

Event Sequence Group ID	End State	Description	Material-At-Risk[1]	Mean[2]	Median[2]	Std Dev[2]	Event Sequence Category	Basis for Categorization	Consequence Analysis[3]
ESD30-FUEL-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a direct exposure during pool operations (fuel assembly lifted too high). In this sequence there are no pivotal events.	1 SNF assembly	5.E-02	2.E-02	7.E-02	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[4]
ESD31-DPC-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a thermal challenge to a DPC inside a transportation cask or an STC due to a fire, resulting in a direct exposure from loss of shielding. In this sequence the canister remains intact, and the shielding fails.	1 DPC	5.E-02	4.E-02	2.E-02	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[4]
ESD18-DPC-SEQ1-RRF	Filtered radionuclide release	This event sequence represents a structural challenge to a DPC, during DPC cutting activities resulting in a filtered radionuclide release. In this sequence the confinement boundary remains intact, and a moderator is excluded from entering the canister.	1 DPC	2.E-02	2.E-02	3.E-03	Category 2	Mean of distribution for number of occurrences of event sequence	2-07
ESD30-DPC-SEQ2-DEL	Direct exposure	This event sequence represents a direct exposure during pool operations (splash of pool water). In this sequence there are no pivotal events.	liquid LLW	2.E-02	2.E-03	1.E-01	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[4]

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

Event Sequence Group ID	End State	Description	Material-At-Risk[1]	Mean[2]	Median[2]	Std Dev[2]	Event Sequence Category	Basis for Categorization	Consequence Analysis[3]
ESD17-DPC-SEQ1-RRF	Filtered radionuclide release	This event sequence represents a structural challenge to a DPC during preparation activities (sampling, gas cooling, water filling), resulting in a filtered radionuclide release. In this sequence the confinement boundary remains intact, and no condition important to criticality occurs.	1 DPC	9.E-03	5.E-03	2.E-02	Category 2	Mean of distribution for number of occurrences of event sequence	2-07
ESD31-CSNF-SEQ5-RRU	Unfiltered radionuclide release	This event sequence represents a thermal challenge to a transportation cask with uncanistered SNF assemblies due to a fire, resulting in an unfiltered radionuclide release. In this sequence the transportation cask fails, the confinement boundary fails, and a moderator is excluded from entering the cask.	1 transportation cask with uncanistered SNF assemblies	3.E-03	3.E-03	1.E-03	Category 2	Mean of distribution for number of occurrences of event sequence	2-14

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

Event Sequence Group ID	End State	Description	Material-At-Risk[1]	Mean[2]	Median[2]	Std Dev[2]	Event Sequence Category	Basis for Categorization	Consequence Analysis[3]
ESD27-TAD-SEQ1-RRF	Filtered radionuclide release	This event sequence represents a structural challenge to a TAD canister during TAD canister drying and inerting activities, resulting in a filtered radionuclide release. In this sequence the confinement boundary remains intact, and a moderator is excluded from entering the canister.	1 TAD canister	2.E-03	3.E-04	6.E-03	Category 2	Mean of distribution for number of occurrences of event sequence	2-09
ESD20-CSNF-SEQ5P-GRRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to a transportation cask with uncanistered SNF assemblies during transfer to pool, resulting in an unfiltered radionuclide release. In this sequence the transportation cask fails, and an adequate boron concentration is maintained. This sequence occurs inside the pool.	1 transportation cask with uncanistered SNF assemblies	7.E-04	3.E-04	2.E-03	Category 2	Mean of distribution for number of occurrences of event sequence	2-06

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

Event Sequence Group ID	End State	Description	Material-At-Risk[1]	Mean[2]	Median[2]	Std Dev[2]	Event Sequence Category	Basis for Categorization	Consequence Analysis[3]
ESD31-CSNF-SEQ3-RRF	Filtered radionuclide release	This event sequence represents a thermal challenge to a transportation cask with uncanistered SNF assemblies due to a localized fire, resulting in a filtered radionuclide release. In this sequence the transportation cask fails, the confinement boundary remains intact, and a moderator is excluded from entering the cask.	1 transportation cask with uncanistered SNF assemblies	6.E-04	5.E-04	3.E-04	Category 2	Mean of distribution for number of occurrences of event sequence	2-14
ESD24-TAD-SEQ6P-GRRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to a TAD canister inside an STC during transfer from pool to closure station, resulting in an unfiltered radionuclide release. In this sequence the STC fails, and an adequate boron concentration is maintained. This sequence occurs inside the pool.	1 TAD canister	5.E-04	2.E-04	1.E-03	Category 2	Mean of distribution for number of occurrences of event sequence	2-10

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

Event Sequence Group ID	End State	Description	Material-At-Risk[1]	Mean[2]	Median[2]	Std Dev[2]	Event Sequence Category	Basis for Categorization	Consequence Analysis[3]
ESD21-CSNF-SEQ2P-GRRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to a transportation cask with uncanistered SNF assemblies during transfer to pool floor, resulting in an unfiltered radionuclide release. In this sequence the transportation cask fails, and an adequate boron concentration is maintained. This sequence occurs inside the pool.	1 transportation cask with uncanistered SNF assemblies	2.E-04	1.E-04	3.E-04	Category 2	Mean of distribution for number of occurrences of event sequence	2-06
ESD11-TAD-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a structural challenge to a TAD canister inside an aging overpack, during export activities, resulting in a direct exposure from loss of shielding. In this sequence the canister remains intact, and the shielding fails.	1 TAD canister	1.E-04	9.E-05	2.E-04	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[4]

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

Event Sequence Group ID	End State	Description	Material-At-Risk[1]	Mean[2]	Median[2]	Std Dev[2]	Event Sequence Category	Basis for Categorization	Consequence Analysis[3]
ESD16-CSNF-SEQ3-RRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to a transportation cask with uncanistered SNF assemblies, during preparation activities (sampling, gas cooling, water filling), resulting in an unfiltered radionuclide release. In this sequence the confinement boundary fails, and no condition important to criticality occurs.	1 transportation cask with uncanistered SNF assemblies	1.E-04	3.E-05	3.E-04	Category 2	Mean of distribution for number of occurrences of event sequence	2-14
ESD21-TAD-SEQ2P-GRRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to a TAD canister inside an STC during transfer from pool floor, resulting in an unfiltered radionuclide release. In this sequence the STC fails, and an adequate boron concentration is maintained. This sequence occurs inside the pool.	1 TAD canister	7.E-05	4.E-05	8.E-05	Category 2	Mean of distribution for number of occurrences of event sequence near a category threshold. Recategorization to higher category by alternative distribution	2-10

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

Event Sequence Group ID	End State	Description	Material-At-Risk[1]	Mean[2]	Median[2]	Std Dev[2]	Event Sequence Category	Basis for Categorization	Consequence Analysis[3]
ESD20-CSNF-SEQ2-DED	Direct exposure, degradation of shielding	This event sequence represents a structural challenge to a transportation cask with uncanistered SNF assemblies during transfer to pool, resulting in a direct exposure from degradation of shielding. In this sequence the transportation cask containment function remains intact, and the shielding fails. This sequence occurs outside the pool.	1 transportation cask with uncanistered SNF assemblies	7.E-05	5.E-05	9.E-05	Category 2	Mean of distribution for number of occurrences of event sequence near a category threshold. Recategorization to higher category by alternative distribution	N/A[4]