ENG.20080406.0002

BSC

Calculation/Analysis Change Notice

Complete only applicable items.

1. QA: ~~NA~~ QA
2. Page 1 of 57

3. Document Identifier: 51A-PSA-IH00-00200-000-00A	4. Rev.: 00A	5. CACN: 001
6. Title: Initial Handling Facility Reliability and Event Sequence Categorization Analysis		
7. Reason for Change: This CACN001 addresses CR No. 11911, dated 3/27/2008. A fault tree gate type and a human error probability is revised.		
8. Supersedes Change Notice: ☐ Yes If, Yes, CACN No.: ______ ☒ No		

9. Change Impact:

Inputs Changed:	☐ Yes	☒ No	Results Impacted:	☒ Yes	☐ No
Assumptions Changed:	☐ Yes	☒ No	Design Impacted:	☐ Yes	☒ No

10. Description of Change:

The calculation method is not changed by this CACN. Change bars, normally on the right margin, on revised and new pages indicate revised or new material. Change bars on the included portions of the table of contents indicate locations changed material as shown on *affected pp. 8 & 11*. (Note that page numbers mentioned here pertain to the page numbers in the footers of the analysis, not the CACN001 numbers at top right). To update to this CACN, discard the replaced pages of Rev 00A, insert the attached revised or new pages, and replace the CD. The following changes are made by this CACN.

(a) Revise data entries in §6.2 & §6.4 of the report – revising the human error probability (HEP) (51A-OPCTMIMPACT1-HFI-COD) from 1E-3 to 4E-8 requires changes in §6.2 fault tree results and §6.4 HEP results. *Affects pp. 126 & 178.*

(b) Revise Table 6.8-3 of the report – correcting the fault tree model results in changes to the event sequence frequency, which is listed in Table 6.8-3. *Affects pp. 202 & 203.*

(c) Revise data entry in Table 6.9-1 – correcting the HEP in the 51A-CTM-HLW-DROPON fault tree model leads to changes in the probability of CTM drop of object (1.4E-5, rounded to 1E-5 in Table 6.9-1). *Affects p. 213.*

(d) Revise the affected pages in Attachment B – correcting the fault tree model and the HEP leads to changes in the fault tree data input tables, the results tables, the cut set tables, and the fault tree figures. In addition some basic event probabilities are changed to address inconsistencies between the model and the tabulated values (Table B4.4-9). To avoid conflict with the header on pages where the header is on the right margin due to the orientation of the page, the change bars have been placed on the left margin. *Affects pp. B4-49, B4-51, B4-52, B4-53, B4-57, B4-68, B4-70, B4-71, B4-72, B4-76, B4-80 through B4-84, & B6-9.*

(e) Revise the appropriate pages in Attachment E – revising the HEP leads to changes in the discussion and documentation of the human reliability assessment associated with the HEP. *Affects pp. E-86, E-90, E-91. Inserts p. E-91-a. Pages E-121-a through E-121-o replace p. E-121. Affects p. E-148.*

(f) Revise Tables G1, G2, G3, and G4 in Attachment G – the corrections lead to changes in the event sequence quantification which is documented in the following tables: (a) the ungrouped event sequence (Table G1), (b) the grouped event sequence listing (Table G2), (c) Beyond Category 2 event sequence listing (Table G3), and (d) event sequence that is also important to criticality (Table G4). *Affects pp. G-14 through G-17, G-45 through G-47, G-62, G-63, G-68, G-69, and G-96.*

(g) Revise Attachment H to reflect the updated contents of the CD. The only file that changed on the CD is indicated by a change bar on p. H-2. The remaining files are the same as those that are provided on the original CD for Rev 00A. Some pages in Attachment G are updated by the hard copy pages of this CACN as noted in Item (f) above. *Affects p. H-2.*

(h) Update SAPHIRE reliability model in Attachment H. *Replace existing CD with updated one.* See Item (g).

11. REVIEWS AND APPROVAL

Printed Name	Signature	Date
11a. Originator: Guy E. Ragan	Guy E Ragan	4/6/08
11b. Checker: Norman L. Graves	Norman L. Graves	4/6/08
11c. EGS: Michael V. Frank	M V Frank	4/6/08
11d. DEM: Thomas D. Dunn	Thomas D. Dunn	4/6/08
11e. Design Authority: Barbara E. Rusinko	BRusinko	4/6/08

CONTENTS

TABLES (Continued)

Table 6.2-4. Summary of Top Event Quantification for the CTM

Top Event	Mean Probability	Standard Deviation
CTM drop below the design basis height	2.1E-4	2.6E-4
CTM high drops from two blocking events	2.8E-8	1.4E-7
Drop of object onto cask	1.4E-5	1.2E-5
CTM collision results in an impact to canister	3.9E-6	2.7E-7
CTM Shear	6.7E-9	1.4E-8

NOTE: CTM = canister transfer machine.

Source: Attachment B, Figures B4.4-1, B4.4-15, B4.4-20, B4.4-34, and B4.4-41

6.2.2.5 Waste Package Transfer Trolley Fault Tree Analysis

The FTA for the WPTT is detailed in Attachment B, Section B5. The following is a summary of the design, operations, success criteria, and results of the fault tree quantification. See Attachment B, Section B5 for sources of information on the physical and operational characteristics of the WPTT.

6.2.2.5.1 Physical Description and Functions

The waste package transfer trolley (WPTT) is an electrically powered machine used to transport the waste package containing various waste canisters from the Waste Package Loading Room to the Waste Package Positioning Room and then to the waste package transfer carriage docking station in the Waste Package Loadout Room. The WPTT consists of a shielded enclosure that holds the waste package, waste package pallet, waste package transfer carriage, and pedestal. The shielded enclosure acts as a radiation shield to minimize radiation to the surroundings. The enclosure pivots between a vertical and horizontal position for waste package loading and unloading.

The WPTT travels on rails between the Waste Package Loading Room and the docking station. The crane rails supporting the WPTT are gapped in multiple locations. Power is supplied to the motor by a third rail system and the maximum speed is less than 20 ft/min, as required by ASME NOG-1-2004 (ASME NOG-1-2004. 2005. *Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder)* (Ref. 2.2.7176239)) and established by the size of the drive motor and the gear drive system. The WPTT includes seismic rail clamps and rails anchored to the floor to ensure the stability of the WPTT during a seismic event.

The rotation of the shielded enclosure from vertical to horizontal is driven by worm gear mechanisms and is also powered by the third rail system. Each of the rotation mechanisms is sized to rotate the full design load (no greater than 178,200 lbs) on its own and at a speed no faster than 18-degrees per minute. The worm gear mechanism has the inherent property to self lock to prevent uncontrolled tilt down.

The waste package transfer carriage is a wheeled platform which carries the waste package pallet and waste package. The transfer carriage is moved by a mechanical screw-driven carriage

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

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
51A-OpCollide001-HFI-NOD	Operator causes low-speed collision of auxiliary vehicle with RC, TT, or CTT	1, 2, 3, 4	2, 3	3.00E-03	5	Preliminary
51A-OpCraneIntfr-HFI-NOD	Operator causes WP handling crane to interfere with TEV or WPTT	11	6	1.00E-04	10	Preliminary
51A-OpCTCollide2-HFI-NOD	Operator causes low-speed collision of CTT during transfer from preparation station to Cask Unloading Room	5	3	1.00E-03	5	Preliminary
51A-OpCTMDrInt01-HFI-COD	Operator lifts object or canister too high with CTM (two-block)	7	4	1.0	N/A	Preliminary
51A-OpCTMdrop001-HFI-COD	Operator drops object onto canister during CTM operations	7	4	4.00E-07	10	Detailed
51A-OpCTMdrop002-HFI-COD	Operator drops canister during CTM operations	7	4	2.00E-04	10	Detailed
51A-OpCTMImpact1-HFI-COD	Operator moves the CTM while canister or object is below or between levels	7	4	4.00E-08	10	Detailed
51A-OpCTMImpact2-HFI-COD	Operator causes canister impact with lid during CTM operations (HLW)	7	4	N/A[b]	N/A	Omitted from analysis
51A-OpCTMImpact5-HFI-COD	Operator causes canister impact with SSC during CTM operations (all)	7	4	1.0	N/A	Preliminary
51A-OpCTTImpact1-HFI-NOD	Operator causes an impact between cask and SSC due to crane operations	1, 2, 3, 4	2, 3	3.00E-03	5	Preliminary
51A-OpDirExpose1-HFI-NOD	Operator causes direct exposure during CTM activities (all waste forms)	12	4	1.0	N/A	Preliminary
51A-OpDirExpose2-HFI-NOD	Operator causes direct exposure during CTM activities (transfer into a WP)	12	4	1.00E-04	10	Preliminary
51A-OpDirExpose3-HFI-NOD	Operator causes direct exposure during TEV loading	12	6	3.00E-05	10	Detailed

Table 6.8-3. Category 2 Final Event Sequences Summary

Event Sequence Group ID	End State	Description	Material-At-Risk[3]	Mean[4]	Median[4]	Std. Dev[4]	Event Sequence Category	Basis for Categorization	Consequence Analysis[1]
ESD12B-NVL-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a direct exposure during preparation activities of a transportation cask containing a naval SNF canister, or during assembly and closure of a waste package containing a naval SNF canister. In this sequence there are no pivotal events	1 naval SNF canister	2.E-01	1.E-01	1.E-01	Category 2	Mean of distribution for number of occurrences of event sequence near a category threshold. Categorization confirmed by alternative distribution	N/A[2]
ESD12B-HLW-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a direct exposure during assembly and closure of a waste package containing HLW canisters. In this sequence there are no pivotal events.	5 HLW canisters	4.E-02	4.E-02	2.E-08	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[2]
ESD13-NVL-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a thermal challenge to a naval SNF canister inside a transportation cask, due to a fire, resulting in a direct exposure from loss of shielding. In this sequence the canister remains intact, and the shielding fails.	1 naval SNF canister	3.E-02	3.E-02	1.E-02	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[2]

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

Event Sequence Group ID	End State	Description	Material-At-Risk[3]	Mean[4]	Median[4]	Std. Dev[4]	Event Sequence Category	Basis for Categorization	Consequence Analysis[1]
ESD12C-NVL-SEQ3-DEL	Direct exposure, loss of shielding	This event sequence represents a direct exposure during export of a waste package containing a naval SNF canister. In this sequence there are no pivotal events.	1 naval SNF canister	1.E-02	4.E-03	2.E-02	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[2]
ESD07-HLW-SEQ5-RRU	Radionuclide release, unfiltered	This event sequence represents a structural challenge to an HLW canister, during canister transfer by the CTM, resulting in an unfiltered radionuclide release. In this sequence the canister fails, the confinement boundary is not relied upon, and a moderator is excluded from entering the canister.	2 HLW canisters	7.E-03	5.E-03	7.E-03	Category 2	Mean of distribution for number of occurrences of event sequence	2-04
ESD12C-HLW-SEQ3-DEL	Direct exposure, loss of shielding	This event sequence represents a direct exposure during export of a waste package containing HLW canisters. In this sequence there are no pivotal events.	5 HLW canisters	6.E-03	2.E-03	1.E-02	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[2]
ESD12A-HLW-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a temporary loss of shielding during CTM operations, while an HLW canister is being transferred. In this sequence there are no pivotal events.	5 HLW canisters	2.E-03	2.E-03	1.E-03	Category 2	Mean of distribution for number of occurrences of event sequence	N/A[2]

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

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

Table B4.4-6. Basic Event Probability for the CTM Drop of Objects onto Canister Fault Tree (Continued)

Name	Description	Calc. Type[a]	Calc. Prob.	Fail. Prob.	Lambda	Miss. Time[a]
51A-CTM-SLIDEGT1-IEL-FOD	CTM Slide Gate Interlock Fails	1	2.750E-05	2.750E-05	0.000E+00	0.000E+00
51A-CTM-SLIDGT2-SRX-FOD	CTM Slide Gate Position Sensor Fails on Demand	1	1.100E-03	1.100E-03	0.000E+00	0.000E+00
51A-CTM-YS01129-ZS-FOD	CTM Drum Brake Ctl Circuit Limit Switch 1129 Fails	1	2.930E-04	2.930E-04	0.000E+00	0.000E+00
51A-CTM-ZSL0111-ZS--SPO	Grapple Disengaged Limit Switch Spurious Operation	3	1.280E-06	0.000E+00	1.280E-06	1.000E+00
51A-LOSS-OFFSITE-PWR	Loss of offsite power	1	2.990E-03	2.990E-03	0.000E+00	0.000E+00
51A-OPCLCTMGATE1-HFI-NOD	Operator commands doors close	1	1.000E-03	1.000E-03	0.000E+00	0.000E+00
51A-OPCTMDRINT01-HFI-COD	Operator raises load too high - two block	1	1.000E+00	1.000E+00	0.000E+00	0.000E+00
51A-OPCTMDROP001-HFI-COD	Operator causes drop of object onto canister	1	4.000E-07	4.000E-07	0.000E+00	0.000E+00
51A-OPCTMIMPACT1-HFI-COD	Operator moves trolley/crane with canister below floor	1	4.000E-08	4.000E-08	0.000E+00	0.000E+00

NOTE: [a] For Calc. Type 3 with a mission time of 0, SAPHIRE performs the quantification using the system mission time.

CCF = common-cause failure; Ctl = control; CTM = canister transfer machine; PLC = programmable logic controller.

Source: Original

Uncertainty Results

Name	51A-CTM-HLW-DROPON		
Random Seed	1234	Events	48
Sample Size	10000	Cut Sets	82
Point estimate			1.415E-005
Mean Value			1.402E-005
5th Percentile Value			4.594E-006
Median Value			1.121E-005
95th Percentile Value			3.209E-005
Minimum Sample Value			1.268E-006
Maximum Sample Value			2.566E-004
Standard Deviation			1.185E-005
Skewness			5.463E+000
Kurtosis			6.093E+001
Elapsed Time			00:00:01.320

OK

Source: Original

Figure B4.4-20 Uncertainty Results of the Drop of Object onto Canister Fault Tree

Cut Set Generation Results

Name: 51A-CTM-HLW-DROPON
Elapsed Time: 00:00:00.010

Cut Size	#	minCut
1	13	9.756E-006
2	40	4.388E-006
3	29	3.547E-009
4	0	------E----
5	0	------E----
6	0	------E----
7	0	------E----
8	0	------E----
9	0	------E----
10	0	------E----
>10	0	------E----
Total	82	1.415E-005

Total Elapsed Time : 00:00:00.030

OK View Results

Source: Original

Figure B4.4-21. Cut Set Generation Results for the Drop of Object onto Canister Fault Tree

B4.4.3.7 Cut Sets

Table B4.4-8 contains the top 20 cut sets for the "Drop of Object onto Canister" fault tree.

Table B4.4-8. Dominant Cut Sets for the "Drop of Object onto Canister Fault" Tree

% Total	% Cut Set	Prob./ Frequency	Basic Event	Description	Event Prob.
28.20	28.20	3.990E-006	51A-CTM--WT0125--SRP-FOD	Load Cell Pressure Sensor Fails	4.0E-003
			51A-OPCLCTMGATE1-HFI-NOD	Operator commands doors close	1.0E-003
37.25	9.05	1.280E-006	51A-CTM--ZSH0111-ZS--SPO	Grapple Engaged Limit Switch Spurious Operation	1.3E-006
46.30	9.05	1.280E-006	51A-CTM-ZSL0111-ZS--SPO	Grapple Disengaged Limit Switch Spurious Operation	1.3E-006
54.43	8.13	1.150E-006	51A-CTM--EQL-SHV-BLK-FOD	equalizer sheaves structural failure	1.2E-006
62.56	8.13	1.150E-006	51A-CTM--GRAPPLE-GPL-FOD	Grapple Failure on Demand	1.2E-006
70.69	8.13	1.150E-006	51A-CTM--LOWERBL-BLK-FOD	ctm lower sheaves structural failure	1.2E-006
78.82	8.13	1.150E-006	51A-CTM--UPPERBL-BLK-FOD	upper sheaves structural failure	1.2E-006
83.58	4.76	6.740E-007	51A-CRN-BRIDGMTR-MOE-SPO	Crane Bridge Motor (Electric) Spurious Operations	6.7E-007
88.34	4.76	6.740E-007	51A-CTM-HSTTRLLY-MOE-SPO	Hoist Trolley Motor (Electric) Spurious Operations	6.7E-007
93.10	4.76	6.740E-007	51A-CTM-SBELTRLY-MOE-SPO	CTM Shield Bell Trolley Motor (Electric) Spurious Operations	6.7E-007
95.93	2.83	4.000E-007	51A-OPCTMDROP001-HFI-COD	Operator causes drop of object onto canister	4.0E-007
98.00	2.07	2.930E-007	51A-CTM--WTSW125-ZS--FOD	Load Cell Limit Switch Fails	2.9E-004
			51A-OPCLCTMGATE1-HFI-NOD	Operator commands doors close	1.0E-003
98.66	0.66	9.400E-008	51A-CTM--CBL0102-WNE-CCF	CCF CTM Hoist wire ropes	9.4E-008
98.94	0.28	4.000E-008	51A-CTM--DRUM001-DM--FOD	Hoisting drum structural failure	4.0E-008
99.22	0.28	4.000E-008	51A-OPCTMIMPACT1-HFI-COD	Operator moves trolley/ crane with canister below floor	4.0E-008
99.47	0.25	3.520E-008	51A-CTM--HOLDBRK-BRK-FOH	Holding Brake (electric) Fails to Hold	3.5E-005
			51A-OPCLCTMGATE1-HFI-NOD	Operator commands doors close	1.0E-003
99.67	0.20	2.795E-008	51A-CTM--121122-ZS--CCF	CCF CTM upper limit postion switches	1.4E-005
			51A-CTM-ASD0122#-CTL-FOD	CTM Hoist ASD Controller fails	2.0E-003
99.86	0.19	2.750E-008	51A-CTM--IMEC125-IEL-FOD	CTM Hoist Motor Control Interlock Fails on Demaned	2.8E-005

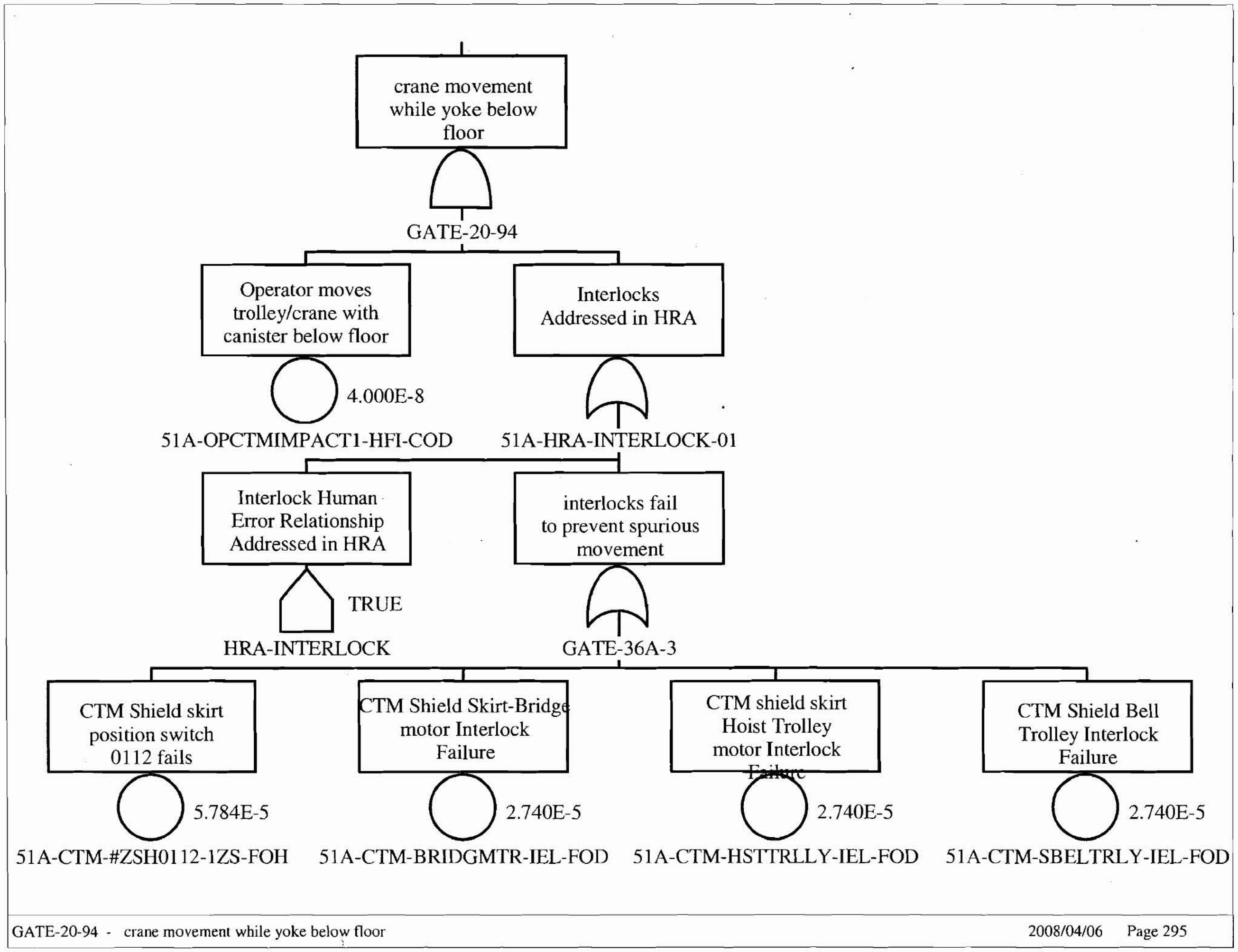
Table B4.4-8. Dominant Cut Sets for the CTM Drop onto Canister Fault Tree (Continued)

% Total	% Cut Set	Prob./ Frequency	Basic Event	Description	Event Prob.
			51A-OPCLCTMGATE1-HFI-NOD	Operator commands doors close	1.0E-003
99.88	0.02	2.689E-009	51A-CTM--PORTGT1-MOE-SPO	spurious port gate1 motor operation	6.7E-007
			51A-CTM--WT0125--SRP-FOD	Load Cell Pressure Sensor Fails	4.0E-003
99.90	0.02	2.689E-009	51A-CTM--PORTGT2-MOE-SPO	spurious port gate 2 motor operation	6.7E-007
			51A-CTM--WT0125--SRP-FOD	Load Cell Pressure Sensor Fails	4.0E-003

NOTE: CCF = common-cause failure; Ctl = control; CTM = canister transfer machine; PLC = programmable logic controller.

Source: Original

B4.4.3.8 Fault Trees



Source: Original.

Figure B4.4-25. Drop of Object onto Cask
Sheet 4

Table B4.4-9. Basic Event Probability for the Canister Impact Fault Tree

Name	Description	Calc. Type[a]	Calc. Prob.	Fail. Prob.	Lambda	Miss. Time[a]
51A-CTM-BREDGMTR--PR-FOH	Bridge Passive Restraints (end stops) Fail	3	1.949E-06	0.000E+00	4.450E-10	4.380E+03
51A-CTM-BRIDGETR-#PR-FOH	Passive restraint (bumper) Failure	3	1.949E-06	0.000E+00	4.450E-10	4.380E+03
51A-CTM-BRIDGETR-MOE-FSO	Motor (Electric) Fails to Shut Off	3	1.350E-08	0.000E+00	1.350E-08	1.000E+00
51A-CTM-BRIDGMTR-IEL-FOD	CTM Shield Skirt-Bridge motor Interlock Failure	1	2.740E-05	2.740E-05	0.000E+00	0.000E+00
51A-CTM-BRIDTR-CT-FOD	CTM Bridge Motor Controller Failure	1	4.000E-06	4.000E-06	0.000E+00	0.000E+00
51A-CTM-HSTTRLLY-IEL-FOD	CTM shield skirt Hoist Trolley motor Interlock Failure	1	2.740E-05	2.740E-05	0.000E+00	0.000E+00
51A-CTM-SBELTRLY-IEL-FOD	CTM Shield Bell Trolley Interlock Failure	1	2.740E-05	2.740E-05	0.000E+00	0.000E+00
51A-CTM-SKRTCTCT-SRP-FOD	CTM Skirt floor contact sensors fail	1	4.000E-03	4.000E-03	0.000E+00	0.000E+00
51A-CTM-TROLLEYT-MOE-FSO	Trolley Motor (Electric) Fails to Shut Off	3	1.080E-07	0.000E+00	1.350E-08	8.000E+00
51A-CTM-TROLLYTR-#PR-FOH	Passive restraint (bumper) Failure	3	1.949E-06	0.000E+00	4.450E-10	4.380E+03
51A-CTM-TROLLYTR--PR-FOH	CTM Trolley & Run Stop Failure	3	1.949E-06	0.000E+00	4.450E-10	4.380E+03
51A-CTM-TROLT1-HC-FOD	Hand Held Radio Remote Controller Failure to Stop (on Demand)	1	1.740E-03	1.740E-03	0.000E+00	0.000E+00
51A-OPCTMIMPACT1-HFI-COD	Operator moves trolley/crane with canister below floor	1	4.000E-08	4.000E-08	0.000E+00	0.000E+00
51A-OPCTMIMPACT5-HFI-COD	Operator Over Runs Travel Collides Into End stop	1	1.000E+00	1.000E+00	0.000E+00	0.000E+00

NOTE: [a] For Calc. Type 3 with a mission time of 0, SAPHIRE performs the quantification using the system mission time.

CCF = common-cause failure; Ctl = control; CTM = canister transfer machine; PLC = programmable logic controller.

Source: Original

Uncertainty Results

Name	CTM-COLLISION		
Random Seed	1234	Events	12
Sample Size	10000	Cut Sets	10
Point estimate			3.902E-006
Mean Value			3.905E-006
5th Percentile Value			3.473E-006
Median Value			3.901E-006
95th Percentile Value			4.366E-006
Minimum Sample Value			2.977E-006
Maximum Sample Value			5.866E-006
Standard Deviation			2.715E-007
Skewness			2.247E-001
Kurtosis			3.335E+000
Elapsed Time			00:00:00.690

OK

Source: Original

Figure B4.4-34 Uncertainty Results of the Canister Impact Fault Tree

Cut Set Generation Results

Name: CTM-COLLISION
Elapsed Time: 00:00:00.010

Cut Size	#	minCut
1	0	------E----
2	10	3.902E-006
3	0	------E----
4	0	------E----
5	0	------E----
6	0	------E----
7	0	------E----
8	0	------E----
9	0	------E----
10	0	------E----
>10	0	------E----
Total	10	3.902E-006

Total Elapsed Time : 00:00:00.030

OK View Results

Source: Original

Figure B4.4-35. Cut Set Generation Results for the Canister Impact Fault Tree

B4.4.4.7 Cut Sets

Table B4.4-11 contains the cut sets for the "Canister Impact" fault tree.

Table B4.4-11. Dominant Cut Sets for the Canister Impact Fault Tree

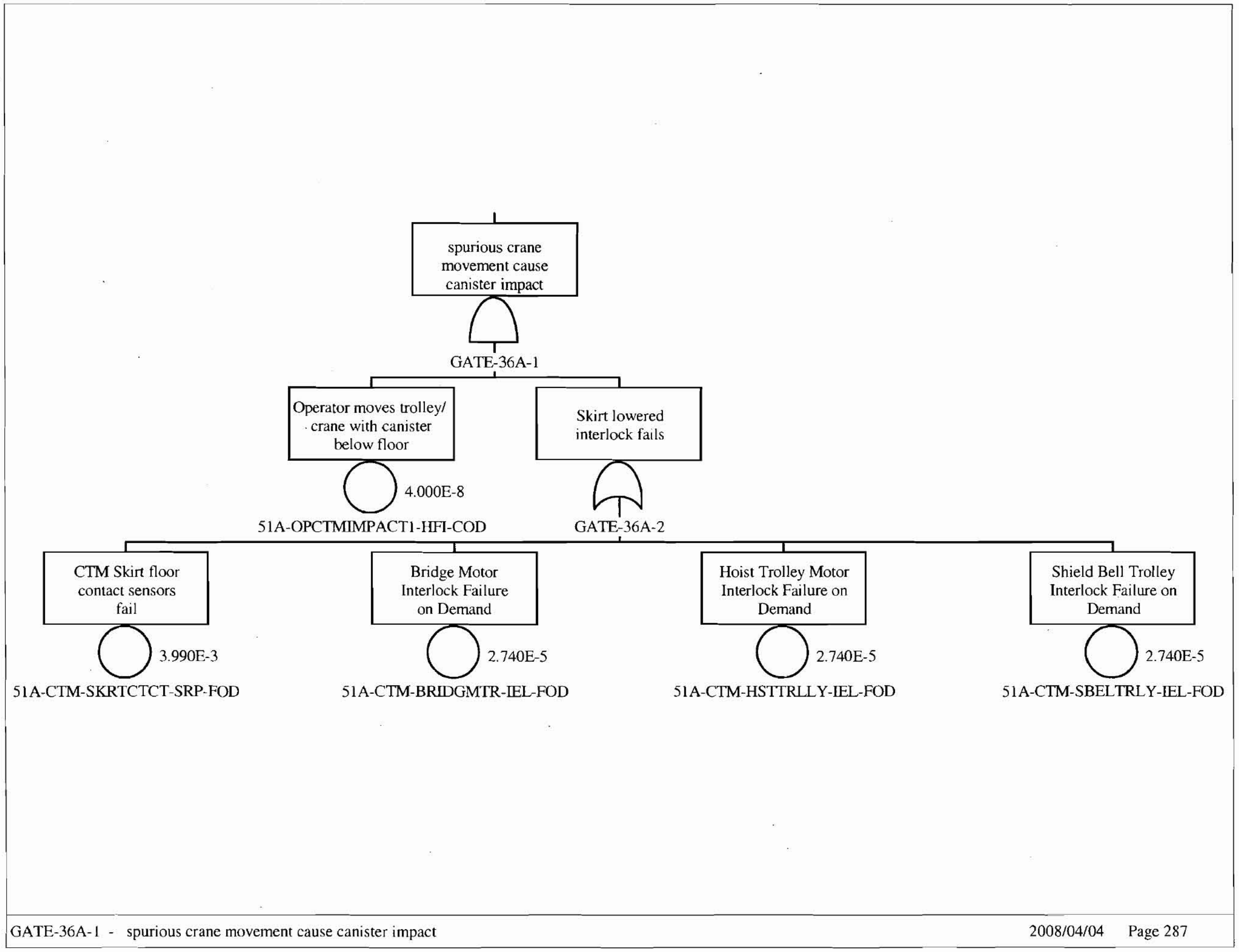
% Total	% Cut Set	Prob./ Frequency	Basic Event	Description	Event Prob.
49.95	49.95	1.949E-06	51A-CTM-BRIDGETR-#PR-FOH	Passive restraint (bumper) Failure	1.9E-006
			51A-OPCTMIMPACT5-HFI-COD	Operator Over Runs Travel Collides Into Endstop	1.0E+000
99.90	49.95	1.949E-06	51A-CTM-TROLLYTR--PR-FOH	CTM Trolley end run stops Failure	1.9E-006
			51A-OPCTMIMPACT5-HFI-COD	Operator Over Runs Travel Collides Into Endstop	1.0E+000
99.99	0.09	3.391E-09	51A-CTM-TROLLYTR--PR-FOH	CTM Trolley end run stops Failure	1.9E-006
			51A-CTM-TROLT1-HC-FOD	Controller Failure to Stop (on Demand)	1.7E-003
99.99	0.00	1.596E-10	51A-CTM-SKRTCTCT-SRP-FOD	CTM Skirt floor contact sensors fail	4.0E-003
			51A-OPCTMIMPACT1-HFI-COD	Operator moves trolley/crane with canister below floor	4.0E-008
99.99	0.00	7.796E-12	51A-CTM-BREDGMTR--PR-FOH	Bridge Passive Restraints (end stops) Fail	1.9E-006
			51A-CTM-BRIDTR-CT-FOD	CTM Bridge Motor Controller Failure	4.0E-006
99.99	0.00	1.096E-12	51A-CTM-BRIDGMTR-IEL-FOD	CTM Shield Skirt-Bridge motoer Interlock Failure	2.7E-005
			51A-OPCTMIMPACT1-HFI-COD	Operator moves trolley/crane with canister below floor	4.0E-008
99.99	0.00	1.096E-12	51A-CTM-HSTTRLLY-IEL-FOD	CTM shield skirt Hoist Trolley motor Interlock Failure	2.7E-005
			51A-OPCTMIMPACT1-HFI-COD	Operator moves trolley/crane with canister below floor	4.0E-008
99.99	0.00	1.096E-12	51A-CTM-SBELTRLY-IEL-FOD	CTM Shield Bell Trolley Interlock Failure	2.7E-005
			51A-OPCTMIMPACT1-HFI-COD	Operator moves trolley/crane with canister below floor	4.0E-008
99.99	0.00	2.105E-13	51A-CTM-TROLLEYT-MOE-FSO	Trolley Motor (Electric) Fails to Shut Off	1.1E-007
			51A-CTM-TROLLYTR--PR-FOH	CTM Trolley end run stops Failure	1.9E-006
99.99	0.00	2.631E-14	51A-CTM-BREDGMTR--PR-FOH	Bridge Passive Restraints (end stops) Fail	1.9E-006

% Total	% Cut Set	Prob./ Frequency	Basic Event	Description	Event Prob.
			51A-CTM-BRIDGETR-MOE-FSO	Motor (Electric) Fails to Shut Off	1.4E-008
99.99		3.902E-06	= Total		

NOTE: CCF = common-cause failure; Ctl = control; CTM = canister transfer machine; PLC = programmable logic controller.

Source: Original

B4.4.4.8 Fault Trees



Source: Original

Figure B4.4-39. CTM Collision Sheet 4

Table B4.4-12. Basic Event Probability for the CTM Movement Subjects Canister to Shearing Forces Fault Trees

Name	Description	Calc. Type[a]	Calc. Prob.	Fail. Prob.	Lambda	Miss. Time[a]
51A-CTM-#ZSH0112-1ZS-FOH	CTM Shield skirt position switch 0112 fails	3	5.784E-05	0.000E+00	7.230E-06	8.000E+00
51A-CTM-BIDGMTR-#TL-FOH	CTM Bridge motor Torque limiter Failure	3	2.856E-02	0.000E+00	8.050E-05	3.600E+02
51A-CTM-BRIDGMTS-MOE-SPO	CTM Bridge Motor (Electric) Spurious Operation - shear	3	6.740E-08	0.000E+00	6.740E-07	1.000E-01
51A-CTM-HSTTRLLS-MOE-SPO	CTM Hoist Trolley Motor (Electric) Spurious Operation m- shear	3	6.740E-08	0.000E+00	6.740E-07	1.000E-01
51A-CTM-HSTTRLLY-#TL-FOH	CTM Hoist motor Torque limiter Failure	3	2.856E-02	0.000E+00	8.050E-05	3.600E+02
51A-CTM-PLC0101S-PLC-SPO	CTM Bridge Motor PLC Spurious Operation - shear	3	3.650E-08	0.000E+00	3.650E-07	1.000E-01
51A-CTM-PLC0102S-PLC-SPO	CTM Shield Bell Trolley PLC Spurious Operation -shear	3	3.650E-08	0.000E+00	3.650E-07	1.000E-01
51A-CTM-PLC0103S-PLC-SPO	CTM Hoist Trolley PLC Spurious Operation - shear	3	3.650E-08	0.000E+00	3.650E-07	1.000E-01
51A-CTM-SBELTRLS-MOE-SPO	CTM shield Bell trolley Motor (Electric) spurious operation-shear	3	6.740E-08	0.000E+00	6.740E-07	1.000E-01
51A-CTM-SBELTRLY-#TL-FOH	CTM Shield Bell Motor Torque limiter Failure	3	2.856E-02	0.000E+00	8.050E-05	3.600E+02
51A-OPCTMIMPACT1-HFI-COD	Operator moves trolley/crane with canister below floor	1	4.000E-08	4.000E-08	0.000E+00	0.000E+00

NOTE: [a] For Calc. Type 3 with a mission time of 0, SAPHIRE performs the quantification using the system mission time.

CCF = common-cause failure; CTM = canister transfer machine; PLC = programmable logic controller.

Source: Original

The shear impact drop probability modeled by the fault tree is evaluated over a mission time of one-tenth of an hour (limited to the time the canister is being lifted and is between the first and second floors). A longer mission time is also considered for specific components. For example, the fault tree accounts for the failure of standby components whose potential malfunction would remain hidden until they are tested. They are consequently evaluated over the interval of time between their tests, and the mission time is assigned a value of the average fault exposure time, half the test interval.

B4.4.5.5.1 Human Failure Events

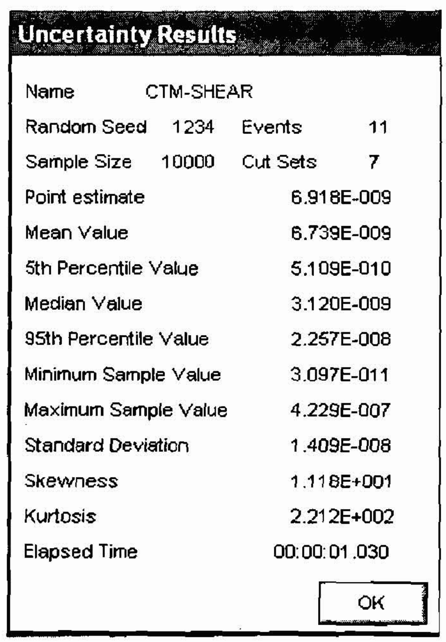
One basic event is associated with human error: 51A-OPCTMIMPACT1-HFI-COD (Operator moves trolley/crane with canister below floor). This event addresses the possible operator initiated movement of the bridge or trolleys while a canister is being lifted and is between IHF floors.

B4.4.5.5.2 Common-Cause Failures

No common-cause failures apply to this fault tree.

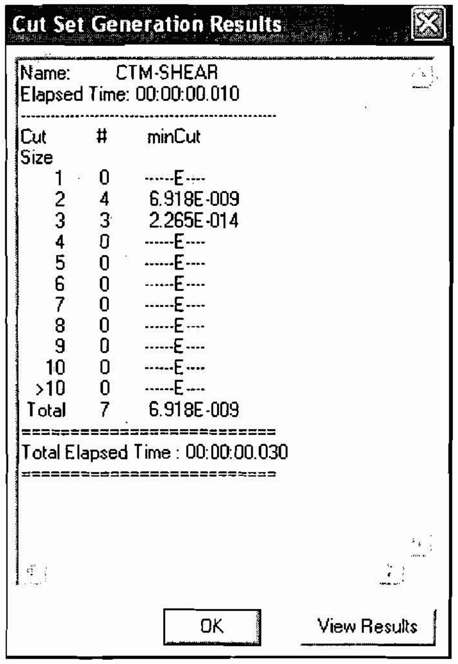
B4.4.5.6 Uncertainty and Cut Set Generation

Figure B4.4-41 contains the uncertainty results obtained from running the fault trees for "CTM Movement Subjects Canister to Shearing Forces" using a cutoff probability of 1E-15. Figure B4.4-42 provides the cut set generation results for the "CTM Movement Subjects Canister to Shearing Forces" fault tree.



Source: Original

Figure B4.4-41. Uncertainty Results of the CTM Movement Subjects Canister to Shearing Forces Fault Tree



Source: Original

Figure B4.4-42. Cut Set Generation Results for the CTM Movement Subjects Canister to Shearing Forces Fault Tree

B4.4.5.7 Cut Sets

Table B4.4-13 contains the cut sets for the "CTM Movement Subjects Canister to Shearing Forces" fault tree.

Table B4.4-13. Dominant Cut Sets for the CTM Movement Subjects Canister to Shearing Forces Fault Tree

% Total	% Cut Set	Prob./ Frequency	Basic Event	Description	Event Prob.
27.83	27.83	1.925E-009	51A-CTM-BIDGMTR-#TL-FOH	CTM Bridge motor Torque limiter Failure	2.9E-002
			51A-CTM-BRIDGMTS-MOE-SPO	CTM Bridge Motor (Electric) Spurious Operation -shear	6.7E-008
55.66	27.83	1.925E-009	51A-CTM-HSTTRLLS-MOE-SPO	CTM Hoist Trolley Motor (Electric) Spurious Operation m- shear	6.7E-008
			51A-CTM-HSTTRLLY-#TL-FOH	CTM Hoist motorTorque limiter Failure	2.9E-002
83.49	27.83	1.925E-009	51A-CTM-SBELTRLS-MOE-SPO	CTM shield Bell trolley Motor (Electric) spurious operation-shear	6.7E-008
			51A-CTM-SBELTRLY-#TL-FOH	CTM Shield Bell MotorTorque limiter Failure	2.9E-002
100.00	16.51	1.143E-009	51A-CTM-BIDGMTR-#TL-FOH	CTM Bridge motor Torque limiter Failure	2.9E-002
			51A-OPCTMIMPACT1-HFI-COD	Operator moves trolley/ crane with canister below floor	4.0E-008

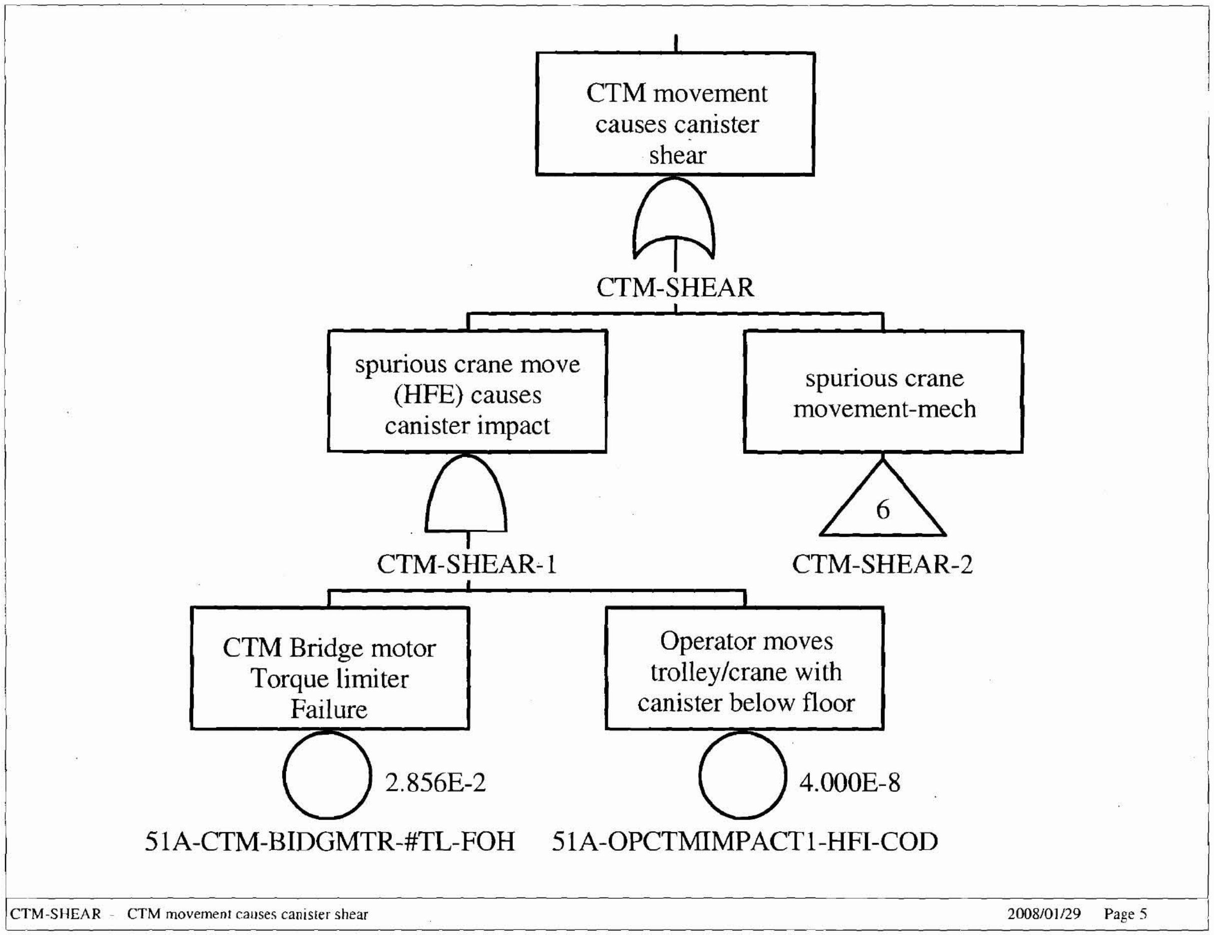
Table B4.4-13. Dominant Cut Sets for the CTM Collision Fault Tree (Continued)

% Total	% Cut Set	Prob./ Frequency	Basic Event	Description	Event Prob.
100.00	0.00	6.030E-014	51A-CTM-#ZSH0112-1ZS-FOH	CTM Shield skirt position switch 0112 fails	5.8E-005
			51A-CTM-BIDGMTR-#TL-FOH	CTM Bridge motor Torque limiter Failure	2.9E-002
			51A-CTM-PLC0101S-PLC-SPO	CTM Bridge Motor PLC Spurious Operation -shear	3.7E-008
100.00	0.00	6.030E-014	51A-CTM-#ZSH0112-1ZS-FOH	CTM Shield skirt position switch 0112 fails	5.8E-005
			51A-CTM-HSTTRLLY-#TL-FOH	CTM Hoist motorTorque limiter Failure	2.9E-002
			51A-CTM-PLC0103S-PLC-SPO	CTM Hoist Trolley PLC Spurious Operation -shear	3.7E-008
100.00	0.00	6.030E-014	51A-CTM-#ZSH0112-1ZS-FOH	CTM Shield skirt position switch 0112 fails	5.8E-005
			51A-CTM-PLC0102S-PLC-SPO	CTM Shield Bell Trolley PLC Spurious Operation -shear	3.7E-008
			51A-CTM-SBELTRLY-#TL-FOH	CTM Shield Bell MotorTorque limiter Failure	2.9E-002

NOTE: CCF = common-cause failure; CTM = canister transfer machine; PLC = programmable logic controller.

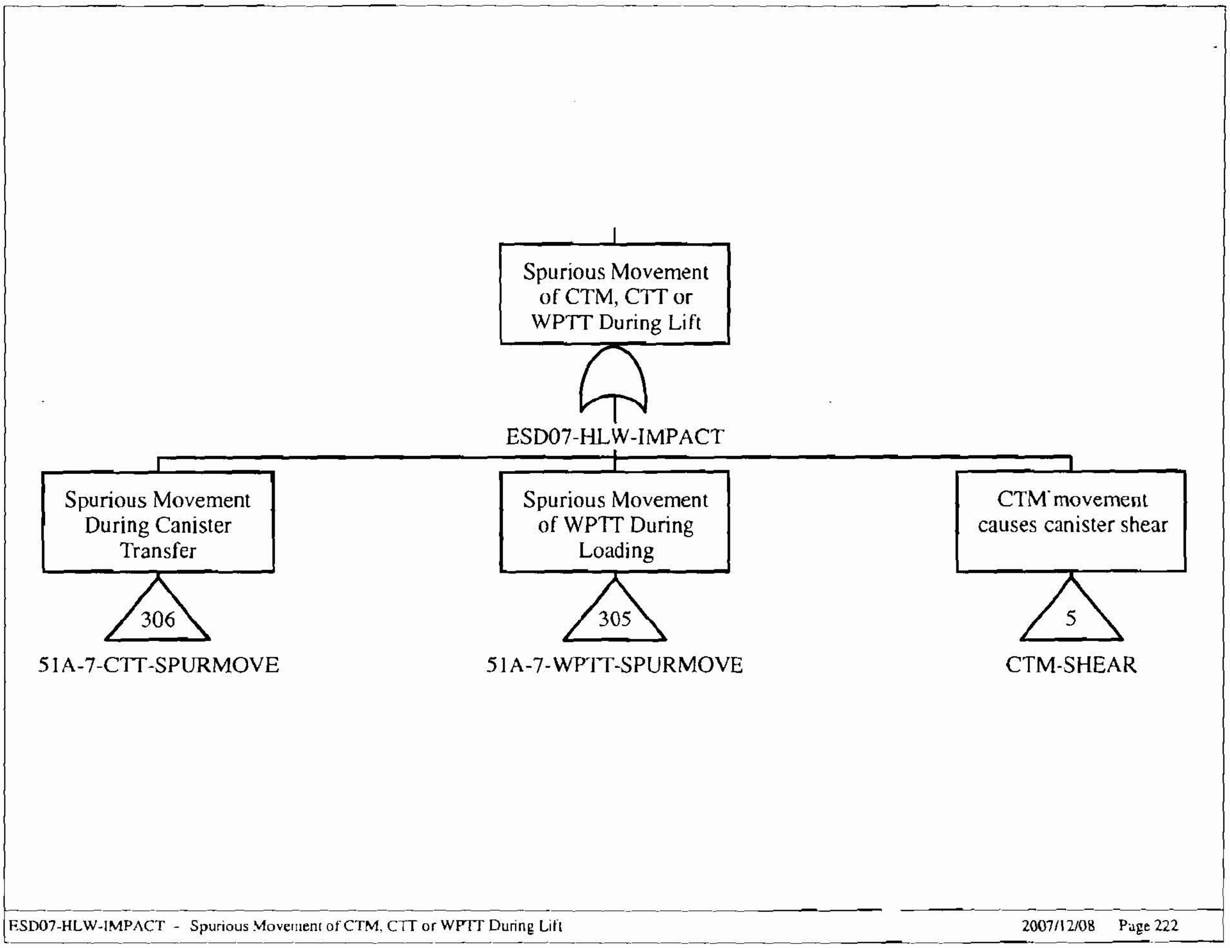
Source: Original

B4.4.5.8 Fault Tree



Source: Original

Figure B4.4-43. CTM Shear Sheet 1



Source: Original

Figure B6.3-4. Fault Tree for Spurious Movement CTM, CTT or WPTT during Lift

Figure B6.3-4 illustrates the fault tree for impact to a canister caused by spurious movement of the CTT during unloading of the transportation cask, the WPTT during loading of the WP, or the CTM during transfer of the canister. The calculated mean probability of an impact due to spurious movement of the carriers is 6.948E-09. Fault trees for the various spurious movements are addressed in their respective sections in Attachment B.

B6.4 LOSS OF SHIELDING LEADING TO DIRECT EXPOSURE

These fault trees describe direct exposure during canister transfer or while closing the waste package. Table B6.4-1 lists the fault trees that describe these direct exposures.

All judgments used in the quantification effort are determined by the HRA team and are based on their own experience, augmented by facility-specific information and the experience of subject matter experts, as discussed in Section E4. If consensus can be reached by the HRA team on an HEP for an unsafe action, that value is used as the mean. If consensus cannot be reached, the highest opinion is used as the mean.

Step 8: Incorporate HFEs into the PCSA

After HFEs are identified, defined, and quantified, they must be incorporated into the PCSA. The summary table of HFEs by group that lists the final HEP by basic event name provides the link between the HRA and the rest of the PCSA. This table can be found in Section E6.4.4.

E6.4.3.1 Human Failure Events Requiring Detailed Analysis

The detailed analysis methodology, Sections E3.2.5 through E3.2.9, states that HFEs of concern are identified for detailed quantification through the preliminary analysis (Section E3.2.4). An initial quantification of the IHF PCSA model determined that there were three HFEs in this group whose preliminary values were too high to demonstrate compliance with the performance objectives stated in 10 CFR 63.111. These HFEs are presented in Table E6.4-2.

Table E6.4-2. Group #4 HFEs Requiring Detailed Analysis

HFE	Description	Preliminary Value
51A-OpCTMdrop001-HFI-COD	Operator causes drop of object onto canister during CTM operations	2E-03
51A-OpCTMdrop002-HFI-COD	Operator causes drop of canister during CTM operations (low-level drop)	2E-03
51A-OpCTMImpact1-HFI-COD	Operator moves CTM while canister or object is below or between levels	1E-03

NOTE: CTM = canister transfer machine; HFE = human failure event. Source: Original

E6.4.3.2 Assessment of Potential Vulnerabilities (Step 5)

For those HFEs requiring detailed analysis, the first step in the approach to detailed quantification is to identify and characterize factors that could create potential vulnerabilities in the crew's ability to respond to the scenarios of interest and might result in HFEs or unsafe actions. In this sense, the "vulnerabilities" are the context and factors that influence human performance and constitute the characteristics, conditions, rules, and tendencies that pertain to all the scenarios analyzed in detail. These vulnerabilities are identified through activities including, but not limited to, the following:

1. The facility familiarization and information collection process discussed in Section E4.1, such as the review of design drawings and concept of operations documents.

2. Discussions with subject matter experts from a wide range of areas, as described in Section E4.2.

Table E6.4-3. HFE Scenarios and Expected Human Failures for Group #4

HFE	HFE Scenarios
51A-OpCTMdrop001-HFI-COD *Operator Causes Drop of Object onto Canister during CTM Operations*	HFE Scenario 1(a): (1) Crew member improperly installs grapple; (2) Pre-operational check fails to note improper installation; (3) Primary grapple interlock gives false positive signal; (4) Operator fails to notice bad connection between hoist and grapple through camera ; (5) Grapple/lid or grapple/shield ring drops from hoist and strikes canister HFE Scenario 1(b): (1) Operator fails to fully engage grapple; (2) Grapple engagement interlock gives false positive signal; (3) Operator fails to notice grapple not fully engaged through camera; (4) Lid or shield ring drops from grapple and strikes canister HFE Scenario 1(c)[a]: (1) Operator leaves ASD in maintenance mode OR Operator places ASD in canister mode OR ASD height control fails; (2) Operator fails to notice lift is taking too long OR Operator "locks" lift button into position; (3) Load cell overload interlock fails; (4) Mechanical failure of hoist under overload causes lid or shield ring to drop HFE Scenario 1(d)[a]: (1) CTT is not sufficiently centered under port; (2) Operator fails to notice CTT not sufficiently centered; (3) Operator fails to notice lid tilt and continues lift OR Operator "locks" lift button into position; (4) Lid catches and jams in port; (5) Load cell overload interlock fails; (6) Mechanical failure of hoist under overload causes lid to drop HFE Scenario 1(e): (1) Operator activates grapple disengagement switch prematurely; (2) Load cell disengagement interlock fails; (3) Lid or shield ring drops from grapple and strikes canister
51A-OpCTMdrop002-HFI-COD *Operator Causes Drop of Canister during CTM Operations (Low-Level Drop)*	HFE Scenario 2(a): (1) Crew member improperly installs grapple; (2) Primary grapple interlock gives false positive signal; (3) Operator fails to notice bad connection between hoist and grapple through camera ; (4) Grapple/canister drops from hoist HFE Scenario 2(b): (1) Operator fails to fully engage grapple; (2) Grapple engagement interlock gives false positive signal; (3) Operator fails to notice grapple not fully engaged through camera; (4) Canister drops from grapple HFE Scenario 2(c)[b]: (1) CTT is not sufficiently centered under port; (2) Operator fails to notice CTT not sufficiently centered; (3) Operator fails to notice canister contacting ceiling and continues lift OR Operator "locks" lift button into position; (4) Load cell overload interlock fails; (5) Mechanical failure of hoist under overload causes canister to drop. HFE Scenario 2(d): (1) Crew member fails to fully withdraw lift fixture bolts; (2) Operator fails to notice canister is rising with lift fixture and shield ring; (3) Canister drops from lift fixture.

HFE	HFE Scenarios
51A-OpCTMImpact1-HFI-COD *Operator moves the CTM while canister or object is below or between levels*	HFE Scenario 3(a): (1) The operator, handling an HLW canister, improperly leaves the CTM in the lid lift mode, (2) the operator fails to notice that the lift stops too soon, (3) the operator fails to close the port slide gate OR fails to notice that it does not fully close, (4) the operator fails to close the CTM slide gate OR fails to notice that it does not fully close, and (5) the CTM slide gate interlock fails. HFE Scenario 3(b): (1) The operator, handling a naval canister, improperly puts the CTM in the lid lift mode, (2) the operator fails to notice that the lift stops too soon, (3) the operator fails to close the port slide gate OR fails to notice that it does not fully close, (4) the operator fails to close the CTM slide gate OR fails to notice that it does not fully close, and (5) the CTM slide gate interlock fails. HFE Scenario 3(c): (1) The operator, handling an HLW canister, improperly puts the CTM in the maintenance mode, (2) the operator terminates the lift prior to the automatic stop, (3) the operator fails to close the port slide gate OR fails to notice that it does not fully close, and (4) the operator fails to close the CTM slide gate OR fails to notice that it does not fully close, (5) the CTM slide gate interlock fails. HFE Scenario 3(d)[c]: (1) The operator, handling a naval canister, leaves the CTM in the maintenance mode, (2) the operator terminates the lift prior to the automatic stop, (3) the operator fails to close the port slide gate OR fails to notice that it does not fully close, and (4) the operator fails to close the CTM slide gate OR fails to notice that it does not fully close, (5) the CTM slide gate interlock fails.

NOTE: [a]Scenarios 1(c) and 1(d) are only applicable to HLW. These scenarios do not apply to placing the waste package inner lid or removing the naval shield ring, because they can only occur over the canister when lifting a transportation cask lid.

[b]This scenario only applies to naval waste because the HLW cask lid was removed in the prep area.

[c]Of Scenarios 3(a) through 3(d), only Scenario 3(d) applies to lids (in this case, the naval waste package lid).

ASD = adjustable speed drive; CTM= canister transfer machine; CTT = cask transfer trolley; HFE = human failure event; HLW = high-level radioactive waste.

Source: Original

Since there are three HFEs identified for detailed analysis in this group, the scenarios are organized under these two HFE categories, with the scenarios numbered for the first category as 1(a), 1(b), 1(c), 1(d), and 1(e) and similarly for the second category.

Each HFE scenario is in turn characterized by several unsafe actions, numbered sequentially as (1), (2), (3), etc. The Boolean logic of the HFE scenarios is expressed with an implicit AND connecting the subsequent unsafe actions and OR notation wherever two unsafe action paths are possible, as shown in Table E6.4-3.

The HFE scenarios summarized in Table E6.4-3 are discussed and quantified in detail in the following sections.

E6.4.3.4 Quantitative Analysis (Step 7)

Once the HFE scenarios and the unsafe actions within them are scoped out, it is then possible to review them in detail and apply the appropriate quantification methodology in each case that permits an HEP to be calculated for each HFE. Stated another way, each HFE is quantified through the analysis and combination of the contributing HFE scenarios. Dependencies between the unsafe actions and equipment responses within each scenario and across the scenarios are carefully considered in the quantification process.

This section provides a description of the quantitative analysis performed. This quantitative analysis is structured hierarchically by each HFE category (identified by a basic event name), followed by the HFE scenario, and then followed by the unsafe actions under each scenario as documented in Table E6.4-3.

Prior to the scenario-specific quantification descriptions, a listing is provided of the values used in the quantification that are common across many of the HFE scenarios.

In generating the final HEP values, the use of more than a single significant figure is not justified given the extensive use of judgment required for the quantification of the individual unsafe actions within a given HFE. For this reason, all calculated final HEP values are reduced to one significant figure. When doing this, the value is always rounded upwards to the next highest single significant figure.

E6.4.3.4.1 Common Values Used in the HFE Detailed Quantification

There are some mechanical failures that combine with unsafe actions to form HFEs. In general, these mechanical failures are independent of the specific HFE scenario, and so they can be quantified independently. These values are presented in this section.

Interlock Failures—There are a number of interlock failures in the HFE scenarios. While the status of these events can affect subsequent events in the scenarios in different ways, the likelihood of this event occurring is independent of the scenario. This event is an equipment failure and does not have a human component to its failure rate. The demand failure rate for an interlock, from Attachment C, Table C4-1, is approximately 2.7E−05 per demand.

Interlock fails to perform function = 2.7E−05

Table E6.4-12. HEP Model for HFE Group #4 Scenario 2(d) for 51A-OpCTMdrop002-HFI-COD

Designator	Description	Probability
A	Crew member fails to fully withdraw lift fixture bolts	0.2
B	Operator fails to notice canister is rising with lift fixture and shield ring	0.003
C	Canister drops from lift fixture	0.25

NOTE: HEP = human error probability.

Source: Original

The Boolean expression for this scenario follows:

$$A \times B \times C = 0.2 \times 0.003 \times 0.25 = 2E{-}4 \quad \text{(Eq. E-20)}$$

E6.4.3.4.3.5 HEP for HFE 51A-OpCTMdrop002-HFI-COD

The Boolean expression for the overall HFE (all scenarios) for moving a naval canister follows:

$$\text{51A-OpCTMdrop002-HFI-COD (Naval Canister)} = \text{HFE 2(a)} + \text{HFE 2(b)} + \text{HFE 2(c)} + \text{HFE 2(d)} = (<1E{-}8) + 5E{-}7 + (<1E{-}8) + 2E{-}4 = 2E{-}4 \quad \text{(Eq. E-21)}$$

The Boolean expression for the overall HFE (all scenarios) for moving an HLW canister follows:

$$\text{51A-OpCTMdrop002-HFI-COD (HLW)} = \text{HFE 2(a)} + \text{HFE 2(b)} = (<1E{-}8) + 5E{-}7 = 5E{-}7 \quad \text{(Eq. E-22)}$$

E6.4.3.4.4 Quantification of HFE Scenarios for 51A-OpCTMImpact1-HFI-COD: Operator Moves the CTM while Canister or Object Is Below or Between Levels

E6.4.3.4.4.1 HFE Group #5 Scenario 3(a) for 51A-OpCTMImpact1-HFI-COD

1. Operator leaves CTM in lid lift mode (HLW only).
2. Operator fails to notice that lift stops too soon.
3. Operator fails to close port slide gate OR fails to notice that it does not fully close.
4. Operator fails to close CTM slide gate OR fails to notice it does not fully close.
5. CTM slide gate interlock fails.

Operator Leaves CTM in Lid Lift Mode (HLW only)—The operator is supposed to set the ASD to canister lift mode prior to lifting the canister. It should be in lid lift mode because the lid was lifted right before the canister. Failing to reset for a canister lift would result in the canister stopping part way through the port.

Setting the CTM system to the appropriate lift mode prior to performing a lift is fundamental to the operation, not simply a step in a procedure that can be missed. The initial action to set the mode is quite simple, so the only realistic way that the operator can leave the ASD in lid lift mode is to completely fail to take any actions to set the CTM system for a lift. This failure can be represented by NARA GTT B3, adjusted by the following EPCs.

- GTT B3: Set system status as part of routine operations using strict administratively controlled procedures. The baseline HEP is 0.0007.

This operation is performed under optimal conditions. It is early in the operation, and the operator is active, so it is too early in the task for boredom to set in. The baseline HEP is used without adjustment.

Operator leaves CTM in lid lift mode = 0.0007

Operator Fails to Notice that Lift Stops too Soon—Lifting the canister takes on the order of ten minutes, whereas lifting the lid takes only on the order of three minutes. Since the operator has to hold the lift button in or the lift stops, there is an opportunity to notice that the hoist has stopped sooner than expected. On the control panel the operator would have the camera view and also the hoist position indication, either of which can confirm that the canister has not been fully lifted. Failure to do so would result in continuing the operations with the canister between floors.

The operator is supposed to hold the lift button until the lift automatically stops. The operator has performed this operation many times in the past and has an instinctive feel for how long the lift takes. A canister lift should take around three times as long as a lid lift. If the operator feels it has not taken long enough, the camera and the indicators on the control panel can provide confirmation that the lift was prematurely terminated. Failing to recognize the short lift (and thus an implied failure to question the result of the action) could be an observation error (CREAM CFF O2, wrong identification made, or O3, observation not made). But the more conservative and more applicable approach is represented by the interpretation error CREAM CFF I1, adjusted by the following CPCs with values not equal to 1.0:

- CFF I1: Faulty diagnosis (either a wrong diagnosis or an incomplete diagnosis). The baseline HEP is 0.2.

- CPC "Working Conditions": The operator has optimal working conditions in the control room. The CPC for an interpretation task with advantageous working conditions is 0.8.

- CPC "Available Time": The operator clearly has adequate time before beginning the next steps in the process to realize that the amount of time spent in the lift is not reasonable for a canister lift. The CPC for an interpretation task with adequate available time is 0.5.

- CPC "Adequacy of Training/Preparation": Training is adequate with high experience. The CPC for an observation task with adequate training and high experience is 0.8.

Applying these factors yields the following:

Operator fails to notice lift is taking too long = $0.2 \times 0.8 \times 0.5 \times 0.8 = 0.07$

Operator Fails to Close Port Slide Gate—The operator is supposed to close the port slide gate as soon as the lift is completed. This gives the operator an opportunity to determine that the canister is not fully withdrawn. The operator would fail to notice this if either the operator skipped this step or if the operator performed the action and failed to notice that the gate had not closed all the way (e.g., because it is blocked from doing so by the canister). In the latter case, the slide gate open/close indicator lights are in an incorrect state (either both on or both off, depending on design).

The operator is supposed to close the port slide gate prior as a part of the lift and transfer process. This is an EOO that can most closely be represented by CREAM CFF E5, adjusted by the following CPCs with values not equal to 1.0:

- CFF E5: Action missed, not performed (omission), including the omission of the last actions in a series. The baseline HEP is 0.03.
- CPC "Available Time": There is adequate time available. The CPC for an execution task with adequate time is 0.5.
- CPC "Adequacy of Training/Preparation": Training is adequate with high experience. The CPC for an execution task with adequate training and high experience is 0.8.

Applying these factors yields the following:

$$\text{Operator fails to close port slide gate} = 0.03 \times 0.5 \times 0.8 = 0.01$$

Operator Fails to Notice that Port Slide Gate Does Not Fully Close—The action of closing the port slide gate is simple. In this scenario, the gate does not close all the way because the canister is in the way. The operator has visible feedback on the failure of the gate to close because the "open" (or "green") light on the control panel stays on and the "closed" (or "red") light also comes on and stays on. Both lights on at the same time signifies that the port is neither fully open nor fully closed. The problem can be easily confirmed by looking at the camera or checking the status of the light curtain at the bottom of the bell. This unsafe action can be represented by NARA GTT C1, adjusted by the following EPCs.

- GTT C1: Simple response to a range of alarms/indications providing clear indication of situation (simple diagnosis required). The baseline HEP is 0.0004.
- EPC 3: Time pressure. The full affect EPC would be ×11, but this applies only in cases where there is barely enough time to complete a task, and rapid work is necessary. In this case, the time pressure is more abstract in that there is a desire to keep the process moving for production reasons, but not a compelling one. The APOA anchor for 0.1 is that the operator feels some time pressure, but there is sufficient time to carry out the task properly with checking. This appears reasonable for this task, so the APOA is set at 0.1.
- EPC 13: Operator underload/boredom. The full affect EPC would be ×3, which applies to a routine task of low importance, carried out by a single individual for several hours. The APOA anchor for 0.1 is for low difficulty, low importance, single individual, for less than one hour. This appears reasonable for this task, so the APOA is set at 0.1.

Using the NARA HEP equation yields the following:

Operator fails to notice that port slide gate does not fully close
$= 0.0004 \times [(11-1) \times 0.1 + 1] \times [(3-1) \times 0.1 + 1] = 0.001$ (Eq. E-22a)

Operator Fails to Close CTM Slide Gate—The operator is supposed to close the CTM slide gate as soon as the port slide gate is closed. This gives the operator another opportunity to determine that the canister is not fully withdrawn. The operator would fail to notice this if either the operator skipped this step or if the operator performed the action and failed to notice that the gate had not closed all the way (e.g., because it is blocked from doing so by the hoist cables or load cell). In the latter case, the slide gate open/close indicator lights would be an incorrect state (either both on or both off, depending on design).

The baseline HEP for failure to close this gate would be the same as for the similar unsafe action for the port slide gate.

Operator fails to close CTM slide gate (independent) = 0.01

However, this would only apply in the case where the earlier unsafe action was failure to notice that the port slide gate had failed to close. In the case where the earlier unsafe action was failure to close the port slide gate, there is a dependence on the failure to perform a similar task next in the sequence. It is judged that the dependence between these two actions is high. Using item (4)(a) from THERP (Ref. E8.1.26) Table 20-21, the HEP follows:

Operator fails to close CTM slide gate (given failure to close the port slide gate) = 0.5

Operator Fails to Notice CTM Slide Gate Does Not Fully Close—The baseline HEP for failure to notice that this gate did not fully close would be the same as for the similar unsafe action for the port slide gate.

Operator fails to notice CTM slide gate does not fully close (independent) = 0.001

However, this would only apply in the case where the earlier unsafe action was failure to close the port slide gate. In the case where the earlier unsafe action was failure to notice that the port slide gate did not fully close, there is a dependence on the failure to perform a similar task next in the sequence. It is judged that the dependence between these two actions is high. Using item (4)(a) from THERP (Ref. E8.1.26) Table 20-21, the HEP follows:

Operator fails to notice CTM slide gate does not fully close
(given failure notice that port slide gate did not fully close) = 0.5

CTM Slide Gate Interlock Fails—The CTM slide gate interlock prevents CTM movement with the slide gate open (the shield skirt cannot be raised). If the interlock itself fails, the operator can move the CTM with the canister between levels.

This is a mechanical failure of the interlock. This event is quantified in Section E6.4.3.4.1.

CTM slide gate interlock fails = 2.7E−5

HEP Calculation for Scenario 3(a)—The events in the HEP model for Scenario 3(a) are presented in Table E6.4-13.

Table E6.4-13. HEP Model for HFE Group #5 Scenario 3(a) for 51A-OpCTMImpact1-HFI-COD

Designator	Description	Probability
A	Operator leaves CTM in lid lift mode	0.0007
B	Operator fails to notice that lift stops too soon	0.07
C	Operator fails to close port slide gate	0.01
D	Operator fails to notice that port slide gate does not fully close	0.001
E1	Operator fails to close CTM slide gate (independent)	0.01
E2	Operator fails to close CTM slide gate (given failure to close the port slide gate)	0.5
F1	Operator fails to notice CTM slide gate does not fully close (independent)	0.001
F2	Operator fails to notice CTM slide gate does not fully close (given failure to notice that port slide gate did not fully close)	0.5
G	CTM slide gate interlock fails	2.7E−05

NOTE: CTM = canister transfer machine; HEP = human error probability.

Source: Original

The Boolean expression for this scenario follows:

$$A \times B \times \{[C \times (E2 + F1)] + [D \times (E1 + F2)]\} \times G =$$
$$0.0007 \times 0.07 \times \{[0.01 \times (0.5 + 0.001)] + [0.001 \times (0.01 + 0.5)]\} \times 2.7E{-}05 =$$
$$0.0007 \times 0.07 \times 0.006 \times 2.7E{-}05 = (<1E{-}8) \qquad \text{(Eq. E-22b)}$$

E6.4.3.4.4.2 HFE Group #5 Scenario 3(b) for 51A-OpCTMImpact1-HFI-COD

1. Operator places CTM in lid lift mode (naval canister).
2. Operator fails to notice that lift stops too soon.
3. Operator fails to close port slide gate OR fails to notice that it does not fully close.
4. Operator fails to close CTM slide gate OR fails to notice it does not fully close.
5. CTM slide gate interlock fails.

Operator Inadvertently Places CTM in Lid Lift Mode (naval)—The operator is supposed to set the ASD to canister lift mode prior to lifting the canister. For naval operations, the ASD is in maintenance (or manual) lift mode because this is the default positioning. Failing to reset for canister lift would result in the canister stopping part way through the port.

The CTM operator is supposed to set the CTM system to the appropriate lift mode prior to performing a lift. This is fundamental to the operation, not simply a step in a procedure that can be missed. For the situation involving the naval canister, the ASD has been in maintenance mode as a default condition; therefore, the operator must inadvertently set the ASD to lid lift mode rather than canister lift mode. There are only two modes to choose from: lid lift and canister lift. The ASD control is a screen where the operator can scroll between the choices to pick the appropriate lift mode. The act of selecting the wrong mode from these two can be best represented by the task execution error NARA GTT A1, adjusted by the following CPCs:

- NARA GTT A1: Carry out a simple single manual action with feedback. Skill-based and therefore not necessarily with procedures. The baseline HEP is 0.005.

- This operation is performed under optimal conditions. It is early in the operation, and the operator is active, so it is too early in the task for boredom to set in. The ASD control system requests confirmation from the operator (e.g., "You have selected canister lift. Confirm Y/N"). The baseline HEP is used without adjustment.

Operator inadvertently places CTM in lid lift mode (naval) = 0.005.

Operator Fails to Notice that Lift Stops too Soon—Lifting the canister takes on the order of ten minutes, whereas lifting the lid takes only on the order of three minutes. Since the operator has to hold the lift button in or the lift stops, the operator has an opportunity to notice that the hoist has stopped sooner than expected. In front on the control panel there is a camera view and also the hoist position indication, either of which can confirm the suspicion that the canister has not been fully lifted. Failure to do so would result in a continuation of the operations with the canister between floors.

The operator is supposed to hold the lift button until the lift automatically stops. The operator has performed this operation many times in the past, and has an instinctive feel for how long the lift takes. A canister lift should take around three times as long as a lid lift. If the operator feels it has not taken long enough, the operator need only look at the camera and the indicators on the control panel. Failing to recognize the short lift (and thus an implied failure to question the result of the action) can be represented by CREAM CFF I1, adjusted by the following CPCs with values not equal to 1.0:

- CFF I3: Faulty diagnosis (either a wrong diagnosis or an incomplete diagnosis). The baseline HEP is 0.2.

- CPC "Working Conditions": The operator has optimal working conditions in the control room. The CPC for an interpretation task with advantageous working conditions is 0.8.

- CPC "Available Time": The operator clearly has adequate time before beginning the next steps in the process to realize that the amount of time spent in the lift is not reasonable for a canister lift. The CPC for an interpretation task with adequate available time is 0.5.

- CPC "Adequacy of Training/Preparation": Training is adequate with high experience. The CPC for an observation task with adequate training and high experience is 0.8.

Applying these factors yields the following:

Operator fails to notice lift is taking too long = $0.2 \times 0.8 \times 0.5 \times 0.8 = 0.07$

Operator Fails to Close Port Slide—The operator is supposed to close the port slide gate as soon as the lift is completed as a part of the lift and transfer process. This gives the operator an opportunity to determine that the canister is not fully withdrawn. The operator would fail to notice this if either the operator skipped this step or if the operator performed the action and failed to notice that the gate had not closed all the way (e.g., because it is blocked from doing so by the canister). In the latter case, the slide gate open/close indicator lights would be in an incorrect state (either both on or both off, depending on design).

This is an EOO that can most closely be represented by CREAM CFF E5, adjusted by the following CPCs with values not equal to 1.0:

- CFF E5: Action missed, not performed (omission), including the omission of the last actions in a series. The baseline HEP is 0.03.
- CPC "Available Time": There is adequate time available. The CPC for an execution task with adequate time is 0.5.
- CPC "Adequacy of Training/Preparation": Training is adequate with high experience. The CPC for an execution task with adequate training and high experience is 0.8.

Applying these factors yields the following:

$$\text{Operator fails to close port slide gate} = 0.03 \times 0.5 \times 0.8 = 0.01$$

Operator Fails to Notice that Port Slide Gate Does Not Fully Close—The action of closing the port slide gate is simple. In this scenario, the gate does not close all the way because the canister is in the way. The operator has visible feedback on the failure of the gate to close because the "open" (or "green") light on the control panel stays on and the "closed" (or "red") light also comes on and stays on. Both lights on at the same sign signify that the port is neither fully open nor fully closed. The problem can be easily confirmed by looking at the camera or checking the status of the light curtain at the bottom of the bell. This unsafe action can be represented by NARA GTT C1, adjusted for the following EPCs:

- GTT C1: Simple response to a range of alarms/indications providing clear indication of situation (simple diagnosis required). The baseline HEP is 0.0004.
- EPC 3: Time pressure. The full affect EPC would be ×11, but this applies only in cases where there is barely enough time to complete a task, and rapid work is necessary. In this case, the time pressure is more abstract, in that there is a desire to keep the process moving for production reasons, but not a compelling one. The APOA anchor for 0.1 is that the operator feels some time pressure, but there is sufficient time to carry out the task properly with checking. This appears reasonable for this task, so the APOA is set at 0.1.
- EPC 13: Operator underload/boredom. The full affect EPC would be ×3, which applies to a routine task of low importance, carried out by a single individual for several hours. The APOA anchor for 0.1 is for low difficulty, low importance, single individual, for less than one hour. This appears reasonable for this task, so the APOA is set at 0.1.

Using the NARA HEP equation yields the following:

Operator fails to notice that port slide gate does not fully close =
$$0.0004 \times [(11-1) \times 0.1 + 1] \times [(3-1) \times 0.1 + 1] = 0.001 \qquad \text{(Eq. E-22c)}$$

Operator Fails to Close CTM Slide Gate—The operator is supposed to close the CTM slide gate as soon as the port slide gate is closed. This gives the operator another opportunity to determine that the canister is not fully withdrawn. This failure would go unnoticed if the operator either skipped this step or performed the action and failed to notice that the gate had not closed all the way (e.g., because it is blocked from doing so by the hoist cables or load cell). In the latter case, the slide gate open/close indicator lights would be an incorrect state (either both on or both off, depending on design).

The baseline HEP for failure to close this gate would be the same as for the similar unsafe action for the port slide gate.

Operator fails to close CTM slide gate (independent) = 0.01

However, this would only apply in the case where the earlier unsafe action was failure to notice that the port slide gate had failed to close. In the case where the earlier unsafe action was failure to close the port slide gate, there is a dependence on the failure to perform a similar task next in the sequence. It is judged that the dependence between these two actions is high. Using item (4)(a) from THERP (Ref. E8.1.26) Table 20-21, the HEP follows:

Operator fails to close CTM slide gate (given failure to close the port slide gate) = 0.5

Operator Fails to Notice CTM Slide Gate Does Not Fully Close—The baseline HEP for failure to notice this gate did not fully close would be the same as for the similar unsafe action for the port slide gate.

Operator fails to notice CTM slide gate does not fully close (independent) = 0.001

However, this would only apply in the case where the earlier unsafe action was failure to close the port slide gate. In the case where the earlier unsafe action was failure to notice that the port slide gate did not fully close, there is a dependence on the failure to perform a similar task next in the sequence. It is judged that the dependence between these two actions is high. Using item (4)(a) from THERP (Ref. E8.1.26) Table 20-21, the HEP follows:

Operator fails to notice CTM slide gate does not fully close
(given failure notice that port slide gate did not fully close) = 0.5

CTM Slide Gate Interlock Fails—The CTM slide gate interlock prevents CTM movement with the slide gate open (i.e., the shield skirt cannot be raised). If the interlock itself fails, the operator can move the CTM with the canister between levels.

This is a mechanical failure of the interlock. This event is quantified in Section E6.4.3.4.1.

CTM slide gate interlock fails = 2.7E−5

HEP Calculation for Scenario 3(b)—The events in the HEP model for Scenario 3(b) are presented in Table E6.4-14.

Table E6.4-14. HEP Model for HFE Group #5 Scenario 3(b) for 51A-OpCTMImpact1-HFI-COD

Designator	Description	Probability
A	Operator inadvertently places CTM in lid lift mode	0.005
B	Operator fails to notice that lift stops too soon	0.07
C	Operator fails to close port slide gate	0.01
D	Operator fails to notice that port slide gate does not fully close	0.001
E1	Operator fails to close CTM slide gate (independent)	0.01
E2	Operator fails to close CTM slide gate (given failure to close the port slide gate)	0.5
F1	Operator fails to notice CTM slide gate does not fully close (independent)	0.001
F2	Operator fails to notice CTM slide gate does not fully close (given failure to notice that port slide gate did not fully close)	0.5
G	CTM slide gate interlock fails	2.7E−05

NOTE: CTM = canister transfer machine; HEP = human error probability.

Source: Original

The Boolean expression for this scenario follows:

$$A \times B \times \{[C \times (E2 + F1)] + [D \times (E1 + F2)]\} \times G = 0.005 \times 0.07 \times \{[0.01 \times (0.5 + 0.001)] + [0.001 \times (0.01 + 0.5)]\} \times 2.7E{-}05 = 0.005 \times 0.07 \times 0.006 \times 2.7E{-}05 = (<1E{-}8) \quad \text{(Eq. E-22d)}$$

E6.4.3.4.4.3 HFE Group #5 Scenario 3(c) for 51A-OpCTMImpact1-HFI-COD

1. Operator puts CTM in maintenance mode (HLW).
2. Operator terminates lift prior to automatic stop.
3. Operator fails to close port slide gate OR fails to notice that it does not fully close.
4. Operator fails to close CTM slide gate OR fails to notice it does not fully close.
5. CTM slide gate interlock fails.

Operator Puts CTM in Maintenance Mode (HLW)—The operator is supposed to set the ASD to canister lift mode prior to lifting the canister. It should be in lid lift mode because the lid was lifted right before the first canister. Placing it in the maintenance mode instead of the canister lift mode removes the ASD height control set point and also defeats the CTM slide gate interlock (since maintenance mode would allow CTM movement with the slide gate open). In order to place it into maintenance mode, the operator is required to enter a password.

In this case, the operator commits the unsafe action of placing the CTM in maintenance mode. This is not easy to do; if the operator inadvertently selects this mode, the operator is asked to confirm the selection and is also required to enter a password, which is not required for the selection of canister mode. This can be represented by NARA GTT A5, adjusted for the following EPCs:

- GTT A5: Completely familiar, well-designed, highly practiced routine task performed to highest possible standards by highly motivated, highly trained, and experienced personnel, totally aware of implications of failure, with time to correct potential errors. The baseline HEP is 0.0001.

- EPC 6: A means of suppressing or overriding information or features that are too easily accessible. In this case, while a warning is given and a password is required, the operator still can still override the feature and enter manual mode. The full affect is ×9. The APOA anchor for 0.5 is for something overridden on a regular basis. The APOA anchor for 0.1 is for something overridden once in a while. Other considerations for a reduction from full affect are a good interface design and good safety culture. Since maintenance mode is required on a regular basis, but there are other mitigating factors, it appears reasonable for this task that the APOA be set at 0.3.

Using the NARA HEP equation yields the following:

$$\text{Operator puts CTM in maintenance mode} = 0.0001 \times [(9-1) \times 0.3 + 1] = 0.0004 \qquad \text{(Eq. E-22e)}$$

Operator Terminates Lift Prior to Automatic Stop—The operator is supposed to hold the lift button until the lift automatically stops. This happens even in the maintenance mode since the interlocks that prevent two-blocking are still active, and the CTM transfer sequence can still be completed successfully. However, if the operator terminates the lift prematurely, the canister could still be between floors.

The unsafe action results from stopping the hoist prematurely and leaving the canister below or between the floors (i.e., a number of feet short of the proper location). This can be represented by CREAM CFF E1, adjusted by the following CPCs with values not equal to 1.0:

- CFF E1: Execution of wrong type performed (with regard to force, distance, speed, or direction). The baseline HEP is 0.003.

There are no CPCs that are deemed to have values not equal to 1.0 for this action.

Applying these factors yields the following:

$$\text{Operator terminates lift prior to automatic stop} = 0.003$$

Operator Fails to Close Port Slide Gate—The operator is supposed to close the port slide gate as soon as the lift is completed. This gives the operator an opportunity to determine that the canister is not fully withdrawn. The operator would fail to notice this if either the operator skipped this step or if the operator performed the action and failed to notice that the gate had not closed all the way (e.g., because it is blocked from doing so by the canister). In the latter case, the slide gate open/close indicator lights would be in an incorrect state (either both on or both off, depending on design).

This value is the same as for Scenario 3(a):

Operator fails to close port slide gate = 0.01

Operator Fails to Notice that Port Slide Gate Does Not Fully Close—This value is the same as for Scenario 3(a):

Operator fails to notice that port slide gate does not fully close = 0.001

Operator Fails to Close CTM Slide Gate—The operator is supposed to close the CTM slide gate as soon as the port slide gate is closed. This gives the operator another opportunity to determine that the canister is not fully withdrawn. The operator would fail to notice this if either the operator skipped this step or if the operator performed the action and failed to notice that the gate had not closed all the way (e.g., because it is blocked from doing so by the hoist cables or load cell). In the latter case, the slide gate open/close indicator lights would be an incorrect state (either both on or both off, depending on design).

This value is the same as for Scenario 3(a):

Operator fails to close CTM slide gate (independent) = 0.01
Operator fails to close CTM slide gate (given failure to close the port slide gate) = 0.5

Operator Fails to Notice CTM Slide Gate Does Not Fully Close—This value is the same as for Scenario 3(a):

Operator fails to notice CTM slide gate does not fully close (independent) = 0.001
Operator fails to notice CTM slide gate does not fully close (given failure notice that port slide gate did not fully close) = 0.5

CTM Slide Gate Interlock Fails

The CTM slide gate interlock prevents CTM movement with the slide gate open (the shield skirt cannot be raised). If the interlock itself fails, the operator can move the CTM with the canister between levels. Note: the maintenance mode does not bypass the shield skirt/slide gate interlock; this interlock cannot be bypassed.

This is a mechanical failure of the interlock. This event is quantified in Section 6.4.3.4.1:

CTM slide gate interlock fails = 2.7E−5

HEP Calculation for Scenario 3(c)—The events in the HEP model for Scenario 3(c) are presented in Table E6.4-15.

Table E6.4-15. HEP Model for HFE Group #5 Scenario 3(c) for 51A-OpCTMImpact1-HFI-COD

Designator	Description	Probability
A	Operator puts CTM in maintenance mode	0.0004
B	Operator terminates lift prior to automatic stop	0.003
C	Operator fails to close port slide gate	0.01
D	Operator fails to notice that port slide gate does not fully close	0.001

Designator	Description	Probability
E1	Operator fails to close CTM slide gate (independent)	0.01
E2	Operator fails to close CTM slide gate (given failure to close the port slide gate)	0.5
F1	Operator fails to notice CTM slide gate does not fully close (independent)	0.001
F2	Operator fails to notice CTM slide gate does not fully close (given failure notice that port slide gate did not fully close)	0.5
G	CTM slide gate interlock fails	2.7E−05

NOTE: CTM = canister transfer machine; HEP = human error probability.

Source: Original

The Boolean expression for this scenario follows:

$$A \times B \times \{[C \times (E2 + F1)] + [D \times (E1 + F2)]\} \times G = 0.0004 \times 0.003 \times \{[0.01 \times (0.5 + 0.001)] + [0.001 \times (0.01 + 0.5)]\} \times 2.7E{-}05 = 0.0004 \times 0.003 \times .006 \times 2.7E{-}05 = 7E{-}09 \times 2.7E{-}05 = (<1E{-}08) \quad \text{(Eq. E-22f)}$$

Truncating the human failure component, the HEP for this scenario becomes:

$$1E{-}5 \times 2.7E{-}5 = (<1E{-}08) \quad \text{(Eq. E-22g)}$$

E6.4.3.4.4.4 HFE Group #5 Scenario 3(d) for 51A-OpCTMImpact1-HFI-COD

1. Operator leaves CTM in maintenance mode (naval).
2. Operator terminates lift prior to automatic stop.
3. Operator fails to close port slide gate OR fails to notice that it does not fully close.
4. Operator fails to close CTM slide gate OR fails to notice it does not fully close.
5. CTM slide gate interlock fails.

Operator Leaves CTM in Maintenance Mode (naval)—The operator is supposed to set the ASD to canister lift mode prior to lifting the canister. For naval operations, the ASD is in maintenance (or manual) lift mode because this is the default positioning. Leaving it in the maintenance mode instead of the canister lift mode removes the ASD height control set point and also defeats the CTM slide gate interlock (since maintenance mode allows CTM movement with the slide gate open).

In this case, this leaves the ASD in maintenance mode, which is the default position for naval operations. The initial action to set the mode is quite simple, so the only realistic way that the operator can leave the ASD in maintenance mode is to completely fail to take any actions to set the CTM system for a lift. This failure can be represented by NARA GTT B3, and adjusted by the following EPCs:

- GTT B3: Set system status as part of routine operations using strict administratively controlled procedures. The baseline HEP is 0.0007.

This operation is performed under optimal conditions. It is early in the operation, and the operator is active, so it is too early in the task for boredom to set in. The baseline HEP is used without adjustment.

Operator leaves CTM in maintenance mode = 0.0007

Operator Terminates Lift Prior to Automatic Stop—The operator is supposed to hold the lift button in until the lift automatically stops. This happens even in the maintenance mode since the interlocks that prevent two-blocking are still active, and the CTM transfer sequence can still be completed successfully. However, if the operator terminates the lift prematurely, the canister could still be between floors.

The unsafe action results from stopping the hoist prematurely and leaving the canister below or between the floors (i.e., a number of feet short of the proper location). This can be represented by CREAM CFF E1, adjusted by the following CPCs with values not equal to 1.0:

- CFF E1: Execution of wrong type performed (with regard to force, distance, speed, or direction). The baseline HEP is 0.003.

There are no CPCs that are deemed to have values not equal to 1.0 for this action.

Applying these factors yields the following:

Operator terminates lift prior to automatic stop = 0.003

Operator Fails to Close Port Slide Gate—The operator is supposed to close the port slide gate as soon as the lift is completed. This gives the operator the opportunity to determine that the canister is not fully withdrawn. This failure would go unnoticed if the operator either skipped this step or performed the action and failed to notice that the gate had not closed all the way (e.g., because it is blocked from doing so by the canister). In the latter case, the slide gate open/close indicator lights would be in an incorrect state (either both on or both off, depending on design).

This value is the same as for Scenario 3(a):

Operator fails to close port slide gate = 0.01

Operator Fails to Notice that Port Slide Gate Does Not Fully Close—This value is the same as for Scenario 3(a):

Operator fails to notice that port slide gate does not fully close = 0.001

Operator Fails to Close CTM Slide Gate—The operator is supposed to close the CTM slide gate as soon as the port slide gate is closed. This gives the operator another opportunity to determine that the canister is not fully withdrawn. This would go unnoticed if the operator either skipped this step or performed the action and failed to notice that the gate had not closed all the way (e.g., because it is blocked from doing so by the hoist cables or load cell). In the latter case, the slide gate open/close indicator lights would be an incorrect state (either both on or both off, depending on design).

This value is the same as for Scenario 3(a):

Operator fails to close CTM slide gate (independent) = 0.01

Operator fails to close CTM slide gate (given failure to close the port slide gate) = 0.5

Operator Fails to Notice CTM Slide Gate Does Not Fully Close—This value is the same as for Scenario 3(a):

Operator fails to notice CTM slide gate does not fully close (independent) = 0.001

Operator fails to notice CTM slide gate does not fully close
(given failure notice that port slide gate did not fully close) = 0.5

CTM Slide Gate Interlock Fails

The CTM slide gate interlock prevents CTM movement with the slide gate open (the shield skirt cannot be raised). If the interlock itself fails, the operator can move the CTM with the canister between levels. Note: the maintenance mode does not bypass the shield skirt/slide gate interlock; this interlock cannot be bypassed.

This is a mechanical failure of the interlock. This event is quantified in Section 6.4.3.4.1.

CTM slide gate interlock fails = 2.7E−5

HEP Calculation for Scenario 3(d)—The events in the HEP model for Scenario 3(d) are presented in Table E6.4-16.

Table E6.4-16. HEP Model for HFE Group #5 Scenario 3(d) for 51A-OpCTMImpact1-HFI-COD

Designator	Description	Probability
A	Operator leaves CTM in maintenance mode	0.0007
B	Operator terminates lift prior to automatic stop	0.003
C	Operator fails to close port slide gate	0.01
D	Operator fails to notice that port slide gate does not fully close	0.001
E1	Operator fails to close CTM slide gate (independent)	0.01
E2	Operator fails to close CTM slide gate (given failure to close the port slide gate)	0.5
F1	Operator fails to notice CTM slide gate does not fully close (independent)	0.001
F2	Operator fails to notice CTM slide gate does not fully close (given failure to notice that port slide gate did not fully close)	0.5
G	CTM slide gate interlock fails	2.7E-05

NOTE: CTM = canister transfer machine; HEP = human error probability.

Source: Original

The Boolean expression for this scenario follows:

$$A \times B \times \{[C \times (E2 + F1)] + [D \times (E1 + F2)]\} \times G =$$
$$0.0007 \times 0.003 \times \{[0.01 \times (0.5 + 0.001)] + [0.001 \times (0.01 + 0.5)]\} \times 2.7E{-}05 =$$
$$0.0004 \times 0.003 \times 0.006 \times 2.7E{-}05 = 7E{-}09 \times 2.7E{-}05 = (<1E{-}08) \quad \text{(Eq. E-22h)}$$

Truncating the human failure component, the HEP for this scenario becomes:

$$1E-5 \times 2.7E-5 = (<1E-08) \quad \text{(Eq. E-22i)}$$

E6.4.3.4.4.5 HEP for HFE 51A-OpCTMImpact1-HFI-COD

The Boolean expression for the overall HFE (all scenarios) follows:

$$51A\text{-}OpCTMImpact1\text{-}HFI\text{-}COD = HFE\ 3(a) + HFE\ 3(b) + HFE\ 3(c) + HFE\ 3(d) = (<1E-8) + (<1E-8) + (<1E-8) + (<1E-08) = 4E-8 \quad \text{(Eq. E-22j)}$$

NOTE: For lifting objects (in this case, the lid of the naval waste package), the only failure mode that is applicable is 3(d); therefore, 4E−8 conservatively models movement with the lid below the floor.

E6.4.4 Results of Detailed HRA for HFE Group #4

The final HEPs for the HFEs that required detailed analysis in HFE Group #4 are presented in Table E6.4-17 (with the original preliminary value shown in parentheses).

Table E6.4-17. Summary of HFE Detailed Analysis for HFE Group #4

HFE	Description	Final Probability
51A-OpCTMdrop001-HFI-COD *Operator causes drop of object onto canister during CTM operations*	Operator causes drop of object onto canister during CTM operations	
	Applied to removing HLW lid and placing a waste package inner lid; does not apply to naval waste	4E−07 (2E−03)
	Applied to removing naval shield ring and placing a waste package inner lid; does not apply to HLW	4E−07 (2E−03)
51A-OpCTMdrop002-HFI-COD *Operator causes drop of canister during CTM operations (low-level drop)*	Operator causes drop of canister during CTM operations (low level drop)	
	Applied to moving an HLW canister	5E−07 (2E−03)
	Applied to moving a naval canister	2E−04 (2E−03)

NOTE: CTM = canister transfer machine; HFE = human failure event; HLW = high-level radioactive waste; WP = waste package.

Source: Original

E7 RESULTS: HUMAN RELIABILITY ANALYSIS DATABASE

Table E7-1 presents a summary of all of the human failures identified in this analysis, and provides a link between the HFE group and the ESD in which the human failure is modeled.

Table E7-1. HFE Data Summary

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

Table G-1. Event Sequence Quantification Summary (Continued)

Event Tree	Seq.	Description	Logic	End State	Mean	Median	Std. Dev.
IHF-ESD-07-HLW	2-4	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release also important to criticality due to a drop of a heavy object onto the canister. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	ESD07-HLW-DROPON, ESD07-HLW-DROPON-CAN, /HVAC-CONF, MOD-NOFIRE	RR-FILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	2-5	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release due to a drop of a heavy object onto the canister. In this sequence the canister fails, the confinement boundary fails, and a moderator is excluded from entering canister.	ESD07-HLW-DROPON, ESD07-HLW-DROPON-CAN, HVAC-CONF, /MOD-NOFIRE	RR-UNFILTERED	4.20E-04	3.36E-04	3.56E-04
IHF-ESD-07-HLW	2-6	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release also important to criticality due to a drop of a heavy object onto the canister. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	ESD07-HLW-DROPON, ESD07-HLW-DROPON-CAN, HVAC-CONF, MOD-NOFIRE	RR-UNFILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	3-2	This sequence represents a structural challenge to a HLW resulting in a direct exposure from loss of shielding due to an impact to the canister due to spurious movement of a conveyance. In this sequence the canister remains intact, and the confinement boundary fails.	ESD07-HLW-IMPACT, /ESD07-HLW-IMPACT-CAN, CTM-SHIELDING	DE-SHIELD-LOSS	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	3-3	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release due to an impact to the canister due to spurious movement of a conveyance. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering canister.	ESD07-HLW-IMPACT, ESD07-HLW-IMPACT-CAN, /HVAC-CONF, /MOD-NOFIRE	RR-FILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	3-4	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release also important to criticality due to an impact to the canister due to spurious movement of a conveyance. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	ESD07-HLW-IMPACT, ESD07-HLW-IMPACT-CAN, /HVAC-CONF, MOD-NOFIRE	RR-FILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	3-5	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release due to an impact to the canister due to spurious movement of a conveyance. In this sequence the canister fails, the confinement boundary fails, and a moderator is excluded from entering canister.	ESD07-HLW-IMPACT, ESD07-HLW-IMPACT-CAN, HVAC-CONF, /MOD-NOFIRE	RR-UNFILTERED	6.95E-06	3.21E-06	1.53E-05
IHF-ESD-07-HLW	3-6	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release also important to criticality due to an impact to the canister due to spurious movement of a conveyance. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	ESD07-HLW-IMPACT, ESD07-HLW-IMPACT-CAN, HVAC-CONF, MOD-NOFIRE	RR-UNFILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	4-2	This sequence represents a structural challenge to a HLW resulting in a direct exposure from loss of shielding due to a drop of the canister from an operational height. In this sequence the canister remains intact, and the confinement boundary fails.	ESD07-HLW-DROP, /ESD07-HLW-DROP-CAN, CTM-SHIELDING	DE-SHIELD-LOSS	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	4-3	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release due to a drop of the canister from an operational height. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering canister.	ESD07-HLW-DROP, ESD07-HLW-DROP-CAN, /HVAC-CONF, /MOD-NOFIRE	RR-FILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	4-4	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release also important to criticality due to a drop of the canister from an operational height. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	ESD07-HLW-DROP, ESD07-HLW-DROP-CAN, /HVAC-CONF, MOD-NOFIRE	RR-FILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	4-5	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release due to a drop of the canister from an operational height. In this sequence the canister fails, the confinement boundary fails, and a moderator is excluded from entering canister.	ESD07-HLW-DROP, ESD07-HLW-DROP-CAN, HVAC-CONF, /MOD-NOFIRE	RR-UNFILTERED	6.49E-03	4.17E-03	8.23E-03
IHF-ESD-07-HLW	4-6	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release also important to criticality due to a drop of the canister from an operational height. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	ESD07-HLW-DROP, ESD07-HLW-DROP-CAN, HVAC-CONF, MOD-NOFIRE	RR-UNFILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	5-2	This sequence represents a structural challenge to a HLW resulting in a direct exposure from loss of shielding due to a drop of the canister above the operational height. In this sequence the canister remains intact, and the confinement boundary fails.	ESD07-HLW-2BLK, /ESD07-HLW-2BLK-CAN, CTM-SHIELDING	DE-SHIELD-LOSS	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	5-3	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release due to a drop of the canister above the operational height. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering canister.	ESD07-HLW-2BLK, ESD07-HLW-2BLK-CAN, /HVAC-CONF, /MOD-NOFIRE	RR-FILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	5-4	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release also important to criticality due to a drop of the canister above the operational height. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	ESD07-HLW-2BLK, ESD07-HLW-2BLK-CAN, /HVAC-CONF, MOD-NOFIRE	RR-FILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	5-5	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release due to a drop of the canister above the operational height. In this sequence the canister fails, the confinement boundary fails, and a moderator is excluded from entering canister.	ESD07-HLW-2BLK, ESD07-HLW-2BLK-CAN, HVAC-CONF, /MOD-NOFIRE	RR-UNFILTERED	2.75E-05	5.61E-06	1.37E-04
IHF-ESD-07-HLW	5-6	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release also important to criticality due to a drop of the canister above the operational height. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	ESD07-HLW-2BLK, ESD07-HLW-2BLK-CAN, HVAC-CONF, MOD-NOFIRE	RR-UNFILTERED-ITC	0.00E+00	0.00E+00	0.00E+00

Table G-1. Event Sequence Quantification Summary (Continued)

Event Tree	Seq.	Description	Logic	End State	Mean	Median	Std. Dev.
IHF-ESD-07-HLW	6-2	This sequence represents a structural challenge to a HLW resulting in a direct exposure from loss of shielding due to an impact to the canister due to spurious movement of a conveyance. In this sequence the canister remains intact, and the confinement boundary fails.	ESD07-HLW-SIDEIMP, /ESD07-HLW-SIDEIMP-CAN, CTM-SHIELDING	DE-SHIELD-LOSS	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	6-3	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release due to an impact to the canister due to spurious movement of a conveyance. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering canister.	ESD07-HLW-SIDEIMP, ESD07-HLW-SIDEIMP-CAN, /HVAC-CONF, /MOD-NOFIRE	RR-FILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	6-4	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release also important to criticality due to an impact to the canister due to spurious movement of a conveyance. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	ESD07-HLW-SIDEIMP, ESD07-HLW-SIDEIMP-CAN, /HVAC-CONF, MOD-NOFIRE	RR-FILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	6-5	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release due to an impact to the canister due to spurious movement of a conveyance. In this sequence the canister fails, the confinement boundary fails, and a moderator is excluded from entering canister.	ESD07-HLW-SIDEIMP, ESD07-HLW-SIDEIMP-CAN, HVAC-CONF, /MOD-NOFIRE	RR-UNFILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	6-6	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release also important to criticality due to an impact to the canister due to spurious movement of a conveyance. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	ESD07-HLW-SIDEIMP, ESD07-HLW-SIDEIMP-CAN, HVAC-CONF, MOD-NOFIRE	RR-UNFILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	7-2	This sequence represents a structural challenge to a HLW resulting in a direct exposure from loss of shielding due to a collision/side impact to a canister. In this sequence the canister remains intact, and the confinement boundary fails.	ESD07-HLW-COLLISION, /ESD07-HLW-COLLISION-CAN, CTM-SHIELDING	DE-SHIELD-LOSS	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	7-3	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release due to a collision/side impact to a canister. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering canister.	ESD07-HLW-COLLISION, ESD07-HLW-COLLISION-CAN, /HVAC-CONF, /MOD-NOFIRE	RR-FILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	7-4	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release also important to criticality due to a collision/side impact to a canister. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	ESD07-HLW-COLLISION, ESD07-HLW-COLLISION-CAN, /HVAC-CONF, MOD-NOFIRE	RR-FILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	7-5	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release due to a collision/side impact to a canister. In this sequence the canister fails, the confinement boundary fails, and a moderator is excluded from entering canister.	ESD07-HLW-COLLISION, ESD07-HLW-COLLISION-CAN, HVAC-CONF, /MOD-NOFIRE	RR-UNFILTERED	3.90E-11	3.91E-11	2.72E-12
IHF-ESD-07-HLW	7-6	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release also important to criticality due to a collision/side impact to a canister. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	ESD07-HLW-COLLISION, ESD07-HLW-COLLISION-CAN, HVAC-CONF, MOD-NOFIRE	RR-UNFILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	8-2	This sequence represents a structural challenge to a HLW resulting in a direct exposure from loss of shielding due to a canister drop inside the CTM bell. In this sequence the canister remains intact, and the confinement boundary fails.	ESD07-HLW-DROPIN, /ESD07-HLW-DROPIN-CAN, CTM-SHIELDING	DE-SHIELD-LOSS	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	8-3	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release due to a canister drop inside the CTM bell. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering canister.	ESD07-HLW-DROPIN, ESD07-HLW-DROPIN-CAN, /HVAC-CONF, /MOD-NOFIRE	RR-FILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	8-4	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release also important to criticality due to a canister drop inside the CTM bell. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	ESD07-HLW-DROPIN, ESD07-HLW-DROPIN-CAN, /HVAC-CONF, MOD-NOFIRE	RR-FILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	8-5	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release due to a canister drop inside the CTM bell. In this sequence the canister fails, the confinement boundary fails, and a moderator is excluded from entering canister.	ESD07-HLW-DROPIN, ESD07-HLW-DROPIN-CAN, HVAC-CONF, /MOD-NOFIRE	RR-UNFILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	8-6	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release also important to criticality due to a canister drop inside the CTM bell. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	ESD07-HLW-DROPIN, ESD07-HLW-DROPIN-CAN, HVAC-CONF, MOD-NOFIRE	RR-UNFILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	9-2	This sequence represents a structural challenge to a HLW resulting in a direct exposure from loss of shielding due to an impact to the TC during lid removal. In this sequence the canister remains intact, and the confinement boundary fails.	ESD07-HLW-LIDIMP, /ESD07-HLW-LIDIMP-CAN, CTM-SHIELDING	DE-SHIELD-LOSS	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	9-3	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release due to an impact to the TC during lid removal. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering canister.	ESD07-HLW-LIDIMP, ESD07-HLW-LIDIMP-CAN, /HVAC-CONF, /MOD-NOFIRE	RR-FILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	9-4	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release also important to criticality due to an impact to the TC during lid removal. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	ESD07-HLW-LIDIMP, ESD07-HLW-LIDIMP-CAN, /HVAC-CONF, MOD-NOFIRE	RR-FILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-HLW	9-5	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release due to an impact to the TC during lid removal. In this sequence the canister fails, the confinement boundary fails, and a moderator is excluded from entering canister.	ESD07-HLW-LIDIMP, ESD07-HLW-LIDIMP-CAN, HVAC-CONF, /MOD-NOFIRE	RR-UNFILTERED	0.00E+00	0.00E+00	0.00E+00

Table G-1. Event Sequence Quantification Summary (Continued)

Event Tree	Seq.	Description	Logic	End State	Mean	Median	Std. Dev.
IHF-ESD-07-HLW	9-6	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release also important to criticality due to an impact to the TC during lid removal. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	ESD07-HLW-LIDIMP, ESD07-HLW-LIDIMP-CAN, HVAC-CONF, MOD-NOFIRE	RR-UNFILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	2-2	This sequence represents a structural challenge to a NVL resulting in a direct exposure from loss of shielding due to a drop of a heavy object onto the canister. In this sequence the canister remains intact, and the confinement boundary fails.	ESD07-NVL-DROPON, /ESD07-NVL-DROPON-CAN, CTM-SHIELDING	DE-SHIELD-LOSS	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	2-3	This sequence represents a structural challenge to a NVL resulting in a filtered radionuclide release due to a drop of a heavy object onto the canister. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering canister.	ESD07-NVL-DROPON, ESD07-NVL-DROPON-CAN, /HVAC-CONF, /MOD-NOFIRE	RR-FILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	2-4	This sequence represents a structural challenge to a NVL resulting in a filtered radionuclide release also important to criticality due to a drop of a heavy object onto the canister. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	ESD07-NVL-DROPON, ESD07-NVL-DROPON-CAN, /HVAC-CONF, MOD-NOFIRE	RR-FILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	2-5	This sequence represents a structural challenge to a NVL resulting in a unfiltered radionuclide release due to a drop of a heavy object onto the canister. In this sequence the canister fails, the confinement boundary fails, and a moderator is excluded from entering canister.	ESD07-NVL-DROPON, ESD07-NVL-DROPON-CAN, HVAC-CONF, /MOD-NOFIRE	RR-UNFILTERED	5.61E-08	4.49E-08	4.74E-08
IHF-ESD-07-NVL	2-6	This sequence represents a structural challenge to a NVL resulting in a unfiltered radionuclide release also important to criticality due to a drop of a heavy object onto the canister. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	ESD07-NVL-DROPON, ESD07-NVL-DROPON-CAN, HVAC-CONF, MOD-NOFIRE	RR-UNFILTERED-ITC	8.28E-11	2.71E-11	2.21E-10
IHF-ESD-07-NVL	3-2	This sequence represents a structural challenge to a NVL resulting in a direct exposure from loss of shielding due to an impact to the canister due to spurious movement of a conveyance. In this sequence the canister remains intact, and the confinement boundary fails.	ESD07-NVL-IMPACT, /ESD07-NVL-IMPACT-CAN, CTM-SHIELDING	DE-SHIELD-LOSS	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	3-3	This sequence represents a structural challenge to a NVL resulting in a filtered radionuclide release due to an impact to the canister due to spurious movement of a conveyance. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering canister.	ESD07-NVL-IMPACT, ESD07-NVL-IMPACT-CAN, /HVAC-CONF, /MOD-NOFIRE	RR-FILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	3-4	This sequence represents a structural challenge to a NVL resulting in a filtered radionuclide release also important to criticality due to an impact to the canister due to spurious movement of a conveyance. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	ESD07-NVL-IMPACT, ESD07-NVL-IMPACT-CAN, /HVAC-CONF, MOD-NOFIRE	RR-FILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	3-5	This sequence represents a structural challenge to a NVL resulting in a unfiltered radionuclide release due to an impact to the canister due to spurious movement of a conveyance. In this sequence the canister fails, the confinement boundary fails, and a moderator is excluded from entering canister.	ESD07-NVL-IMPACT, ESD07-NVL-IMPACT-CAN, HVAC-CONF, /MOD-NOFIRE	RR-UNFILTERED	2.78E-06	1.29E-06	6.14E-06
IHF-ESD-07-NVL	3-6	This sequence represents a structural challenge to a NVL resulting in a unfiltered radionuclide release also important to criticality due to an impact to the canister due to spurious movement of a conveyance. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	ESD07-NVL-IMPACT, ESD07-NVL-IMPACT-CAN, HVAC-CONF, MOD-NOFIRE	RR-UNFILTERED-ITC	4.50E-09	7.93E-10	3.58E-08
IHF-ESD-07-NVL	4-2	This sequence represents a structural challenge to a NVL resulting in a direct exposure from loss of shielding due to a drop of the canister from an operational height. In this sequence the canister remains intact, and the confinement boundary fails.	ESD07-NVL-DROP, /ESD07-NVL-DROP-CAN, CTM-SHIELDING	DE-SHIELD-LOSS	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	4-3	This sequence represents a structural challenge to a NVL resulting in a filtered radionuclide release due to a drop of the canister from an operational height. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering canister.	ESD07-NVL-DROP, ESD07-NVL-DROP-CAN, /HVAC-CONF, /MOD-NOFIRE	RR-FILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	4-4	This sequence represents a structural challenge to a NVL resulting in a filtered radionuclide release also important to criticality due to a drop of the canister from an operational height. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	ESD07-NVL-DROP, ESD07-NVL-DROP-CAN, /HVAC-CONF, MOD-NOFIRE	RR-FILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	4-5	This sequence represents a structural challenge to a NVL resulting in a unfiltered radionuclide release due to a drop of the canister from an operational height. In this sequence the canister fails, the confinement boundary fails, and a moderator is excluded from entering canister.	ESD07-NVL-DROP, ESD07-NVL-DROP-CAN, HVAC-CONF, /MOD-NOFIRE	RR-UNFILTERED	8.65E-07	5.55E-07	1.10E-06
IHF-ESD-07-NVL	4-6	This sequence represents a structural challenge to a NVL resulting in a unfiltered radionuclide release also important to criticality due to a drop of the canister from an operational height. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	ESD07-NVL-DROP, ESD07-NVL-DROP-CAN, HVAC-CONF, MOD-NOFIRE	RR-UNFILTERED-ITC	1.30E-09	3.54E-10	4.43E-09
IHF-ESD-07-NVL	5-2	This sequence represents a structural challenge to a NVL resulting in a direct exposure from loss of shielding due to a drop of the canister above the operational height. In this sequence the canister remains intact, and the confinement boundary fails.	ESD07-NVL-2BLK, /ESD07-NVL-2BLK-CAN, CTM-SHIELDING	DE-SHIELD-LOSS	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	5-3	This sequence represents a structural challenge to a NVL resulting in a filtered radionuclide release due to a drop of the canister above the operational height. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering canister.	ESD07-NVL-2BLK, ESD07-NVL-2BLK-CAN, /HVAC-CONF, /MOD-NOFIRE	RR-FILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	5-4	This sequence represents a structural challenge to a NVL resulting in a filtered radionuclide release also important to criticality due to a drop of the canister above the operational height. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	ESD07-NVL-2BLK, ESD07-NVL-2BLK-CAN, /HVAC-CONF, MOD-NOFIRE	RR-FILTERED-ITC	0.00E+00	0.00E+00	0.00E+00

Table G-1. Event Sequence Quantification Summary (Continued)

Event Tree	Seq.	Description	Logic	End State	Mean	Median	Std. Dev.
IHF-ESD-07-NVL	5-5	This sequence represents a structural challenge to a NVL resulting in a unfiltered radionuclide release due to a drop of the canister above the operational height. In this sequence the canister fails, the confinement boundary fails, and a moderator is excluded from entering canister.	ESD07-NVL-2BLK, ESD07-NVL-2BLK-CAN, HVAC-CONF, /MOD-NOFIRE	RR-UNFILTERED	1.10E-10	2.24E-11	5.49E-10
IHF-ESD-07-NVL	5-6	This sequence represents a structural challenge to a NVL resulting in a unfiltered radionuclide release also important to criticality due to a drop of the canister above the operational height. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	ESD07-NVL-2BLK, ESD07-NVL-2BLK-CAN, HVAC-CONF, MOD-NOFIRE	RR-UNFILTERED-ITC	1.51E-13	0.00E+00	1.34E-12
IHF-ESD-07-NVL	6-2	This sequence represents a structural challenge to a NVL resulting in a direct exposure from loss of shielding due to side impact to canister. In this sequence the canister remains intact, and the confinement boundary fails.	ESD07-NVL-SIDEIMP, /ESD07-NVL-SIDEIMP-CAN, CTM-SHIELDING	DE-SHIELD-LOSS	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	6-3	This sequence represents a structural challenge to a NVL resulting in a filtered radionuclide release due to side impact to canister. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering canister.	ESD07-NVL-SIDEIMP, ESD07-NVL-SIDEIMP-CAN, /HVAC-CONF, /MOD-NOFIRE	RR-FILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	6-4	This sequence represents a structural challenge to a NVL resulting in a filtered radionuclide release also important to criticality due to side impact to canister. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	ESD07-NVL-SIDEIMP, ESD07-NVL-SIDEIMP-CAN, /HVAC-CONF, MOD-NOFIRE	RR-FILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	6-5	This sequence represents a structural challenge to a NVL resulting in a unfiltered radionuclide release due to side impact to canister. In this sequence the canister fails, the confinement boundary fails, and a moderator is excluded from entering canister.	ESD07-NVL-SIDEIMP, ESD07-NVL-SIDEIMP-CAN, HVAC-CONF, /MOD-NOFIRE	RR-UNFILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	6-6	This sequence represents a structural challenge to a NVL resulting in a unfiltered radionuclide release also important to criticality due to side impact to canister. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	ESD07-NVL-SIDEIMP, ESD07-NVL-SIDEIMP-CAN, HVAC-CONF, MOD-NOFIRE	RR-UNFILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	7-2	This sequence represents a structural challenge to a NVL resulting in a direct exposure from loss of shielding due to Canister collision or impact. In this sequence the canister remains intact, and the confinement boundary fails.	ESD07-NVL-COLLISION, /ESD07-NVL-COLLISION-CAN, CTM-SHIELDING	DE-SHIELD-LOSS	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	7-3	This sequence represents a structural challenge to a NVL resulting in a filtered radionuclide release due to Canister collision or impact. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering canister.	ESD07-NVL-COLLISION, ESD07-NVL-COLLISION-CAN, /HVAC-CONF, /MOD-NOFIRE	RR-FILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	7-4	This sequence represents a structural challenge to a NVL resulting in a filtered radionuclide release also important to criticality due to Canister collision or impact. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	ESD07-NVL-COLLISION, ESD07-NVL-COLLISION-CAN, /HVAC-CONF, MOD-NOFIRE	RR-FILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	7-5	This sequence represents a structural challenge to a NVL resulting in a unfiltered radionuclide release due to Canister collision or impact. In this sequence the canister fails, the confinement boundary fails, and a moderator is excluded from entering canister.	ESD07-NVL-COLLISION, ESD07-NVL-COLLISION-CAN, HVAC-CONF, /MOD-NOFIRE	RR-UNFILTERED	1.56E-11	1.56E-11	1.09E-12
IHF-ESD-07-NVL	7-6	This sequence represents a structural challenge to a NVL resulting in a unfiltered radionuclide release also important to criticality due to Canister collision or impact. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	ESD07-NVL-COLLISION, ESD07-NVL-COLLISION-CAN, HVAC-CONF, MOD-NOFIRE	RR-UNFILTERED-ITC	1.38E-14	0.00E+00	5.27E-14
IHF-ESD-07-NVL	8-2	This sequence represents a structural challenge to a NVL resulting in a direct exposure from loss of shielding due to a canister drop inside the CTM bell. In this sequence the canister remains intact, and the confinement boundary fails.	ESD07-NVL-DROPIN, /ESD07-NVL-DROPIN-CAN, CTM-SHIELDING	DE-SHIELD-LOSS	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	8-3	This sequence represents a structural challenge to a NVL resulting in a filtered radionuclide release due to a canister drop inside the CTM bell. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering canister.	ESD07-NVL-DROPIN, ESD07-NVL-DROPIN-CAN, /HVAC-CONF, /MOD-NOFIRE	RR-FILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	8-4	This sequence represents a structural challenge to a NVL resulting in a filtered radionuclide release also important to criticality due to a canister drop inside the CTM bell. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	ESD07-NVL-DROPIN, ESD07-NVL-DROPIN-CAN, /HVAC-CONF, MOD-NOFIRE	RR-FILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	8-5	This sequence represents a structural challenge to a NVL resulting in a unfiltered radionuclide release due to a canister drop inside the CTM bell. In this sequence the canister fails, the confinement boundary fails, and a moderator is excluded from entering canister.	ESD07-NVL-DROPIN, ESD07-NVL-DROPIN-CAN, HVAC-CONF, /MOD-NOFIRE	RR-UNFILTERED	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-07-NVL	8-6	This sequence represents a structural challenge to a NVL resulting in a unfiltered radionuclide release also important to criticality due to a canister drop inside the CTM bell. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	ESD07-NVL-DROPIN, ESD07-NVL-DROPIN-CAN, HVAC-CONF, MOD-NOFIRE	RR-UNFILTERED-ITC	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-08-HLW	2-2	This sequence represents a structural challenge to a HLW resulting in a direct exposure from loss of shielding due to a waste package transfer trolley collision with structures or equipment. In this sequence the canister remains intact, and the shielding fails.	ESD08-HLW-COLLIDE, /ESD08-HLW-COLLIDE-CAN, ESD08-HLW-COLLIDE-SHIELD	DE-SHIELD-LOSS	0.00E+00	0.00E+00	0.00E+00
IHF-ESD-08-HLW	2-3	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release due to a waste package transfer trolley collision with structures or equipment. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering canister.	ESD08-HLW-COLLIDE, ESD08-HLW-COLLIDE-CAN, /HVAC-CONF, /MOD-NOFIRE	RR-FILTERED	0.00E+00	0.00E+00	0.00E+00

Table G-2. Event Sequence Grouping and Categorization (Continued)

Event Sequence Group ID	End State	Description	Material at Risk	Mean[a]	Median[a]	Standard Deviation[a]	Event Sequence Category	Basis for Categorization
ESD06-NVL-SEQ13-RRC	Unfiltered radionuclide release, important to criticality	This event sequence represents a structural challenge to a naval SNF canister inside a transportation cask, due to CTT collision with shield door, resulting in an unfiltered radionuclide release also important to criticality. In this sequence the cell door fails and impacts the waste form, the canister fails, the confinement boundary is not relied upon, and a moderator enters the canister.	1 TAD canister	0.E+00	0.E+00	0.E+00	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD07-HLW-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a structural challenge to an HLW canister, during canister transfer by the CTM, resulting in a direct exposure from loss of shielding. In this sequence the canister remains intact, and the shielding fails.	2 HLW canisters	0.E+00	0.E+00	0.E+00	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD07-HLW-SEQ3-RRF	Filtered radionuclide release	This event sequence represents a structural challenge to an HLW canister, during canister transfer by the CTM, resulting in a filtered radionuclide release. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering the canister.	2 HLW canisters	0.E+00	0.E+00	0.E+00	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD07-HLW-SEQ4-RRC	Filtered radionuclide release, important to criticality	This event sequence represents a structural challenge to an HLW canister, during canister transfer by the CTM, resulting in a filtered radionuclide release also important to criticality. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters the canister.	2 HLW canisters	0.E+00	0.E+00	0.E+00	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD07-HLW-SEQ5-RRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to an HLW canister, during canister transfer by the CTM, resulting in an unfiltered radionuclide release. In this sequence the canister fails, the confinement boundary is not relied upon, and a moderator is excluded from entering the canister.	2 HLW canisters	7.E-03	5.E-03	7.E-03	Category 2	Mean of distribution for number of occurrences of event sequence

Table G-2. Event Sequence Grouping and Categorization (Continued)

Event Sequence Group ID	End State	Description	Material at Risk	Mean[a]	Median[a]	Standard Deviation[a]	Event Sequence Category	Basis for Categorization
ESD07-HLW-SEQ6-RRC	Unfiltered radionuclide release, important to criticality	This event sequence represents a structural challenge to an HLW canister, during canister transfer by the CTM, resulting in an unfiltered radionuclide release also important to criticality. In this sequence the canister fails, the confinement boundary is not relied upon, and a moderator enters the canister.	2 HLW canisters	0.E+00	0.E+00	0.E+00	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD07-NVL-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a structural challenge to a naval SNF canister, during canister transfer by the CTM, resulting in a direct exposure from loss of shielding. In this sequence the canister remains intact, and the shielding fails.	1 naval SNF canister	0.E+00	0.E+00	0.E+00	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD07-NVL-SEQ3-RRF	Filtered radionuclide release	This event sequence represents a structural challenge to a naval SNF canister, during canister transfer by the CTM, resulting in a filtered radionuclide release. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering the canister.	1 naval SNF canister	0.E+00	0.E+00	0.E+00	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD07-NVL-SEQ4-RRC	Filtered radionuclide release, important to criticality	This event sequence represents a structural challenge to a naval SNF canister, during canister transfer by the CTM, resulting in a filtered radionuclide release also important to criticality. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters the canister.	1 naval SNF canister	0.E+00	0.E+00	0.E+00	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD07-NVL-SEQ5-RRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to a naval SNF canister, during canister transfer by the CTM, resulting in an unfiltered radionuclide release. In this sequence the canister fails, the confinement boundary is not relied upon, and a moderator is excluded from entering the canister.	1 naval SNF canister	4.E-06	2.E-06	6.E-06	Beyond category 2	Mean of distribution for number of occurrences of event sequence

Table G-2. Event Sequence Grouping and Categorization (Continued)

Event Sequence Group ID	End State	Description	Material at Risk	Mean[a]	Median[a]	Standard Deviation[a]	Event Sequence Category	Basis for Categorization
ESD07-NVL-SEQ6-RRC	Unfiltered radionuclide release, important to criticality	This event sequence represents a structural challenge to a naval SNF canister, during canister transfer by the CTM, resulting in an unfiltered radionuclide release also important to criticality. In this sequence the canister fails, the confinement boundary is not relied upon, and a moderator enters the canister.	1 naval SNF canister	5.E-09	1.E-09	2.E-08	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD08-HLW-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a structural challenge to an HLW canister inside a waste package, during WPTT transfer to the Waste Package Positioning Room, resulting in a direct exposure from loss of shielding. In this sequence the canister remains intact, and the shielding fails.	5 HLW canisters	0.E+00	0.E+00	0.E+00	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD08-HLW-SEQ3-RRF	Filtered radionuclide release	This event sequence represents a structural challenge to an HLW canister inside a waste package, during WPTT transfer to the Waste Package Positioning Room, resulting in a filtered radionuclide release. In this sequence the canister fails, the confinement boundary remains intact, and a moderator is excluded from entering the canister.	5 HLW canisters	0.E+00	0.E+00	0.E+00	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD08-HLW-SEQ4-RRC	Filtered radionuclide release, important to criticality	This event sequence represents a structural challenge to an HLW canister inside a waste package, during WPTT transfer to the Waste Package Positioning Room, resulting in a filtered radionuclide release also important to criticality. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters the canister.	5 HLW canisters	0.E+00	0.E+00	0.E+00	Beyond category 2	Mean of distribution for number of occurrences of event sequence

Table G-3. Beyond Category 2 Final Event Sequences Summary

Event Sequence Group ID	End State	Description	Material at Risk	Mean[a]	Median[a]	Standard Deviation[a]	Event Sequence Categorization	Basis for Categorization
ESD10-NVL-SEQ6-RRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to a naval SNF canister inside a waste package, during WPTT transfer to docking station, resulting in an unfiltered radionuclide release. In this sequence the waste package fails, the canister fails, the confinement boundary is not relied upon, and a moderator is excluded from entering the canister.	1 naval SNF canister	1.E-05	7.E-06	2.E-05	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD13-HLW-SEQ5-RRU	Unfiltered radionuclide release	This event sequence represents a thermal challenge to an HLW canister, due to a fire, resulting in an unfiltered radionuclide release. In this sequence the canister fails, the confinement boundary is not relied upon, and a moderator is excluded from entering the canister.	5 HLW canisters	9.E-06	8.E-06	4.E-06	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD05-HLW-SEQ5-RRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to an HLW canister inside a transportation cask, during CTT transfer to the Cask Unloading Room, resulting in an unfiltered radionuclide release. In this sequence the canister fails, the confinement boundary is not relied upon, and a moderator is excluded from entering the canister.	5 HLW canisters	6.E-06	4.E-06	8.E-06	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD11-NVL-SEQ6-RRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to a naval SNF canister inside a waste package, during export activities, resulting in an unfiltered radionuclide release. In this sequence the waste package fails, the canister fails, the confinement boundary is not relied upon, and a moderator is excluded from entering the canister.	1 naval SNF canister	4.E-06	3.E-06	5.E-06	Beyond category 2	Mean of distribution for number of occurrences of event sequence

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

Event Sequence Group ID	End State	Description	Material at Risk	Mean[a]	Median[a]	Standard Deviation[a]	Event Sequence Categorization	Basis for Categorization
ESD07-NVL-SEQ5-RRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to a naval SNF canister, during canister transfer by the CTM, resulting in an unfiltered radionuclide release. In this sequence the canister fails, the confinement boundary is not relied upon, and a moderator is excluded from entering the canister.	1 naval SNF canister	4.E-06	2.E-06	6.E-06	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD05-NVL-SEQ5-RRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to a naval SNF canister inside a transportation cask, during CTT transfer to the Cask Unloading Room, resulting in an unfiltered radionuclide release. In this sequence the canister fails, the confinement boundary is not relied upon, and a moderator is excluded from entering the canister.	1 naval SNF canister	4.E-06	2.E-06	5.E-06	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD13-NVL-SEQ5-RRU	Unfiltered radionuclide release	This event sequence represents a thermal challenge to a naval SNF canister, due to a fire, resulting in an unfiltered radionuclide release. In this sequence the canister fails, the confinement boundary is not relied upon, and a moderator is excluded from entering the canister.	1 naval SNF canister	4.E-06	4.E-06	2.E-06	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD13-NVL-SEQ6-RRC	Unfiltered radionuclide release, important to criticality	This event sequence represents a thermal challenge to a naval SNF canister, due to a fire, resulting in an unfiltered radionuclide release also important to criticality. In this sequence the canister fails, the confinement boundary is not relied upon, and a moderator enters the canister.	1 naval SNF canister	4.E-06	4.E-06	2.E-06	Beyond category 2	Mean of distribution for number of occurrences of event sequence

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

Event Sequence Group ID	End State	Description	Material at Risk	Mean[a]	Median[a]	Standard Deviation[a]	Event Sequence Categorization	Basis for Categorization
ESD01-HLW-SEQ2-DED	Direct exposure, degradation of shielding	This event sequence represents a structural challenge to an HLW canister inside a transportation cask, during receipt activities, resulting in a direct exposure from degradation of shielding. In this sequence the transportation cask containment function remains intact, and the shielding fails.	5 HLW canisters	3.E-08	2.E-08	6.E-08	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD01-HLW-SEQ6-RRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to an HLW canister inside a transportation cask, during receipt activities, resulting in an unfiltered radionuclide release. In this sequence the transportation cask fails, the canister fails, the confinement boundary is not relied upon, and a moderator is excluded from entering the canister.	5 HLW canisters	3.E-08	2.E-08	6.E-08	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD10-NVL-SEQ7-RRC	Unfiltered radionuclide release, important to criticality	This event sequence represents a structural challenge to a naval SNF canister inside a waste package, during WPTT transfer to docking station, resulting in an unfiltered radionuclide release also important to criticality. In this sequence the waste package fails, the canister fails, the confinement boundary is not relied upon, and a moderator enters the canister.	1 naval SNF canister	2.E-08	5.E-09	6.E-08	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD10-HLW-SEQ6-RRU	Unfiltered radionuclide release	This event sequence represents a structural challenge to an HLW canister inside a waste package, during WPTT transfer to docking station, resulting in an unfiltered radionuclide release. In this sequence the waste package fails, the canister fails, the confinement boundary is not relied upon, and a moderator is excluded from entering the canister.	5 HLW canisters	7.E-09	5.E-09	8.E-09	Beyond category 2	Mean of distribution for number of occurrences of event sequence

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

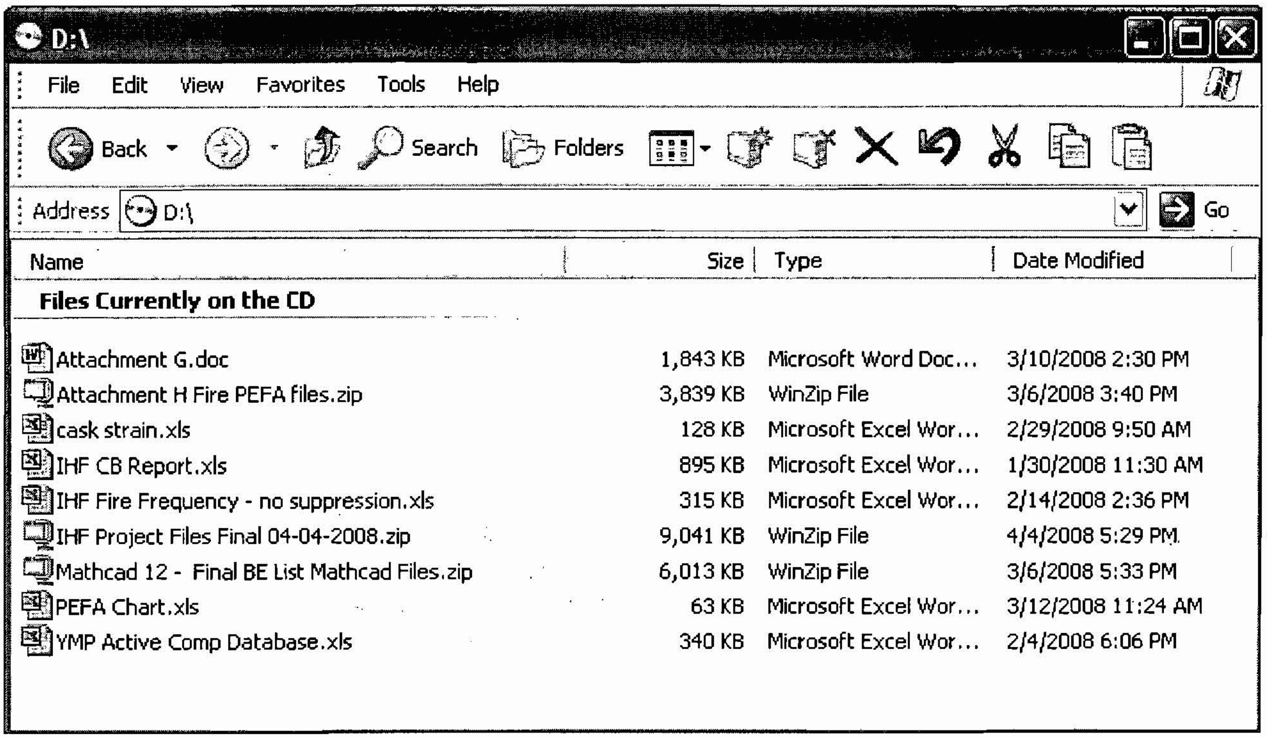
Event Sequence Group ID	End State	Description	Material at Risk	Mean[a]	Median[a]	Standard Deviation[a]	Event Sequence Categorization	Basis for Categorization
ESD05-HLW-SEQ2-DEL	Direct exposure, loss of shielding	This event sequence represents a structural challenge to an HLW canister inside a transportation cask, during CTT transfer to the Cask Unloading Room, resulting in a direct exposure from loss of shielding. In this sequence the canister remains intact, and the shielding fails.	5 HLW canisters	6.E-09	4.E-09	8.E-09	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD11-NVL-SEQ7-RRC	Unfiltered radionuclide release, important to criticality	This event sequence represents a structural challenge to a naval SNF canister inside a waste package, during export activities, resulting in an unfiltered radionuclide release also important to criticality. In this sequence the waste package fails, the canister fails, the confinement boundary is not relied upon, and a moderator enters the canister.	1 naval SNF canister	6.E-09	2.E-09	2.E-08	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD05-NVL-SEQ6-RRC	Unfiltered radionuclide release, important to criticality	This event sequence represents a structural challenge to a naval SNF canister inside a transportation cask, during CTT transfer to the Cask Unloading Room, resulting in an unfiltered radionuclide release also important to criticality. In this sequence the canister fails, the confinement boundary is not relied upon, and a moderator enters the canister.	1 naval SNF canister	5.E-09	1.E-09	2.E-08	Beyond category 2	Mean of distribution for number of occurrences of event sequence
ESD07-NVL-SEQ6-RRC	Unfiltered radionuclide release, important to criticality	This event sequence represents a structural challenge to a naval SNF canister, during canister transfer by the CTM, resulting in an unfiltered radionuclide release also important to criticality. In this sequence the canister fails, the confinement boundary is not relied upon, and a moderator enters the canister.	1 naval SNF canister	5.E-09	1.E-09	2.E-08	Beyond category 2	Mean of distribution for number of occurrences of event sequence

Table G-4. Important to Criticality Final Event Sequences Summary (Continued)

Event Sequence Group ID	End State	Description	Material-At-Risk	Mean	Median	Std Dev	Event Sequence. Cat.	Basis for Categorization
ESD06-NVL-SEQ11-RRC	RR-FILTERED-ITC	This sequence represents a structural challenge to a NVL inside a transportation cask resulting in a filtered radionuclide release also important to criticality due to CTT collision with shield door. In this sequence the cell door fails and impacts the waste form, the transportation cask fails, the confinement boundary remains intact, and a moderator enters canister.	1 NAVAL CANISTER	0.E+00	0.E+00	0.E+00	Beyond Category 2	Categorization by mean frequency and grouping by sequences
ESD06-NVL-SEQ13-RRC	RR-UNFILTERED-ITC	This sequence represents a structural challenge to a NVL inside a transportation cask resulting in a unfiltered radionuclide release also important to criticality due to CTT collision with shield door. In this sequence the cell door fails and impacts the waste form, the transportation cask fails, the confinement boundary fails, and a moderator enters canister.	1 NAVAL CANISTER	0.E+00	0.E+00	0.E+00	Beyond Category 2	Categorization by mean frequency and grouping by sequences
ESD07-HLW-SEQ4-RRC	RR-FILTERED-ITC	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release also important to criticality due to object dropped on to canister, or impact due to movement of CTM, CTT, or WPTT, or drop from operational height or above operation height; a side impact, a side impact, a canister dropped inside CTM or TC impact with lid removed. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	5 HLW CANISTERS	0.E+00	0.E+00	0.E+00	Beyond Category 2	Categorization by mean frequency and grouping by sequences
ESD07-HLW-SEQ6-RRC	RR-UNFILTERED-ITC	This sequence represents a structural challenge to a HLW resulting in a unfiltered radionuclide release also important to criticality due to object dropped on to canister, or impact due to movement of CTM, CTT, or WPTT, or drop from operational height or above operation height; a side impact, a side impact, a canister dropped inside CTM or TC impact with lid removed. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	5 HLW CANISTERS	0.E+00	0.E+00	0.E+00	Beyond Category 2	Categorization by mean frequency and grouping by sequences
ESD07-NVL-SEQ4-RRC	RR-FILTERED-ITC	This sequence represents a structural challenge to a NVL resulting in a filtered radionuclide release also important to criticality due to object dropped on to canister, a movement inside CTM, CTT, or WPTT, a canister drop from or above operational height, a side impat to canister, a canister collision or impact or a canister dropped inside CTM. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	1 NAVAL CANISTER	0.E+00	0.E+00	0.E+00	Beyond Category 2	Categorization by mean frequency and grouping by sequences
ESD07-NVL-SEQ6-RRC	RR-UNFILTERED-ITC	This sequence represents a structural challenge to a NVL resulting in a unfiltered radionuclide release also important to criticality due to object dropped on to canister, a movement inside CTM, CTT, or WPTT, a canister drop from or above operational height, a side impat to canister, a canister collision or impact or a canister dropped inside CTM. In this sequence the canister fails, the confinement boundary fails, and a moderator enters canister.	1 NAVAL CANISTER	5.E-09	1.E-09	2.E-08	Beyond Category 2	Categorization by mean frequency and grouping by sequences
ESD08-HLW-SEQ4-RRC	RR-FILTERED-ITC	This sequence represents a structural challenge to a HLW resulting in a filtered radionuclide release also important to criticality due to a WPTT collision, a premature WPTT tilt-down or a WPTT derailment. In this sequence the canister fails, the confinement boundary remains intact, and a moderator enters canister.	5 HLW CANISTERS	0.E+00	0.E+00	0.E+00	Beyond Category 2	Categorization by mean frequency and grouping by sequences

ATTACHMENT H
SAPHIRE MODEL AND SUPPORTING FILES

This attachment is the CD containing the SAPHIRE model and supporting files. The electronic files contained on the CD are identified below.



Files Currently on the CD

Name	Size	Type	Date Modified
Attachment G.doc	1,843 KB	Microsoft Word Doc...	3/10/2008 2:30 PM
Attachment H Fire PEFA files.zip	3,839 KB	WinZip File	3/6/2008 3:40 PM
cask strain.xls	128 KB	Microsoft Excel Wor...	2/29/2008 9:50 AM
IHF CB Report.xls	895 KB	Microsoft Excel Wor...	1/30/2008 11:30 AM
IHF Fire Frequency - no suppression.xls	315 KB	Microsoft Excel Wor...	2/14/2008 2:36 PM
IHF Project Files Final 04-04-2008.zip	9,041 KB	WinZip File	4/4/2008 5:29 PM
Mathcad 12 - Final BE List Mathcad Files.zip	6,013 KB	WinZip File	3/6/2008 5:33 PM
PEFA Chart.xls	63 KB	Microsoft Excel Wor...	3/12/2008 11:24 AM
YMP Active Comp Database.xls	340 KB	Microsoft Excel Wor...	2/4/2008 6:06 PM