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

Basic Event Name	Basic Event Description	SAPHIRE Calculation Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate[b]	Mission Time (Hours)
200-VCT0-AHU0002-CTL-FOD	RF ITS elec AHU 00002 controller fails	1	2.03E-03	—	—
200-VCT0-AHU0002-FAN-FTS	RF ITS elec AHU 00002 fails to start	1	2.02E-03	—	—
200-VCT0-AHU0003-AHU-FTR	RF ITS elec AHU 00003 fails to run	3	2.73E-03	3.80E-06	720
200-VCT0-AHU0003-CTL-FOD	RF ITS elec AHU 00003 controller fails	1	2.03E-03	—	—
200-VCT0-AHU0004-AHU-FTR	RF ITS elec AHU 00004 fails to run	3	2.73E-03	3.80E-06	720
200-VCT0-AHU0004-CTL-FOD	RF ITS elec AHU 00004 controller fails	1	2.03E-03	—	—
200-VCT0-AHU0004-FAN-FTS	RF ITS elec AHU 00004 fails to start	1	2.02E-03	—	—
200-VCT0-AHU0103-AHU-CCR	CCF of the running RF ITS elec AHUs to continue to run	C	6.42E-05	—	—
200-VCT0-AHU0202-AHU-CCR	CCF of standby RF ITS elec AHUs to run	C	6.42E-05	—	—
200-VCT0-AHU0202-AHU-CCS	CCF of standby RF ITS elec AHUs to start	C	9.49E-05	—	—
200-VCT0-EXH-009-CTL-FOD	RF ITS Elec Exh Fan 00005 controller fails	1	2.03E-03	—	—
200-VCT0-EXH-009-FAN-FTR	RF ITS Elec Exhaust Fan 00005 fails to run	3	5.06E-02	7.21E-05	720
200-VCT0-EXH-010-CTL-FOD	RF ITS Elec Exh Fan 0006 controller fails	1	2.03E-03	—	—
200-VCT0-EXH-010-FAN-FTR	RF ITS Elec Exh Fan 0010 fails to run	3	5.06E-02	7.21E-05	720
200-VCT0-EXH-010-FAN-FTS	RF ITS Elec Exh Fan 00006 fails to start	1	2.02E-03	—	—
200-VCT0-EXH-011-CTL-FOD	RF ITS Elec Exh Fan 00007 controller fails	1	2.03E-03	—	—
200-VCT0-EXH-011-FAN-FTR	RF ITS Elec Exhaust Fan 00007 fails to run	3	5.06E-02	7.21E-05	720
200-VCT0-EXH-012-CTL-FOD	RF ITS Elec Exh Fan 0008 controller fails	1	2.03E-03	—	—
200-VCT0-EXH-012-FAN-FTR	RF ITS Elec Exh Fan 00012 fails to run	3	5.06E-02	7.21E-05	720
200-VCT0-EXH-012-FAN-FTS	RF ITS Elec Exh Fan 00008 fails to start	1	2.02E-03	—	—
200-VCT0-EXH0911-FAN-CCR	CCF of running exh fans for RF ITS elec	C	1.19E-03	—	—
200-VCT0-EXH1012-FAN-CCF	CCF to run: standby exh fans for the RF ITS elec	C	1.19E-03	—	—
200-VCT0-EXH1012-FAN-CCSS	CCF to start: standby exh fans for the RF ITS elec	C	9.49E-05	—	—
200-VCTO--B---FAN-FTS	Train B fan fails to start	1	2.02E-03	—	—
200-VCTO-AHU0006-FAN-FTR	AHU 0006 fan fails to run	3	5.06E-02	7.21E-05	720
200-VCTO-AHU0007-FAN-FTR	AHU 0007 fan fails to run	3	2.56E-02	7.21E-05	360
200-VCTO-AHU0007-FAN-FTS	AHU 0007 fan fails to start	1	2.02E-03	—	—
200-VCTO-BDMP00A-UDM-FOH	Train A fan discharge backdraft damper fails closed	3	1.61E-02	2.26E-05	720
200-VCTO-BDMP00B-DMP-FTO	Train B backdraft damper fails to open when fan starts	1	8.71E-04	—	—

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

Basic Event Name	Basic Event Description	SAPHIRE Calculation Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate[b]	Mission Time (Hours)
200-VCTO-BDMP00B-UDM-FOH	Train B fan discharge backdraft damper fails closed	3	8.10E-03	2.26E-05	360
200-VCTO-DTC0A-DTC-RUP	Train A duct ruptures	3	2.68E-03	3.72E-06	720
200-VCTO-DTC0B-DTC-RUP	Train B duct ruptures	3	1.34E-03	3.72E-06	360
200-VCTO-DMP000A-DMP-FRO	Train A fan discharge manual isolation damper fails closed	3	6.03E-05	8.38E-08	720
200-VCTO-DMP000B-DMP-FRO	Train B fan discharge manual isolation damper fails closed	3	3.02E-05	8.38E-08	360
200-VCTO-DMP000A-DMP-FRO	Manual Damper for Train A fails	3	6.03E-05	8.38E-08	720
200-VCTO-DMP000B-DMP-FRO	Manual Damper for Train B fails	3	3.02E-05	8.38E-08	360
200-VCTO-DMP001A-DMP-FRO	Manual Damper Input to Exhaust Fan A fails	3	6.03E-05	8.38E-08	720
200-VCTO-DMP001B-DMP-FRO	Manual Damper Input to Exhaust Fan B fails	3	3.02E-05	8.38E-08	360
200-VCTO-DMPA05I-DMP-FRO	Manual Damper #05 input Train A fails	3	6.03E-05	8.38E-08	720
200-VCTO-DMPA05O-DMP-FRO	Manual Damper #05 output Train A fails	3	6.03E-05	8.38E-08	720
200-VCTO-DMPA06I-DMP-FRO	Manual Damper #06 input Train A fails	3	6.03E-05	8.38E-08	720
200-VCTO-DMPA06O-DMP-FRO	Manual Damper #06 output Train A fails	3	6.03E-05	8.38E-08	720
200-VCTO-DMPA07I-DMP-FRO	Manual Damper #07 in Train A fails	3	6.03E-05	8.38E-08	720
200-VCTO-DMPA07O-DMP-FRO	Manual Damper #07 output Train A fails	3	6.03E-05	8.38E-08	720
200-VCTO-DMPB08I-DMP-FRO	Manual Damper #08 input Train B fails	3	3.02E-05	8.38E-08	360
200-VCTO-DMPB08O-DMP-FRO	Manual Damper #08 output Train A fails	3	3.02E-05	8.38E-08	360
200-VCTO-DMPB09I-DMP-FRO	Manual Damper #09 input Train A fails	3	3.02E-05	8.38E-08	360
200-VCTO-DMPB09O-DMP-FRO	Manual Damper #09 output Train A fails	3	3.02E-05	8.38E-08	360
200-VCTO-DMPB10I-DMP-FRO	Manual Damper #10 input in Train B fails	3	3.02E-05	8.38E-08	360
200-VCTO-DMPB10O-DMP-FRO	Manual Damper #10 output Train A fails	3	3.02E-05	8.38E-08	360
200-VCTO-DTC0A-DTC-RUP	Duct fails between HEPA and exhaust fan (10 feet)	3	2.68E-03	3.72E-06	720
200-VCTO-DTC0B-DTC-RUP	Duct fails between HEPA and exhaust fan (10 feet)	3	1.34E-03	3.72E-06	360
200-VCTO-FAN00A-FAN-FTR	Exhaust fan in Train A fails	3	5.06E-02	7.21E-05	720
200-VCTO-FAN00A-PRM-FOH	Train A exhaust fan fails due to ASD malfunction	3	3.87E-04	5.38E-07	720
200-VCTO-FAN00B-FAN-FTR	Exhaust fan in Train B fails	3	2.56E-02	7.21E-05	360
200-VCTO-FAN00B-FAN-FTS	Exhaust fan in Train B fails to start	1	2.02E-03	—	—
200-VCTO-FAN00B-PRM-FOH	Train B exhaust fan fails due to ASD malfunction	3	1.94E-04	5.38E-07	360
200-VCTO-FANBASD-CTL-FOD	Train B ASD start logic signal fails	1	2.03E-03	—	—

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

Basic Event Name	Basic Event Description	SAPHIRE Calculation Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate[b]	Mission Time (Hours)
200-VCTO-FANA-PRM-FOH	Speed control exhaust fan train A fails to maintain delta P	3	5.38E-07	5.38E-07	1
200-VCTO-FANB-PRM-FOH	Speed control exhaust fan train B fails to maintain delta P	3	1.94E-04	5.38E-07	360
200-VCTO-FSLAB0-SRF-FOH	Low flow train A sensor failure	3	7.70E-04	1.07E-06	720
200-VCTO-HEPA-CCF	CCF of HEPA filters (2 of 3)	C	9.53E-05	—	—
200-VCTO-HEPA05-DMS-FOH	Moisture separator/demister HEPA 05 fails	3	6.55E-03	9.12E-06	720
200-VCTO-HEPA06-DMS-FOH	Moisture separator/demister HEPA 06 fails	3	6.55E-03	9.12E-06	720
200-VCTO-HEPA07-DMS-FOH	Moisture separator/demister HEPA 07 fails	3	6.55E-03	9.12E-06	720
200-VCTO-HEPA0A5-HEP-LEK	HEPA #05 Train A leaks	3	2.16E-03	3.00E-06	720
200-VCTO-HEPAA05-HEP-LEK	HEPA #05 Train A leaks	3	3.00E-06	3.00E-06	1
200-VCTO-HEPAA05-HEP-PLG	HEPA #A05 Train A plugged	3	3.07E-03	4.27E-06	720
200-VCTO-HEPAA06-DMS-FOH	Moisture separator/demister HEPA 06 fails	3	6.55E-03	9.12E-06	720
200-VCTO-HEPAA06-HEP-LEK	HEPA #06 Train A leaks	3	2.16E-03	3.00E-06	720
200-VCTO-HEPAA06-HEP-PLG	HEPA #A10 Train A plugged	3	3.07E-03	4.27E-06	720
200-VCTO-HEPAA07-HEP-LEK	HEPA #07 Train A leaks	3	2.16E-03	3.00E-06	720
200-VCTO-HEPAA07-HEP-PLG	HEPA #A07 Train A plugged	3	3.07E-03	4.27E-06	720
200-VCTO-HEPAB-CCF	CCF of HEPA filters (2 of 3)	C	4.77E-05	—	—
200-VCTO-HEPAB08-DMS-FOH	Moisture separator/demister HEPA 08 fails	3	3.28E-03	9.12E-06	360
200-VCTO-HEPAB08-HEP-LEK	HEPA #B12 Train B leaks	3	1.08E-03	3.00E-06	360
200-VCTO-HEPAB08-HEP-PLG	HEPA #B08 Train B plugged	3	1.54E-03	4.27E-06	360
200-VCTO-HEPAB09-DMS-FOH	Moisture separator/demister HEPA 09 fails	3	3.28E-03	9.12E-06	360
200-VCTO-HEPAB09-HEP-LEK	HEPA #B09 Train B leaks	3	1.08E-03	3.00E-06	360
200-VCTO-HEPAB09-HEP-PLG	HEPA #B09 Train B plugged	3	1.54E-03	4.27E-06	360
200-VCTO-HEPAB10-DMS-FOH	Moisture separator/demister HEPA 10 fails	3	3.28E-03	9.12E-06	360
200-VCTO-HEPAB10-HEP-LEK	HEPA #B10 Train B leaks	3	1.08E-03	3.00E-06	360
200-VCTO-HEPAB10-HEP-PLG	HEPA #B10 Train B plugged	3	1.54E-03	4.27E-06	360
200-VCTO-IEL0001-IEL-FOD	RF door interlock failure	1	2.75E-05	—	—
200-VCTO-PDSLA0B-SRP-FOD	Pressure differential train A switch fails	1	3.99E-03	—	—
200-VCTO-PLEN05-DMS-FOH	Train A plenum 05 moisture separator/demister plugs	3	6.55E-03	9.12E-06	720
200-VCTO-PLEN05-HEP-LEK	Train A plenum 05 HEPA filters leak	3	2.16E-03	3.00E-06	720

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

Basic Event Name	Basic Event Description	SAPHIRE Calculation Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate[b]	Mission Time (Hours)
200-VCTO-PLEN05-HEP-PLG	Train A plenum 05 HEPA filters plug	3	3.07E-03	4.27E-06	720
200-VCTO-PLEN05I-DMP-FRO	Train A filter plenum 05 inlet damper fails to remain open	3	6.03E-05	8.38E-08	720
200-VCTO-PLEN05O-DMP-FRO	Train A filter plenum 05 outlet damper fails to remain open	3	6.03E-05	8.38E-08	720
200-VCTO-PLEN06-DMS-FOH	Train A plenum 06 moisture separator/demister plugs	3	6.55E-03	9.12E-06	720
200-VCTO-PLEN06-HEP-LEK	Train A plenum 06 HEPA filters leak	3	2.16E-03	3.00E-06	720
200-VCTO-PLEN06-HEP-PLG	Train A plenum 06 HEPA filters plug	3	3.07E-03	4.27E-06	720
200-VCTO-PLEN06I-DMP-FRO	Train A filter plenum 06 inlet damper fails to remain open	3	6.03E-05	8.38E-08	720
200-VCTO-PLEN06O-DMP-FRO	Train A filter plenum 06 outlet damper fails to remain open	3	6.03E-05	8.38E-08	720
200-VCTO-PLEN07-DMS-FOH	Train A plenum 07 moisture separator/demister plugs	3	6.55E-03	9.12E-06	720
200-VCTO-PLEN07-HEP-LEK	Train A plenum 07 HEPA filters leak	3	2.16E-03	3.00E-06	720
200-VCTO-PLEN07-HEP-PLG	Train A plenum 07 HEPA filters plug	3	3.07E-03	4.27E-06	720
200-VCTO-PLEN07I-DMP-FRO	Train A filter plenum 07 inlet damper fails to remain open	3	6.03E-05	8.38E-08	720
200-VCTO-PLEN07O-DMP-FRO	Train A filter plenum 07 outlet damper fails to remain open	3	6.03E-05	8.38E-08	720
200-VCTO-PLEN08-DMS-FOH	Train B plenum 08 moisture separator/demister plugs	3	3.28E-03	9.12E-06	360
200-VCTO-PLEN08-HEP-LEK	Train B plenum 08 HEPA filters leak	3	1.08E-03	3.00E-06	360
200-VCTO-PLEN08-HEP-PLG	Train B plenum 08 HEPA filters plug	3	1.54E-03	4.27E-06	360
200-VCTO-PLEN08I-DMP-FRO	Train B filter plenum 08 inlet damper fails to remain open	3	3.02E-05	8.38E-08	360
200-VCTO-PLEN08O-DMP-FRO	Train B filter plenum 08 outlet damper fails to remain open	3	3.02E-05	8.38E-08	360
200-VCTO-PLEN09-DMS-FOH	Train B plenum 09 moisture separator/demister plugs	3	3.28E-03	9.12E-06	360
200-VCTO-PLEN09-HEP-LEK	Train B plenum 09 HEPA filters leak	3	1.08E-003	3.00E-06	360
200-VCTO-PLEN09-HEP-PLG	Train B plenum 09 HEPA filters plug	3	1.54E-03	4.27E-06	360
200-VCTO-PLEN09I-DMP-FRO	Train B filter plenum 09 inlet damper fails to remain open	3	3.02E-05	8.38E-08	360
200-VCTO-PLEN09O-DMP-FRO	Train B filter plenum 09 outlet damper fails to remain open	3	3.02E-05	8.38E-08	360
200-VCTO-PLEN10-DMS-FOH	Train B plenum 10 moisture separator/demister plugs	3	3.28E-03	9.12E-06	360
200-VCTO-PLEN10-HEP-LEK	Train B plenum 10 HEPA filters leak	3	1.08E-03	3.00E-06	360
200-VCTO-PLEN10-HEP-PLG	Train B plenum 10 HEPA filters plug	3	1.54E-03	4.27E-06	360
200-VCTO-PLEN10I-DMP-FRO	Train B filter plenum 10 inlet damper fails to remain open	3	3.02E-05	8.38E-08	360
200-VCTO-PLEN10O-DMP-FRO	Train B filter plenum 10 inlet damper fails to remain open	3	3.02E-05	8.38E-08	360
200-VCTO-RSH114-SRR-FOH	Exhaust high radiation alarm fails	3	2.00E-05	2.00E-05	1

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

Basic Event Name	Basic Event Description	SAPHIRE Calculation Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate[b]	Mission Time (Hours)
200-VCTO-TDMP00A-DTM-FOH	Damper (tornado) failure	3	1.61E-02	2.26E-05	720
200-VCTO-TDMP00B-DTM-FOD	Tornado damper Train B fails on demand	1	8.71E-04	—	—
200-VCTO-TDMP00B-DTM-FOH	Tornado damper Train B fails	3	8.10E-03	2.26E-05	360
200-VCTO-TRAINB-MAINT	Train B HVAC is off-line for maintenance	1	4.57E-03	—	—
200-VCTO-TRATRIP-CTL-FOD	Signal from Train A tripped logic fails	1	2.03E-03	—	—
200-VCTO-UDMP000-UDM-FOH	Backdraft damper for Train B exhaust fails	3	8.10E-03	2.26E-05	360
200CTM-PLC0101#-PLC-SPO	CTM bridge motor PLC spurious operation	3	3.65E-07	3.65E-07	1
200CTM-PLC0102#-PLC-SPO	CTM shield bell trolley PLC spurious operation	3	3.65E-07	3.65E-07	1
200CTM-PLC0103#-PCL-SPO	CTM hoist trolley PLC spurious operation	3	3.65E-07	3.65E-07	1
26D-##EG-DAYTNKA-TKF-FOH	ITS DG A day tank (00002A) fails	3	1.58E-04	4.40E-07	360
26D-##EG-DAYTNKB-TKF-FOH	ITS DG B day fuel tank fails	3	1.58E-04	4.40E-07	360
26D-##EG-FLITLKA-IEL-FOD	ITS DG A fuel transfer pumps interlock failure	1	2.75E-05	—	—
26D-##EG-FLITLKB-IEL-FOD	ITS DG B fuel transfer pumps interlock failure	1	2.75E-05	—	—
26D-##EG-FTP1DGA-PMD-FTR	ITS DG A fuel transfer pump fails to run	3	1.23E-02	3.45E-05	360
26D-##EG-FTP1DGA-PMD-FTS	ITS DG A fuel pump 1A fails to start	1	2.50E-03	—	—
26D-##EG-FTP1DGB-PMD-FTR	ITS DG B fuel transfer pump 1 (motor driven) fails to run	.3	1.23E-02	3.45E-05	360
26D-##EG-FTP1DGB-PMD-FTS	ITS DG B fuel transfer pump 1 (motor driven) fails to start	1	2.50E-03	—	—
26D-##EG-FTP2DGA-PMD-FTR	ITS DG A fuel transfer pump 2A fails to run	3	1.23E-02	3.45E-05	360
26D-##EG-FTP2DGA-PMD-FTS	ITS DG A fuel transfer pump 2A fails to start	1	2.50E-03	—	—
26D-##EG-FTP2DGB-PMD-FTR	ITS DG B fuel transfer pump 2 (motor driven) fails to run	3	1.23E-02	3.45E-05	360
26D-##EG-FTP2DGB-PMD-FTS	ITS DG B fuel transfer pump 2 (motor driven) fails to start on demand	1	2.50E-03	—	—
26D-##EG-FULPMPA-PMD-CCR	Common-cause failure of ITS DG A fuel pumps to run	C	2.90E-04	—	—
26D-##EG-FULPMPA-PMD-CCS	Common-cause failure of ITS DG A fuel pumps to start	C	1.18E-04	—	—
26D-##EG-FULPMPB-PMD-CCR	Common-cause failure of ITS DG B fuel pumps to run	C	2.90E-04	—	—
26D-##EG-FULPMPB-PMD-CCS	Common-cause failure of ITS DG B fuel pumps to start	C	1.18E-04	—	—
26D-##EG-HVACFN1-FAN-FTR	ITS DG B room fan 1 (motor-driven) fails to run	3	2.56E-02	7.21E-05	360
26D-##EG-HVACFN1-FAN-FTS	ITS DG B room fan (motor-driven) fails to start	1	2.02E-03	—	—
26D-##EG-HVACFN2-FAN-FTR	ITS DG B room fan 2 (motor-driven) fails to run	3	2.56E-02	7.21E-05	360

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

Basic Event Name	Basic Event Description	SAPHIRE Calculation Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate[b]	Mission Time (Hours)
26D-##EG-HVACFN2-FAN-FTS	ITS DG B room fan (motor-driven) fails to start	1	2.02E-03	—	—
26D-##EG-HVACFN3-FAN-FTR	ITS DG B room fan 3 (motor-driven) fails to run	3	2.56E-02	7.21E-05	360
26D-##EG-HVACFN3-FAN-FTS	ITS DG B room fan 3 (motor-driven) fails to start	1	2.02E-03	—	—
26D-##EG-HVACFN4-FAN-FTR	ITS DG B fan 4 (motor-driven) fails to run	3	2.56E-02	7.21E-05	360
26D-##EG-HVACFN4-FAN-FTS	ITS DG B room fan 4 (motor-driven) fails to start	1	2.02E-03	—	—
26D-##EG-STRTDGA-C72-SPO	ITS switchgear A battery circuit breaker (DC) spur op	3	3.85E-04	1.07E-06	360
26D-##EG-STRTDGB-C72-SPO	13.8 kV ITS SWGR battery B circuit breaker (DC) Spur Op	3	3.85E-04	1.07E-06	360
26D-##EG-WKTNK_A-TKF-FOH	ITS DG A bulk fuel tank (00001A) fails	3	1.58E-04	4.40E-07	360
26D-##EG-WKTNK_B-TKF-FOH	ITS DG B bulk fuel tank fails	3	1.58E-04	4.40E-07	360
26D-##EGBATCHRGA-BYC-FOH	ITS switchgear A battery: battery charger failure	3	1.28E-03	7.60E-06	168
26D-##EGBATCHRGB-BYC-FOH	ITS DG B battery charger failure	3	1.28E-03	7.60E-06	168
26D-#EEE-SWGRDGA-BUA-FOH	13.8 kV ITS switchgear A failure	3	4.39E-04	6.10E-07	720
26D-#EEE-SWGRDGB-AHU-FTR	EDGF switchgear room air handling unit failure to run	3	2.73E-03	3.80E-06	720
26D-#EEE-SWGRDGB-BUA-FOH	13.8 kV ITS switchgear B bus failure	3	4.39E-04	6.10E-07	720
26D-#EEESWGRDGA-AHU-FTR	13.8 kV ITS switchgear room air handling unit fails	3	2.73E-03	3.80E-06	720
26D-#EEG-HVACFA1-FAN-FTR	ITS DG A room fan 1 (motor-driven) fails to run	3	2.56E-02	7.21E-05	360
26D-#EEG-HVACFA1-FAN-FTS	ITS DG A room fan 1 (motor-driven) fails to start	1	2.02E-03	—	—
26D-#EEG-HVACFA2-FAN-FTR	ITS DG A room fan 2 (motor-driven) fails to run	3	2.56E-02	7.21E-05	360
26D-#EEG-HVACFA2-FAN-FTS	ITS DG A room fan 2 (motor-driven) fails to start	1	2.02E-03	—	—
26D-#EEG-HVACFA3-FAN-FTR	ITS DG A room fan 3 (motor-driven) fails to run	3	2.56E-02	7.21E-05	360
26D-#EEG-HVACFA3-FAN-FTS	ITS DG A room fan 3 (motor-driven) fails to start	1	2.02E-03	—	—
26D-#EEG-HVACFA4-FAN-FTR	ITS DG A room fan 4 (motor-driven) fails to run	3	2.56E-02	7.21E-05	360
26D-#EEG-HVACFA4-FAN-FTS	ITS DG A room fan 4 (motor-driven) fails to start	1	2.02E-03	—	—
26D-#EEU-208_DGA-BUD-FOH	ITS DC panel A DC bus failure	3	8.64E-05	2.40E-07	360
26D-#EEU-208_DGB-BUD-FOH	DC bus failure	3	8.64E-05	2.40E-07	360
26D-#EEY-DGALOAD-C52-FOD	DG A load breaker (AC) fails to close	1	2.24E-03	—	—
26D-#EEY-DGBLOAD-C52-FOD	ITS DG B load breaker (AC) fails to close	1	2.24E-03	—	—
26D-#EEY-DGLOADS-C52-CCF	Common-cause failure of ITS DG load breakers to close	C	1.05E-04	—	—
26D-#EEY-ITS-DGB-#DG-FTS	Diesel generator fails to start	1	8.38E-03	—	—

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

Basic Event Name	Basic Event Description	SAPHIRE Calculation Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate[b]	Mission Time (Hours)
26D-#EEY-ITSDG-A-#DG-FTR	ITS diesel generator A fails to run	3	7.70E-01	4.08E-03	360
26D-#EEY-ITSDG-A-#DG-FTS	Diesel generator fails to start	1	8.38E-03	—	—
26D-#EEY-ITSDGAB-#DG-CCR	CCF ITS DG A & B fail to run	C	1.81E-02	—	—
26D-#EEY-ITSDGAB-#DG-CCS	CCF DG A and B to start	C	3.94E-04	—	—
26D-#EEY-ITSDGB-#DG-FTR	Diesel generator fails to run	3	7.70E-01	4.08E-03	360
26D-#EEY-OB-SWGA-C52-FOD	13.8 kV ITS SWGR feed breaker (AC) fails to open	1	2.24E-03	—	—
26D-#EEY-OB-SWGA-C52-SPO	13.8 kV ITS SWGR A feed breaker spurious operation	3	3.82E-03	5.31E-06	720
26D-#EEY-OB-SWGB-C52-FOD	Circuit breaker (AC) fails on demand	1	2.24E-03	—	—
26D-#EEY-OB-SWGB-C52-SPO	Circuit breaker (AC) spurious operation	3	3.82E-03	5.31E-06	720
26D-#EEY-OB-SWGS-C52-CCF	Common-cause failure of 13.8 kV ITS SWGR feed breakers to open	C	1.05E-04	—	—
26D-#EG-BATTERYB-BTR-FOD	ITS SWGR control battery B no output	1	8.20E-03	—	—
26D-#EG-LCKOUTRL-RLY-FTP	13.8 kV ITS switchgear feed breaker lock out relay fails to open CB	3	3.15E-03	8.77E-06	360
26D-#EG-LDSQNCRB-SEQ-FOD	ITS DG B load sequencer fails	1	2.67E-03	—	—
26D-#EG-LOCKOUTB-RLY-FTP	13.8 kV ITS SWGR lockout relay (power) fails to open CB	3	3.15E-03	8.77E-06	360
26D-#EGLDSQNCRA-SEQ-FOD	DG A load sequencer fails	1	2.67E-03	—	—
26D-EG-BATTERYA-BTR-FOD	ITS switchgear A battery no output given challenge	1	8.20E-03	—	—
27A-#EEE-BUS2DGA-C52-SPO	13.8 kV open bus 2 ITS load breaker spurious operation	3	3.82E-03	5.31E-06	720
27A-#EEE-BUS3DGB-C52-SPO	Circuit breaker (AC) spurious operation	3	3.82E-03	5.31E-06	720
27A-#EEN-OPENBS2-BUA-FOH	13.8 kV open bus 2 bus failure	3	4.39E-04	6.10E-07	720
27A-#EEN-OPENBS4-BUA-FOH	13.8 kV open bus 4 bus failure	3	4.39E-04	6.10E-07	720
27A-#EEN-OPNBS1A-SWP-SPO	13.8 kV open bus 2 to ITS div A electric power switch spur. xfer	3	1.12E-04	1.55E-07	720
27A-#EEN-OPNBS3B-SWP-SPO	13.8 kV open bus 4 to ITS B electric power switch spur xfer	3	1.12E-04	1.55E-07	720

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

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

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

AC = alternating current; AHU = air handling unit; AO = aging overpack; ASD = adjustable speed drive; C = compound event; CCF = common-cause failure; CRCF = Canister Receipt and Closure Facility; CTM = canister transfer machine; DG = diesel generator; EDGF = Emergency Diesel Generator Facility; HEPA = high-efficiency particulate air; ITS = important to safety; MCC = motor control center; PLC = programmable logic controller; RF = Receipt Facility; SPMRC = site prime mover railcar; ST = site transporter; STC = shielded transfer cask; SV = solenoid valve ; WP = waste package; WPTT = waste package transfer trolley.

Source: Attachment C, Section C4

6.3.2 Passive Equipment Failure Analysis

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

6.3.2.1 Probability of Loss of Containment

An overview of the methodology for calculating the probability of failure of passive equipment from drops and impact loads is presented in Section 4.3.2.2. Consistent with HLWRS-ISG-02 (Ref. 2.2.69), the methodology essentially consists of comparing the demand upon the equipment to a capacity curve. The probability of failure is the value of the cumulative distribution function for the capacity curve, evaluated at the demand upon the container. More detailed discussion is presented in Attachment D. The methodology is applicable to all of the waste containers that are processed in the RF, including transportation casks, aging overpacks, and canisters. As described in Section 4.3.2.2, the condition at which a passive component is said to fail depends on the success criteria defined for the component in the RF operation. Passive components are designed and manufactured to ensure that the success criteria are met in normal operating conditions and with margin, to ensure that the success criteria are also met when subjected to abnormal loads, including those expected during event sequences. The design margins, and in some cases materials, may be dictated by the code and standards applied to a given type of container as characterized by tensile elongation data for impact loads and by strength at temperature data for thermal loads.

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

6.3.2.2 Probability of Loss of Containment for Drops and Impacts

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

- *Seismic and Structural Container Analyses for the PCSA* (Ref. 2.2.35)
- *Structural Analysis Results of the DOE SNF Canisters Subjected to the 23-Foot Vertical Repository Drop Event to Support Probabilistic Risk Evaluations*, EDF-NSNF-085 (Ref. 2.2.78) and *Qualitative Analysis of the Standardized DOE SNF Canister for Specific Canister-on-Canister Drop Events at the Repository*, EDF-NSNF-087 (Ref. 2.2.79)
- *Naval Long Waste Package Vertical Impact on Emplacement Pallet and Invert* (Ref.2.2.22).

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

Failure probabilities for drops are summarized in Table 6.3-2. Conservative representations of drop height are defined for operations with each type of container. Sometimes more than one conservative drop height is specified, for example, for normal height crane lifts and two-block height crane lifts. Lawrence Livermore National Laboratory (LLNL) predicts failure probabilities of $<1.0 \times 10^{-8}$ for most of the events (Ref. 2.2.35). If a probability for the event sequence is less than 1×10^{-8}, additional conservatism is incorporated in the PCSA by using a failure probability of 1.0×10^{-5}, which are termed "LLNL, adjusted." This additional conservatism is added to account for (a) future evolutions of cask and canister designs, and (b) uncertainties, such as undetected material defects, undetected manufacturing deviations, and undetected damage associated with handling before the container reaches the repository, which are not included in the tensile elongation data.

LLNL calculates strains by modeling representative casks, aging overpacks, and canisters that encompass TAD canisters, naval SNF canisters, and a variety of DPCs with the dynamic finite element code, LS-DYNA (Ref. 2.2.35). For these canisters, only flat-bottom drops are considered to model transfers by a CTM. This is justified because these canisters fit sufficiently tightly within the CTM and potential dropped canisters are guided by the canister guide sleeve of the CTM to remain in a vertical position.

INL calculates strains by modeling DOE SNF and MCOs with the static finite element code, ABAQUS (Ref. 2.2.78). The structural evaluations consider off-vertical drops. In such cases, the deformation of the waste form container is greater on the localized area of impact than for a flat-bottom drop, and will therefore yield a greater calculated probability of breach.

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

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

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

	Drop Height (ft)	**Failure Probability**	**Note**
Representative transportation cask[a]	13.1	1.0×10^{-5}	4 degrees from vertical, LLNL, adjusted, no impact limiters
	6	1.0×10^{-5}	3 degrees from horizontal, LLNL, adjusted, no impact limiters
	Slapdown after 13.1 ft drop	1.0×10^{-5}	LLNL, adjusted, no impact limiters
Representative canister	32.5[b]	1.0×10^{-5}	Flat bottomed, LLNL, adjusted
DOE standardized 24 in. or 18 in. canister	23	1.0×10^{-5}	3 degrees from vertical, LLNL, adjusted using INL FEA
Aging overpack	3	1.0×10^{-5}	LLNL, adjusted
MCO canister	23	9.0×10^{-2}	LLNL using INL FEA
HLW canister	30	6.7×10^{-2}	Bayesian interpretation of test data, 0 failures in 13 drops.

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

[b] For transfers by the CTM, this drop height is greater than the maximum drop height (except for CTM transfers in the IHF)

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

Source: Attachment D

Containment failure probabilities due to other physical impact conditions, equivalent to drops, are listed in Table 6.3-3. These probabilities were modeled by LLNL using FEA, resulting in prediction of failure probabilities of $<1.0 \times 10^{-8}$. Again, additional conservatism was incorporated by using a failure probability of 1.0×10^{-5} for most of these events. The side impact event was not adjusted from the LLNL result of $< 1.0 \times 10^{-8}$ because of the very low velocities involved. A comparison of the strains induced by drops and slow speed, side impacts indicates significantly lower strains for the low velocity impacts.

Table 6.3-3. Failure Probabilities Due to Miscellaneous Events

Event	Failure Probability	Note
Derail	1.0×10^{-5}	LLNL, adjusted, analogous to 6 ft, 3 degrees from horizontal
Rollover	1.0×10^{-5}	LLNL, adjusted, analogous to 6 ft, 3 degrees from horizontal
Drop on	1.0×10^{-5}	LLNL, adjusted 10-metric-ton load onto container
Tip over	1.0×10^{-5}	LLNL, adjusted, analogous to 13.1 ft drop plus slap-down
Side impact from collision with rigid surface	1.0×10^{-8}	Or value for low speed collision, whichever is greater (Table 6.3-4) Crane moving 20 ft/min
Tilt down/up	1.0×10^{-5}	LLNL, adjusted; Bounded by slap-down

NOTE: LLNL = Lawrence Livermore National Laboratory.

Source: Attachment D

Table 6.3-4 shows failure probabilities for various collision events for various containers as a function of impact speed. For each of the events, the collision speed, whether in miles per hour (mph) or feet per minute (ft/min) is converted to feet per second (ft/sec), then to an equivalent drop height in feet. The drop heights are very small compared with the drop heights for the modeled situations summarized in Table 6.3-2. The damage to a container, expressed in terms of strain, is roughly proportional to the impact energy, which is proportional to the drop height, as is readily seen from the following:

$$\text{Energy from drop} = mgh \propto Fs \text{ and } F \propto mg\text{, therefore, } s \propto h$$

where

s = strain
F = local force on container from drop
m = mass of container
h = drop height
g = acceleration of gravity

For drop heights other than those for the modeled situations presented in Table D3.4-1, failure probabilities can be estimated by shifting capacity curve to match the conservative failure probabilities listed in Table D3.4-1. The mean failure drop height, H_m, is found so that the probability of failure, P, is the value listed in Table D3.4-1 for the drop height, H_d, listed in Table D3.4-1.

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

				Failure Probabilities for Various Container Types				
Collision Scenario	**Speed**	**Velocity (ft/sec)**	**Equivalent Drop Height (ft)[a]**	**Transportation Cask**	**Canister**	**Waste Package**	**MCO**	**High-Level Radioactive Waste**
Railcar	2.5 (mph)	3.67	0.21	1.00E-08	—	—	—	—
Truck trailer	2.5 (mph)	3.67	0.21	1.00E-08	—	—	—	—
Crane	20 (ft/min)	0.33	0.00	1.00E-08	—	—	—	—
CTT	10 (ft/min)	0.17	0.00	1.00E-08	1.00E-08	—	1.00E-08	1.00E-08
ST	2.5 (mph)	3.67	0.21	—	1.00E-08	—	1.00E-08	1.00E-08
WPTT	40 (ft/min)	0.67	0.01	—	1.00E-08	1.00E-08	1.00E-08	1.00E-08
WP (in TEV)	1.7 (mph)	2.49	0.10	—	—	1.00E-08	—	—
CTM	20 (ft/min)	0.33	0.00	—	1.00E-08	—	1.00E-08	1.00E-08
CTM	40 (ft/min)	0.67	0.01	—	1.00E-08	—	1.00E-08	1.00E-08
Two-blocking	—	—	—	1.00E-05	1.00E-05	—	1.00E+00	6.70E-02

NOTE: [a]Values that are less than 0.005 are reported as 0.00.
CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; DSTD = DOE standardized canister; MCO = multicanister overpack; ST = site transporter; TEV = transport and emplacement vehicle; WP =waste package; WPTT = waste package transfer trolley.

Source: Original

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

where

P = Probability of failure for container dropped from height H_d
N(t) = Standard normal distribution with mean of zero and standard deviation of one
t = Variable of integration
H_d = Modeled drop height for which the failure probability has been determined
H_m = Median failure drop height of the failure drop height distribution such that the failure probability at the modeled drop height, H_d, is P
COV = Coefficient of variation = ratio of standard deviation to mean for strain capacity distribution, applied here to stress capacity or true tensile strength

The probabilities of failure for the collision cases listed in Table 6.3-4 are then determined using the above formula with H_m determined above and with H_d being the drop height corresponding to the collision speed as listed in Table 6.3-4.

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

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

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

6.3.2.3 Probability of Canister Failure in a Fire

In addition to passive equipment failures as a result of structural loads, passive failures can also occur as a result of thermal loads such as exposure to fires or abnormal environmental conditions, for example, loss of HVAC cooling. The PCSA evaluates the probability of loss of containment (breach) due to a fire for several types of waste form containers, including: transportation casks containing uncanistered SNF assemblies, and canisters representative of TAD canisters, DPCs, DOE standardized canisters, HLW canisters, and naval SNF canisters.

The methods for analyzing thermally-induced passive failures are discussed in Section 4.3.2.2, and detailed in Attachment D. In summary, the probability of failure of a waste form container as a result of a fire is evaluated by comparing the demand upon a container (which represents the thermal challenges of the fire vis-à-vis the container), with the capacity of the container (which represents the variability in the temperature at which failure would occur). The demand upon the container is controlled by the fire duration and temperature, because these factors control the amount of energy that the fire could transfer to the container.

In response to a fire, the temperature of the waste form container under consideration increases as a function of the fire duration. The maximum temperature is calculated using a heat transfer model that is simplified to allow a probabilistic analysis to be performed that accounts for the variability of key parameters. The model accounts for radiative and convective heat transfers from the fire, and also for the decay heat from the waste form inside a container. The temperature evolution of waste form containers is analyzed based on a simplified geometry with a wall thickness that, for the range of waste form containers of interest in the PCSA, is representative or conservatively small. Specifically, two characteristic canister wall thicknesses are modeled: 0.5 inches, characteristic of some DPCs and other waste canisters; and 1.0 inches, the anticipated thickness of TAD canisters and naval SNF canisters. The wall thickness of a container is an important parameter that governs both container heating and failure. Other conservative and realistic modeling approaches are introduced in the heat transfer model, as appropriate. For example, fires are conservatively considered to engulf a container, regardless of the fact that a fire at the GROA may simply be in the same room as a container. When handled, TAD canisters, DPCs, DOE standardized canisters, HLW canisters and naval SNF canisters are enclosed within another SSC, for example a transportation cask, the shielded bell of a canister transfer machine, or a waste package. Therefore, a fire does not directly impinge on such canisters. In contrast, the external surface of a transportation cask containing uncanistered SNF may be impinged upon directly by the flames of the fire.

Accounting for the uncertainty of the key parameters of the fires and the heat transfer model, the maximum temperature reached by a waste form container, which represents the demand upon the container due to a fire, is characterized with a probability distribution. The distribution is obtained through Monte Carlo simulations.

To determine whether the temperature reached by a waste form container is sufficient to cause the container to fail, the fire fragility distribution curve for the container is evaluated. In the PCSA, this curve is expressed as the probability of breach of the container as a function of its temperature. Two failure modes are considered for a container that is subjected to a thermal challenge: creep-induced failure and limit load failure. Creep, the plastic deformation that takes place when a material is held at high temperature for an extended period under tensile load, is possible for long duration fires. Limit load failure corresponds to situations where the load exerted on a material exceeds its structural strength. This failure mode is considered because the strength of a container decreases as its temperature increases. The variability of the key parameters that can lead to a creep-induced failure or limit load failure is modeled with probability distributions. Monte Carlo simulations are then carried out to produce the fire fragility distribution curve for a container.

The probability of a waste form container losing its containment function as a result of a fire is calculated by running numerous Monte Carlo simulations in which the temperature reached by the container, sampled from the probability distribution representing the demand on the container, is compared to the sampled failure temperature from the fragility curve. The model counts the simulation result as a failure if the container temperature exceeds the failure temperature. Statistics based upon the number of recorded failures in the total number of simulations are used to estimate the mean of the canister failure probability.

Table 6.3-5 shows the calculated mean and standard deviation for the failure probability of a canister in the following configurations: a canister in a transportation cask, a canister in a waste package, and a canister in a shielded bell.

Table 6.3-5. Summary of Canister Failure Probabilities in Fire

Configuration[b]	Failure Probability	
	Mean	**Standard Deviation**
Thin-walled[c] canister in a waste package[a]	3.2×10^{-4}	5.7×10^{-5}
Thick-walled[c] canister in a waste package[a]	1.0×10^{-4}	2.2×10^{-5}
Thin-walled canister in a transportation cask	2.0×10^{-6}	1.4×10^{-6}
Thick-walled canister in a transportation cask	1.0×10^{-6}	1.0×10^{-6}
Thin-walled canister in a shielded bell	1.4×10^{-4}	2.6×10^{-5}
Thick-walled canister in a shielded bell	9.0×10^{-5}	1.7×10^{-5}

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

[b] Configurations not addressed in this table include any canister in a waste package that is inside the transfer trolley or any canister inside an aging overpack. In these configurations, the canister is protected from the fire by the massive steel transfer trolley or by the massive concrete overpack. Calculations have shown that the temperatures experienced by the canister in these configurations are well below the canister failure temperature, so that failures for these configurations can be screened. For conservatism, a screening conditional probability of 1×10^{-6} could be used.

[c] Naval SNF canisters are modeled as thick-walled. Other canisters are modeled as thin-walled.

Source: Attachment D, Table D2.1-9

Note that no failure probability is provided for a bare canister configuration. The reason for this is that the canister is outside of a waste package or cask for only a short time. During that time, the canister is usually inside the shielded bell of the CTM. The preceding analysis addressed a fire outside the shielded bell. When in that configuration, the canister is shielded from the direct effects of the fire. A fire inside the shielded bell, which could directly heat the canister, is not considered to be credible for two reasons. First, the hydraulic fluid used in the CTM equipment is non-flammable and no other combustible material could be present inside the bell to cause a fire. Second, the annular gap between the canister and the bell is only 3 inches wide, but is approximately 27 feet long. Given this configuration, it is unlikely that there would be sufficient inflow of air to sustain a large fire that could heat a significant portion of the canister wall. There may be sufficient inflow to sustain a localized fire, but such a fire would not be adequate to heat the canister to failure.

The canister is also outside of a cask, waste package, or shielded bell as it is being moved from a cask into the shielded bell or from the shielded bell into a waste package. The time during which the canister would be in this configuration is extremely short, a matter of minutes, so a fire that occurs during this time is extremely unlikely. In addition, because the gap between the top of the waste package or cask and ceiling of the transfer cell is generally much shorter than the height of the canister, only a small portion of the canister surface would be exposed to the fire. Furthermore, this exposure would only be for the short time that the canister was in motion.

In addition, monolithic borosilicate glasses incorporating HLW do not appear to have the potential to release any significant amount of nonvolatile radionuclides. These materials would have been heated to temperatures exceeding those anticipated for most fire situation during formation and are not anticipated to undergo any chemical change under fire conditions (Ref. 2.2.9, Section II).

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

6.3.2.4 Probability of Loss of Containment from Heatup

In addition to fire-related passive failures, the PCSA considered other passive equipment failures due to abnormal thermal conditions. The thermal event of greatest concern for the surface facilities is loss of HVAC cooling. If HVAC cooling is lost, the ambient temperature in the facility will increase. This increase would be particularly significant for relatively small enclosures such as the transfer cells.

A series of bounding calculations was performed to determine the maximum temperature that could be reached by a canister following loss of HVAC cooling (Ref. 2.2.14). These calculations consider a range of decay heat levels and a loss of cooling for 30 days, which is consistent with NUREG-0800 (Ref. 2.2.64, Section 9.2.5). These analyses indicate that the canister temperature would remain well below 500°C (773 K) (Ref. 2.2.14). This temperature is hundreds of degrees below the temperature at which the canister would fail (Attachment D, Figures D2.1-4 and D2.1-5). For that reason, canister failure due to a loss of HVAC is physically unrealizable and considered beyond Category 2.

6.3.2.5 Probability of Loss/Degradation of Shielding

Loss or degradation of shielding probabilities are summarized in Table 6.3-6.

Shielding of a waste form that is being transported inside the GROA is accomplished by several types of shielded containers, including: transportation casks, shielded transfer casks, aging overpacks, shielded components of a WPTT, and shielded components of a TEV. In addition to a shielding function, sealed transportation casks and shielded transfer casks exert a containment function.

A structural challenge may cause shielding degradation or shielding loss. Loss of shielding occurs when an SSC fails in a manner that leaves a direct path for radiation to stream, for example, as a result of a breach. Degradation of shielding occurs when a shielding SSC is not breached but its shielding function is degraded. In the PCSA, a shielding degradation probability after a structural challenge is derived for those transportation casks that employ lead for shielding. Finite-element analyses on the behavior of transportation casks subjected to impacts associated with various collision speeds, reported in NUREG/CR-6672 (Ref. 2.2.80), indicate that lead slumping after an end impact could result in a reduction of shielding; transportation casks without lead are not susceptible to such shielding degradation. This information is used in Attachment D to derive the shielding degradation probability of a transportation cask at drop heights characteristic of crane operations. The distribution is developed for impacts on surfaces made of concrete, which compare to the surfaces onto which drops could occur at the GROA. No impact limiter is relied upon to limit the severity of the impact. Conservatively, the distribution is applied to transportation casks and also shielded transfer casks, regardless of whether or not they use lead for shielding. Thus, for containers that have both a containment and shielding function, the PCSA considers a probability of containment failure (which is considered to result in a concurrent loss of shielding), and also a probability of shielding degradation (which is associated with those structural challenges that are not sufficiently severe to cause loss of containment). Table 6.3-6 displays the resulting shielding degradation probabilities for transportation casks and shielded transfer casks after a structural challenge. Given that there is significant conservatism in the calculation of strain and the uncertainty associated with the fragility (strength), the resulting estimates include uncertainties and are considered conservative.

Shielding loss is also considered to potentially affect an aging overpack subjected to a structural challenge, if the waste form container inside does not breach. Given the robustness of aging overpacks, a shielding loss after a 3-ft drop height is calculated to have a probability of 5×10^{-6} per aging overpack impact, based upon the judgment that this probability may be conservatively related to but lower than the probability of breach of an unprotected waste form container inside the aging overpack (Attachment D). If the structural challenge is sufficiently severe to cause the loss of containment (breach) of the waste form container inside the aging overpack, the loss of the aging overpack shielding function is considered guaranteed to occur.

A CTM provides shielding with the shield bell, shield skirt, and associated slide gates. Also, the CTM is surrounded by shield walls and doors, which are unaffected by structural challenges resulting from internal random initiating events. Therefore, such challenges leave the shielding function intact.

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

	Probability	Note
Sealed transportation cask and shielded transfer casks shielding degradation after structural challenge	1×10^{-5}	Attachment D, Section D3.4.
Aging overpack shielding loss after structural challenge	5×10^{-6}	Attachment D, Section D3.4.
CTM shielding loss after structural challenge	0	Structural challenges sufficiently mild to leave the shielding function intact.
WPTT shielding loss after structural challenge	0	Structural challenges sufficiently mild to leave the shielding function intact.
TEV shielding loss (shield end)	0	Structural challenges sufficiently mild to leave the shielding function intact.
Shielding loss by fire for waste forms in transportation casks or shielded transfer casks	1	Lead shielding could potential expand and degrade. This probability is conservatively applied to transportation casks and STCs that do not use lead for shielding.
Shielding loss by fire for aging overpacks, CTM shield bell, and WPTT shielding	0	Type of concrete used for aging overpacks is not sensitive to spallation; Uranium used in CTM shield bell and WPTT shielding does not lose its shielding function as a result of a fire.

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

Source: Attachment D, Table D3.4-1

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

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

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

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

If the thermal challenge is not sufficiently severe to cause a loss of containment function, it is nevertheless postulated that it will cause shielding loss of the transportation cask, shielded transfer cask, canister transfer machine, cask transfer trolley, waste package transfer trolley, or TEV affected by the thermal challenge and in which the waste form container is enclosed. This is because the neutron shield on these SSCs is made of a polymer which is not anticipated to withstand a fire without failing. Note, however, that the degradation of gamma shielding of these SSCs is unlikely to be affected by a credible fire. Although credible fires could result in the lead melting in a lead-sandwich transportation cask, there is no way to displace the lead, unless the fire is accompanied by a puncture or rupture of the outer steel wall of the cask. Preliminary calculations were unable to disprove the possibility of hydraulic failure of the steel encasing due to the thermal expansion of molten lead, so loss of gamma shielding for steel-lead-steel transportation casks engulfed in fire is postulated. Conservatively, in the PCSA, transportation casks and shielded transfer casks are postulated to lose their shielding function with a probability of one, regardless of whether or not they use lead for shielding.

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

6.3.2.6 Probability of Other Fire-Related Passive Failures

In addition to the canisters, other passive equipment could fail as a result of a fire. For the PCSA, only failures that would result in a radionuclide release or radiation exposure are considered.

6.3.2.7 Application to Event Sequence Models

Table 6.3-7 summarizes passive failure events needed for the event sequence modeling. The values are either specifically developed in Attachment D, or are values from bounding events. Probabilities for some events were obtained by extrapolation from developed probabilities as described in this section or in Attachment D. The derivation of all passive failure probabilities is described in Attachment D and shown in PEFA Chart.xls included in Attachment H.

It should be noted that Table 6.3-7 addresses all passive event failures for the various waste form configurations. Table 6.3-8 identifies the specific passive failure basic events used in event sequence modeling and quantification for the RF. The probability of each basic event is based on one of the values presented in Tables 6.3-2 through 6.3-7.

Table 6.3-7. Summary of Passive Event Failure Probabilities

	10 ton dropped on container	Container vertical drop from normal operating height	Container 30-foot vertical drop	Container 45-foot vertical drop	6-foot horizontal drop, rollover	2.5 mph flat side impact/ collision	2.5 mph localized side impact/ collision	9 mph flat side impact/ collision	2.5 mph end-to-end collision	9 mph end-to-end collision	Slapdown (bounds tipover)	Thin-walled canister fire	Thick-walled canister fire
Loss of containment													
Canister in transport cask	1.E-05	1.E-05	1.E-05	N/A	1.E-05	1.E-08	1.E-08	1.E-08	1.E-08	1.E-08	1.E-05	2.E-06	1.E-06
Transport cask with bare fuel	1.E-05	1.E-05	1.E-05	N/A	1.E-05	1.E-08	1.E-08	1.E-08	1.E-08	1.E-08	1.E-05	5.E-02[a]	6.E-03[b]
Canister	1.E-05	1.E-05	1.E-05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.E-05	N/A	N/A
Waste package	1.E-05	N/A	N/A	N/A	1.E-05	1.E-08	N/A	1.E-08	1.E-05	1.E-05	No challenge	3.E-04	1.E-04
Bare MCO	N/A	1.E-01	~ 1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Bare DOE standard canister	1.E-05	1.E-05	1.E-03	N/A	N/A	N/A	N/A	N/A	1.E-05	1.E-05	N/A	N/A	N/A
Bare high-level waste canister	N/A	3.E-02	7.E-02	~ 1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Canister in shield bell	N/A	1.E-05	N/A	N/A	N/A	1.E-08	N/A	N/A	N/A	N/A	N/A	1.E-04	9.E-05
Canister in AO	1.E-05	1.E-05	N/A	N/A	N/A	1.E-08	1.E-08	1.E-08	N/A	N/A	1.E-05	1.E-06	1.E-06
Loss of shielding													
Transport cask	1.E-05	1.E-05	1.E-05	N/A	1.E-05	1.E-08	1.E-08	1.E-08	1.E-08	1.E-08	1.E-05	~ 1	~ 1
Aging overpack	1.E-05	5.E-06	N/A	N/A	N/A	1.E-05	1.E-05	1.E-05	1.E-05	1.E-05	1.E-05	~ 0	~ 0
TEV, CTM, WPTT	No challenge	No challenge	N/A	N/A	No challenge	No challenge	N/A	No challenge	No challenge	No challenge	No challenge	~ 0	~ 0

NOTE: [a] Truck cask

[b] Rail cask

AO = aging overpack; CTM = canister transfer machine; DOE = U.S. Department of Energy; MCO = multicanister overpack; N/A = not applicable, no scenarios identified; TEV = transport and emplacement vehicle; WPTT = waste package transfer trolley.

Source: Attachment D

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

Basic Event Name	Basic Event Description	BE Value	Condition
Passive Failures from Mechanical Events			
CAN-FAIL-SD-IMPACT	Canister fails due to collision	1.00E-08	2.5 mph flat side impact/collision with canister in TC
CAN-IN-AO-DROP	Canister failure from miscellaneous impacts	1.00E-05	AO container drop
CAN-IN-AO-DROPON	Canister failure from drop, drop on, roll or tip	1.00E-05	10-ton dropped on container
CAN-IN-AO-IMPACT	Canister failure from miscellaneous impacts	1.00E-08	2.5 mph localized side impact/collision
CAN-IN-AO-ROLLOVER	Canister failure from miscellaneous impacts	1.00E-05	AO container drop
CAN-IN-AO-TIP	Canister failure from miscellaneous impacts	1.00E-05	Slapdown (bounds tipover)
CANISTER-FAIL-CTM-2BLOCK	Canister failure due to CTM two-block drop	1.00E-05	30-ft canister drop
DPC_FAIL_IN_TC	Canister failure	1.00E+00	DPC fails given transportation cask fails
DPC-CAN-IN-AO-COLL	Canister failure from collision	1.00E-08	2.5 mph flat side impact/collision with canister in AO
DPC-FAIL-CTM-IMPACT	Canister failure	1.00E-08	2.5 mph flat side impact/collision with canister in CTM
DPC-FAIL-NO-CASK	Canister failure	1.00E-05	Canister drop or 10 ton dropped on canister in CTM
DPC-FAIL-NO-CASK-IMP	Canister failure	1.00E-08	2.5 mph flat side impact/collision with canister in TC
DPC-FAIL-SPURMOVE	Canister failure	1.00E+00	Spurious movement of CTT or ST during unloading or unloading a canister
TAD_FAIL_IN_TC	Canister failure	1.00E+00	TAD canister fails given transportation cask fails
TAD-CAN-IN-AO-COLL	Canister failure from ST collision	1.00E-08	2.5 mph Flat side impact/collision with canister in AO
TAD-FAIL-CTM-IMPACT	Canister failure	1.00E-08	2.5 mph Flat side impact/collision with canister in Shielded Bell
TAD-FAIL-NO-CASK	Canister failure	1.00E-05	Canister drop or 10 ton dropped on canister in CTM
TAD-FAIL-NO-CASK-IMP	Canister failure	1.00E-08	2.5 mph flat side impact/collision with canister in TC
TAD-FAIL-SPURMOVE	Canister failure	1.00E+00	Spurious movement of CTT or ST during unloading or unloading a canister

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

Basic Event Name	Basic Event Description	BE Value	Condition
Passive Failures from Mechanical Events			
TCASK	Transportation cask fails	1.00E-08	2.5 mph flat side impact/collision with canister in TC
TCASK-2BLOCK	Cask failure due to two-block drop	1.00E-05	30-ft drop
TCASK-FAIL-COLL	Transportation cask fails	1.00E-08	2.5 mph flat side impact/collision with canister in TC on HCTT
TCASK-FAIL-ROLLOVER	TC fails due to rollover	1.00E-05	6-foot horizontal drop, rollover with canister in TC on HCTT
TCASK-MISC-DROP	TC fails from drop	1.00E-05	TC drop during handling and transfer to CTT
TCASK-MISC-DROPON	TC fails due load drop onto cask	1.00E-05	10 ton dropped on container during handling and transfer to CTT
TCASK-MISC-IMP	TC fails from side Impacts	1.00E-08	2.5 mph Localized side impact/collision during handling and transfer to CTT
TCASK-SPURMOVE	TC fails due to spurious movement	1.00E-08	2.5 mph flat side impact/collision to TC
TCASK-TIPOVER	Transportation cask fails due tipover	1.00E-05	Slapdown (bounds tipover)
Shielding Failures			
CTM-SHIELDING	CTM shielding fails	0.00E+00	Loss of CTM shielding during CTM handling activities
TCASK-SHIELDING-DROP	Transportation cask shielding fails	1.00E-05	Loss of cask shielding from 15-ft drop during handling and transfer to CTT
TCASK-SHIELDING-IMP	Transportation cask shielding fails	1.00E-08	2.5 mph flat side impact/collision to TC
TCASK-SHIELDING	Transportation cask shielding fails	1.00E-05	6-foot horizontal drop, rollover with canister in TC on HCTT
TCASK-SHIELDING-2BLK	TC shielding fails from two-block drop	1.00E-05	Two-block drop of TC during cask handling and movement to CTT
AO_SHIELDING	AO shielding fails	1.00E-05	AO shielding failure from 2.5 mph collision or impact

NOTE: AO = aging overpack; CTM = canister transfer machine; DPC = dual-purpose canister; HCTT = cask tractor and cask transfer trailer; TAD = transportation, aging and disposal; TC = transportation cask.

Source: Original

6.3.3 Miscellaneous Data

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

Table 6.3-10 provides details on how specific residence time fractions were developed for the IHF fire event sequence analysis. The formulas use the index notation in Table 6.3-9.

Data that is not defined as Active Component Reliability Data (Section 6.3.1) or Passive Equipment Failure Data (Section 6.3.2), but are used in the reliability analysis for this facility are listed in the following Table 6.3-11.

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

Location	Mean Fire Initiation Frequency		Container Type or Location
	DPC	TAD	
Localized Fire			
Vestibule/Lid Bolting Room, diesel present	8.1E-07	8.1E-07	AO
Loading Room, diesel present	3.5E-07	3.5E-07	AO
Vestibule/Preparation Area, diesel present	1.9E-06	4.6E-07	TC
Preparation Area, no diesel present	1.2E-05	3.1E-06	TC
Preparation Area	2.1E-06	9.1E-07	TC
Cask Unloading Room	3.9E-07	3.9E-07	TC
Transfer Room	1.1E-07	1.1E-07	CTM
Large Fire			
Large fire threatens TC/TAD, no diesel present	—	1.1E-05	TC
Large fire threatens TC/TAD or TC/DPC, diesel present	8.6E-07	8.6E-07	TC
Large fire threatens TC/DPC, no diesel present	1.6E-05	—	TC
Large fire threatens TC/DPC, no diesel present	1.2E-05	—	TC
Large fire threatens TC/DPC, diesel present	1.8E-06	—	TC
Large fire threatens TC/DPC, no diesel present	1.1E-05	—	TC
Large Fire Totals for Waste Forms in Various Containers			
Large fire threatens waste form in TC	4.2E-05	1.2E-05	TC
Large fire threatens waste form in CTM	4.9E-07	4.9E-07	CTM
Large fire threatens waste form in AO, diesel present	6.1E-06	6.1E-06	AO
Total for large fire threatens waste form in RF	4.9E-05	1.9E-05	All

NOTE: AO = aging overpack; CTM = canister transfer machine; DPC = dual-purpose canister; RF = Receipt Facility; TAD = transportation, aging, and disposal canister; TC = transportation cask.

Source: Table 6.5-4

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

Fire Scenario	Mean	Split Fraction
TAD Calculation		
Large fire threatens TAD in TC	1.2E-05	6.5E-01
Large fire threatens TAD in CTM	4.9E-07	2.6E-02
Large fire threatens TAD in AO	6.1E-06	3.3E-01
Total	1.9E-05	—
DPC Calculation		
Large fire threatens DPC in TC	4.2E-05	8.6E-01
Large fire threatens DPC in CTM	4.9E-07	1.0E-02
Large fire threatens DPC in AO	6.1E-06	1.3E-01
Total	4.9E-05	—

NOTE: AO = aging overpack; CTM = canister transfer machine; DPC = dual-purpose canister; RF = Receipt Facility; TAD = transportation, aging, and disposal canister.

Source: Original

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

Basic Event Name	Basic Event Description	BE Value	Bases	References
200-#EEE-LDCNTRA-BUA-MTN	ITS load center train A OOS for maintenance	1.025E-004	Probability equipment will be in maintenance over preclosure period as determined by HRA.	Section 6.4
200-#EEE-LDCNTRA-BUA-ROE	Failure to restore ITS load center train A post maintenance	1.025E-005	Probability equipment will not be restored following maintenance over preclosure period as determined by HRA.	Section 6.4
200-#EEE-LDCNTRB-BUA-MTN	ITS load center train B OOS for maintenance	1.025E-004	Probability equipment will be in maintenance over preclosure period as determined by HRA.	Section 6.4
200-#EEE-LDCNTRB-BUA-ROE	Failure to restore ITS load center train B post maintenance	1.025E-005	Probability equipment will not be restored following maintenance over preclosure period as determined by HRA.	Section 6.4
200-CR-CASK-UNLOADING	Canister is exposed during mid-unloading	1.000E+000	Probability that canister will be partially unshielded during unloading and loading operations.	Section 6.4
200-CSKPREPLIFTNUMBER	Number of object lifts for cask prep	1.000E+000	Total number of lifts by 200-ton crane during transportation cask preparation.	Section 6.4
200-CTMOBJLIFTNUMBERD	Number of objects lifted by CTM during DPC canister transfer	1.000E+000	Number of lifts required by the CTM to transfer a DPC.	Section 6.4

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

Basic Event Name	Basic Event Description	BE Value	Bases	References
200-CTMOBJLIFTNUMBERT	Number of objects lifted by CTM during TAD canister transfer	1.000E+000	Number of lifts required by the CTM to transfer a TAD.	Section 6.4
200-DPCPREPLIFTNUMBER	Number of object lifts for DPC prep	3.000E+000	There are three crane lifts associated with the preparation of the DPC in the Cask Preparation Area. Therefore, a value of 3 is assigned to this basic event.	Section 6.4
200-EXCESSIVE-WIND-SPEED	Sustained wind exceeds 40 mph & gust to 90 mph	4.700E-003	Sustained wind with speed exceeding 40 mph and gust to 90 mph has an estimated frequency of 5.7E-02 per year and with a mission time of 720 hours, the probability of such an occurrence is 4.7E-3.	Ref. 2.2.26
200-FIRE-SUPPRESSION	Inadvertent actuation of the fire suppression system	5.000E-007	Fire suppression system inadvertently activates during normal IHF operations (no fire).	Section 6.2.2.9
200-LIFTS-PER-DPC-CAN	Number of lifts per DPC canister	1.000E+000	HRA determination of the number of lifts associated with DPC canisters in CTM.	Section 6.4
200-LIFTS-PER-TAD-CAN	Number of lifts per TAD canister	1.000E+000	HRA determination of the number of lifts associated with TAD canisters in CTM.	Section 6.4
200-MODERATOR-IN-FIRE	Water moderator enters cask	1.000E+000	Conservative estimate of probability of water entering a cask from fire suppression during a fire.	N/A
200-OIL-MODERATOR	Oil moderator sources in RF (gear boxes)	9.000E-005	Crane gearbox leaks oil during normal RF operations (no fire) that could potentially create a moderator source.	Section 6.2.2.9.2
200-PWR-LOSS	Loss of site power	4.100E-006	Commercial power reliability requirement.	N/A
200-SPMRC-MILES-IN-RF	Miles traveled in RF	4.000E-002	Site prime mover travel distance on rails inside the RF.	(Ref. 2.2.24)
200-TRANSCTTLIFTNUMBER	Number of crane lifts	3.000E+000	Total number of crane lifts.	
200-TRANSNSCTTLIFTNUMBER	Number of crane lifts	1.000E+000	Total number of lifts by the 200-ton crane during transfer of a TC from conveyance to preparation station.	Section 6.4
200-TRANSSTANDLIFTNUMBER	Crane lifts with sling lift	2.000E+000	Number of lifts performed by sling lift.	Section 6.4

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

Basic Event Name	Basic Event Description	BE Value	Bases	References
200-UPENDOBJLIFTNUMBER	Number of object lifts	3.000E+000	Number of crane lifts performed during upending TC in Cask Preparation Area.	Section 6.4
200-VCOO-NITS-PWR-FAILS	Non-ITS power failure to RF supply fan	2.991E-003	Commercial power reliability requirement.	N/A
200-VCTO-CONTDOORS-OPEN	Vestibule doors open receipt or export from RF	1.000E+000	House event set to true to account for the probability that a vestibule door is open at the time of release.	N/A
200-VCTO-DRS0000-DRS-OPN	Vestibule door open during receipt/export	1.600E-004	Probability that vestibule doors are open over preclosure period as determined by HRA.	Section 6.4
26D-#EEY-ITSDG-A-#DG-MTN	ITS DG A OOS maintenance	1.950E-003	Probability equipment will be in maintenance over preclosure period as determined by HRA.	Section 6.4
26D-#EEY-ITSDG-A-#DG-RSS	Failure to properly return ITS DG A to service	1.950E-004	Probability equipment will not be restored following maintenance over preclosure period as determined by HRA.	Section 6.4
26D-#EEY-ITSDG-B-#DG-MTN	ITS DG B OOS maintenance	1.950E-003	Probability equipment will be in maintenance over preclosure period as determined by HRA.	Section 6.4
26D-#EEY-ITSDG-B-#DG-RSS	Failure to properly restore ITS DG-B to service	1.950E-004	Probability equipment will not be restored following maintenance over preclosure period as determined by HRA.	Section 6.4
CELL-DOOR	Door remains on tracks and does not fall onto CTT/ST	1.000E+000	Value used in analysis.	N/A
DPC	Number of DPCs	3.460E+002	Total number of DPCs received at RF over preclosure period.	(Ref. 2.2.27)
DPCS	Number of DPCs processed through the RF during preclosure period	3.460E+002	Total number of DPCs received at RF over preclosure period.	(Ref. 2.2.27)
DPCS-TADS	Number of DPCs & TADs processed through the RF during preclosure period	7.324E+003	Total number of DPCs and TADs processed at RF over preclosure period.	(Ref. 2.2.27)

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

Basic Event Name	Basic Event Description	BE Value	Bases	References
LOSP	Loss of offsite power	2.990E-003	Commercial power reliability requirement.	N/A
LOSP-4	Failure of offsite power	4.100E-006	Commercial power reliability requirement.	N/A
TAD	Number of TADs	6.976E+003	Total number of TADs received at RF over preclosure period.	(Ref. 2.2.27)
TADS	Number of TADs processed through the RF during preclosure period	6.976E+003	Total number of TADs received at RF over preclosure period.	(Ref. 2.2.27)
ESD12-DFIRE-IN-PREP-DPC	TC with DPC in Vestibule/Prep Area threatened by diesel fire	1.850E-006	Localized fire threatens a TC containing a DPC in the Vestibule/Preparation Area when diesel is present.	Section 6.3, Table 6.3-9
ESD12-DFIRE-IN-PREP-TAD	TC with TAD in Vestibule/Prep Area threatened by diesel fire	4.600E-007	Localized fire threatens a TC containing a TAD in the Vestibule/Preparation Area when diesel is present.	Section 6.3, Table 6.3-9
ESD12-DPC-IN-LG-FIRE	DPC threatened by large fire	4.830E-005	A large fire threatens a container with a DPC in the facility. Variations in container type failure probabilities are accounted for by assigning split fractions.	Section 6.3, Table 6.3-9 and 6.3-10
ESD12-FIRE-CTM-DPC	Fire in transfer area threatens DPC	1.100E-007	Localized fire threatens a TC containing a DPC in the Transfer Area when diesel is present.	Section 6.3, Table 6.3-9
ESD12-FIRE-CTM-TAD	Fire in transfer area threatens TAD	1.100E-007	Localized fire threatens a TC containing a TAD in the Transfer Area when diesel is present.	Section 6.3, Table 6.3-9
ESD12-FIRE-IN-BOLT-DPC	DPC threatened by fire in Lid Bolting Room	8.100E-007	Localized fire threatens a TC containing a DPC in the Lid Bolting Room, diesel is present in the site transporter.	Section 6.3, Table 6.3-9
ESD12-FIRE-IN-BOLT-TAD	TAD threatened by fire in Lid Bolting Room	8.100E-007	Localized fire threatens a TC containing a TAD in the Lid Bolting Room, diesel is present in the site transporter.	Section 6.3, Table 6.3-9
ESD12-FIRE-IN-LOAD-DPC	DPC threatened by fire in Loading Room	3.500E-007	Localized fire threatens a TC containing a DPC in the Loading Room, diesel is present in the site transporter.	Section 6.3, Table 6.3-9

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

Basic Event Name	Basic Event Description	BE Value	Bases	References
ESD12-FIRE-IN-LOAD-TAD	TAD threatened by fire in Loading Room	3.500E-007	Localized fire threatens a TC containing a TAD in the Loading Room, diesel is present in the site transporter.	Section 6.3, Table 6.3-9
ESD12-FIRE-IN-PREP-DPC	DPC in TC threatened by fire in prep area	1.200E-005	Localized fire threatens a TC containing a DPC in the Preparation Area with diesel present.	Section 6.3, Table 6.3-9
ESD12-FIRE-IN-PREP-TAD	TAD in TC threatened by fire in prep area	3.100E-006	Localized fire threatens a TC containing a TAD in the Preparation Area with diesel present.	Section 6.3, Table 6.3-9
ESD12-FIRE-IN-PREPCT-DPC	DPC in TC threatened by fire in prep area	2.100E-006	Localized fire threatens a TC containing a DPC in the Preparation Area.	Section 6.3, Table 6.3-9
ESD12-FIRE-IN-PREPCT-TAD	TAD in TC threatened by fire in prep area	9.100E-007	Localized fire threatens a TC containing a TAD in the Preparation Area.	Section 6.3, Table 6.3-9
ESD12-FIRE-IN-UNLD-DPC	DPC threatened by fire in unloading room	4.000E-007	Localized Fire Threatens a TC containing a DPC in the Unloading Room, diesel is present in the site transporter.	Section 6.3, Table 6.3-9
ESD12-FIRE-IN-UNLD-TAD	TAD threatened by fire in unloading room	3.900E-007	Localized Fire Threatens a TC containing a TAD in the Unloading Room, diesel is present in the site transporter.	Section 6.3, Table 6.3-9
ESD12-TAD-IN-LG-FIRE	TAD threatened by large fire	1.850E-005	A large fire threatens a container with a TAD in the facility. Variations in container type failure probabilities are accounted for by assigning split fractions.	Section 6.3, Table 6.3-9 and 6.3-10

NOTE: CTM = canister transfer machine; CTT = cask transfer trolley; DG = diesel generator; DPC = dual-purpose canister; HRA = human reliability analysis; IHF = Initial Handling Facility; ITS = important to safety; OOS = out of service; RF = Receipt Facility; ST = site transporter; TAD = transportation, aging, and disposal canister; TC = transportation cask.

Source: Original

6.4 HUMAN RELIABILITY ANALYSIS

The PCSA has emphasized human reliability analysis because the waste handling processes include substantial interactions between equipment and operating personnel. If there are human interactions that are typically associated with the operation, testing, calibration, or maintenance of a certain type of SSC (e.g., drops from a crane when using slings) and this SSC has been treated using industry-wide data per Attachment C, then human failure events may be implicit in the reliability data. The analyst is tasked with determining whether that is the case. Otherwise, the analyst includes explicit identification, qualitative modeling, and quantification of HFEs, as described in this section. The methodology applied is provided in Section 4.3.4, and the detailed description of the HRA is presented in Attachment E.

6.4.1 HRA Scope

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

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

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

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

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

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

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

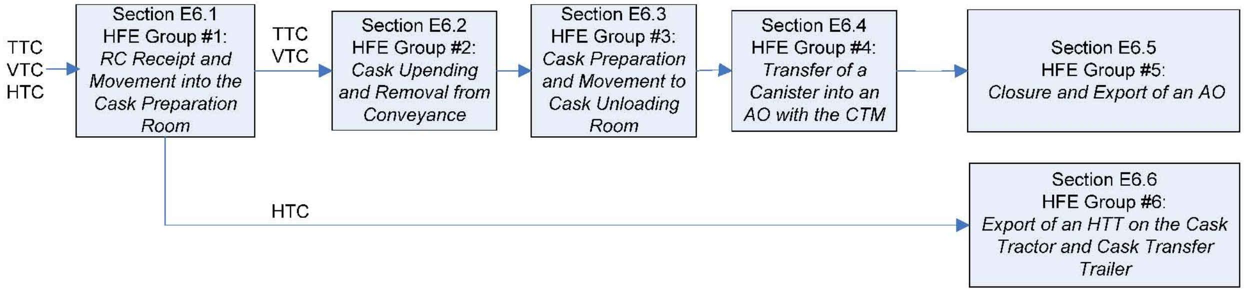
4. The exception to number 3 is that system-level HFEs are considered for support systems (e.g., electrical power for confinement HVAC) when those HFEs could result in a loss of a safety function related to the occurrence or consequences associated with the events specified in number 1.

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

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

6.4.2 Base Case Scenarios

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



NOTE: AO = aging overpack; CTM = canister transfer machine; HFE =human failure event; HTC = a transportation cask that is never upended; RC = railcar; TTC = a transportation cask that is upended using a tilt frame; VTC = a transportation cask that is upended on a railcar.

Source: Original

Figure 6.4-1. RF Operations

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

6.4.3 Identification of Human Failure Events

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

- Pre-initiator HFEs
- Human-induced initiator HFEs

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

Each of these types of HFEs is defined in Attachment E, Section E5.1.1.1. The PCSA model was developed and quantified with pre-initiator and human-induced initiator HFEs included in the model. The safety philosophy of waste handling operations is that an operator need not take any action after an initiating event and there are no actions identified that could exacerbate the consequences of an initiating event. This stems from the definitions and modeling of initiating events and subsequent pivotal events as described in Section 6.1 and Attachment A. All initiating events are proximal causes of either radionuclide release or direct exposure to personnel. With respect to the latter, personnel evacuation was not considered in reducing the frequency of direct exposure but personnel action could cause an initiating event. With respect to the former, pivotal events address containment integrity, confinement availability, shielding integrity, and moderator availability that have no post-initiator human interactions. Containment and shielding integrity are associated only with the physical robustness of the waste containers. Confinement availability is associated with a continuously operating HVAC and the status of equipment confinement doors. Human interactions for HVAC are pre-initiator. Human actions for shielding are associated the with the initiator phase. Moreover, recovery post-initiator HFEs were not identified and not relied upon to reduce event sequence frequency. Thus, the focus of the HRA task is to support the other PCSA tasks to identify these two HFE phases.

Pre-Initiator HFEs

Pre-initiators are identified by the system analysts when modeling fault trees during the system analysis task. Special attention is paid to the possibility that an error can be repeated in similar redundant components or trains, leading to a human CCF.

Human-Induced Initiator HFEs

Human-induced initiator HFEs are identified through an iterative process whereby the human reliability analysts, in conjunction with other PCSA analysts and engineering and operations personnel, meet and discuss the design and operations of the facility and the SSCs in order to appropriately model the human interface. This iterative process began with the HAZOP evaluation, the MLD and event sequence development, and the event tree and fault tree modeling, and it culminated in the preliminary analysis and incorporation of HFEs into the model. Included in this process is an extensive information collection process where industry data for potential vulnerabilities and HFE scenarios are reviewed. The following sources were examined:

- *A Survey of Crane Operating Experience at U.S. Nuclear Power Plants from 1968 – 2002*, NUREG-1774 (Ref. 2.2.52)

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

- *Control of Heavy Loads at Nuclear Power Plants*. NUREG-0612 (Ref. 2.2.62)
- Naval Facilities Engineering Command Internet Web Site, Navy Crane Center (NCC). The database includes the following information:
  - NCC Quarterly Reports ("Crane Corner") 2001 through 2007
  - NCC Fiscal Year 2006 Crane Safety Reports (covers fiscal year 2001 through 2006)
  - NCC Fiscal Year 2006 Audit Report.
- DOE Occurrence Reporting and Processing System (ORPS) Internet Web Site, Operational Experience Summaries (2002 through 2007) (http://www.hss.energy.gov/CSA/analysis/orps/orps.html)
- Institute of Nuclear Power Operations (INPO) database (https://www.inpo.org). The INPO database contains the following information:
  - Licensee event reports
  - Equipment Performance and Information Exchange System
  - Nuclear Plant Reliability Data System.
- *Savannah River Site Human Error Data Base Development for Nonreactor Nuclear Facilities (U)* (Ref. 2.2.12)
- All Scientech/Licensing Information Service (LIS) data on Independent Spent Fuel Storage Installation (ISFSI) events (1994 through 2007) and Dry Storage Information Forum (New Orleans, LA, May 2-3, 2001). This database includes the following information:
  - Inspection reports
  - Trip reports
  - Letters, etc.

HFEs identified include both EOCs and EOOs.

The result of this identification process is a list of HFEs and a description of each HFE scenario, including system and equipment conditions and any resident or triggered human factor concerns (e.g., PSFs). This combination of conditions and human factors concerns then becomes the EFC for a specific HFE. Additions and refinements to these initial EFCs are made during the preliminary and detailed analyses.

6.4.4 Preliminary Analysis

A preliminary analysis is performed to allow HRA resources for the detailed analyses to be focused on only the most risk-significant HFEs. The preliminary analysis includes verification of the validity of HFEs included in the initial PCSA model, assignment of conservative HEPs to all HFEs and verification of those probabilities. The actual quantification of preliminary values is a six-step process that is described in detail in Appendix E.III of Attachment E. Once the preliminary probabilities are assigned, the PCSA model is quantified (initial quantification) to determine which HFEs require a detailed quantification. HFEs are identified for a detailed analysis if (1) the HFE is a risk-driver for a dominant sequence, and (2) using the preliminary values, an aggregated event sequence is above Category 1 or Category 2 according to 10 CFR 63.111 (Ref. 2.3.2) performance objectives.

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

6.4.5 Detailed Analysis

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

- CREAM (Ref. 2.2.51)
- HEART (Ref. 2.2.85)/NARA (Ref. 2.2.37)
- THERP with some modifications (Ref. 2.2.81)
- ATHEANA’s expert elicitation approach (Ref. 2.2.67).

For the preliminary analysis, HFEs are modeled at a high level where several subtasks are combined into a single task so that explicit consideration of dependencies between subtasks is eliminated. For a detailed assessment, where the various actions that constitute an HFE are explicitly quantified, dependencies are also explicitly addressed using the basic formulae in Table 6.4-1 from the THERP method (Ref. 2.2.81), where N is the independently derived HEP.

Table 6.4-1. Formulae for Addressing HFE Dependencies

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

Source: Modified from Ref. 2.2.81, Table 20-17, p. 20–33

After estimates for HFE probabilities are generated, these results are reviewed by the HRA team and, in some cases, by knowledgeable operations personnel, as a "sanity check." Principally, such checks are used, for example, to compare the probabilities of different HFEs and determine whether or not these probabilities are consistent with the judgment of experts regarding the associated operator actions. A review of this type is particularly important for HFE probabilities that are generated using data from the THERP method (Ref. 2.2.81) since it is difficult to identify all important PSFs that are appropriate for repository operations. In addition, the HFE probability estimates are reviewed to ensure that they do not exceed the lower limit of credible human performance as defined by NARA (Ref. 2.2.37). HFE probabilities produced in this HRA are mean values; uncertainties are accounted for by applying an error factor to the mean value of the overall HFE according to the guidelines presented in Section E3.4 of Attachment E.

6.4.6 Human Failure Event Probabilities used in RF Event Sequences Analysis

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

Table 6.4-2. Human Failure Event Probability Summary

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
200-#EEE-LDCNTRA-BUA-ROE	Operator fails to restore load center train-A post maintenance	Electrical	OA	1.03E-05	10	Preliminary
200-#EEE-LDCNTRA-BUA-ROE	Operator fails to restore load center train-B post maintenance	Electrical	OA	1.03E-05	10	Preliminary
26D-#EEY-ITSDG-A-#DG-RSS	Operator fails to restore diesel generator A to service	Electrical	OA	1.95E-04	10	Preliminary
26D-#EEY-ITSDG-B-#DG-RSS	Operator fails to restore diesel generator B to service	Electrical	OA	1.95E-04	10	Preliminary
200-Liddisplace1-HFI-NOD	Operator inadvertently displaces cask lid during platform activities	10	3, 5	N/A[b]	N/A	Omitted from analysis
200-OpAOImpact01-HFI-NOW	Operator causes AO impact during AO closure	7	5	3.00E-03	5	Preliminary
200-OpCaskDrop01-HFI-NOD	Operator drops cask during cask preparation activities	3	3	N/A[b]	N/A	Omitted from analysis
200-OpClCTMGate1-HFI-NOD	Operator inappropriately closes slide or port gate during vertical canister movement and continues lifting	6	4	1.00E-03	5	Preliminary
200-OpCollide001-HFI-NOD	Operator causes low-speed collision of auxiliary vehicle with RC, HCTT, CTT, or TTC	2	2, 6	3.00E-03	5	Preliminary
200-OpCTCollide1-HFI-NOD	Operator causes low-speed collision of auxiliary vehicle with CTT	3, 7	3, 5	3.00E-03	5	Preliminary
200-OpCTCollide2-HFI-NOD	Operator causes low-speed collision of CTT with SSC during transfer from preparation station to Unloading Room	4	3	1.00E-03	5	Preliminary

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

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
060-OpCTMDirExp1-HFI-NOD	Operator causes direct exposure during CTM activities (second floor)	11	4	8E−06	10	Detailed
200-OpCTMDrInt01-HFI-COD	Operator lifts object or canister too high with CTM (two-block)	6	4	1.0	N/A	Preliminary
200-OpCTMdrop001-HFI-COD	Operator drops object onto canister during CTM operations	6	4	4.00E-07	10	Detailed
200-OpCTMdrop002-HFI-COD	Operator drops canister during CTM operations	6	4	5.00E-07	10	Detailed
200-OpCTMImpact1-HFI-COD	Operator moves the CTM while canister or object is below or between levels	6	4	4.00E-08	10	Detailed
200-OpCTMImpact2-HFI-COD	Operator causes canister impact with lid during CTM operations (TAD canister)	6	4	N/A[b]	N/A	Omitted from analysis
200-OpCTMImpact5-HFI-COD	Operator causes canister impact with SSC during CTM operations	6	4	1.0	N/A	Preliminary
200-OpCTTImpact1-HFI-NOD	Operator causes an impact between cask and SSC due to crane operations	3	3	3.00E-03	5	Preliminary
200-OpDirExpose1-HFI-NOD	Operator causes direct exposure during CTM activities (first floor)	11	4	1.00E-01	3	Preliminary
200-OpDirExpose2-HFI-NOD	Operator causes direct exposure during CTM activities (transfer into an AO)	11	4	1.00E-04	10	Preliminary
200-OpDPCShield1-HFI-NOW	Operator causes loss of shielding while installing DPC lift fixture	10	3	4.00E-04	10	Detailed
200-OpFailRstInt-HFI-NOM	Operator fails to restore interlock after maintenance	11	4	1.00E-02	3	Preliminary
200-OpFailSG-HFI-NOD	Operator fails to close the CTM slide gate moving CTM with canister inside bell (direct exposure)	11	4	1.00E-03	5	Preliminary

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

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
200-OpFailStop-HFI-NOD	Operator fails to stop ST if tread fails	8	5	1.0	N/A	Preliminary
200-OpFLCollide1-HFI-NOD	Operator causes high speed collision of auxiliary vehicle with RC, HTC, ST, CTT or TTC	2, 3, 7, 9	2, 6, 3, 5	1.0	N/A	Preliminary
200-OpHTCollide1-HFI-NOD	Operator causes low speed collision between HCTT and facility SSCs	9	6	3.00E-03	5	Preliminary
200-OpHTIntCol01-HFI-NOD	Operator causes high speed collision between HCTT and facility SSCs	9	6	1.0	N/A	Preliminary
200-OpImpact0000-HFI-NOD	Operator causes impact of cask during transfer of CTT into the Cask Unloading Room or ST out of Loading Room	4, 7	3, 5	N/A[b]	N/A	Omitted from analysis
200-OpLoadDrop-HFI-NOD	Operator causes ST to drop AO	8	5	N/A	N/A	Preliminary
200-OpNoDiscoAir-HFI-NOD	Operator causes spurious movement of the CTT while canister is being unloaded	6	4	1.00E-03	5	Preliminary
200-OpNoUnBolt00-HFI-NOD	Operator fails to fully unbolt the cask lid before moving CTT into the Cask Unloading Room (TAD canister)	6	4	1.00E-03	5	Preliminary
200-OpNoUnBoltDP-HFI-NOD	Operator fails to fully unbolt the cask lid before moving CTT into the Cask Unloading Room (DPC)	6	4	N/A[b]	N/A	Omitted from Analysis
200-OpNoUnplugST-HFI-NOD	Operator causes spurious movement of the ST while canister is being loaded	6	4	1.00E-03	5	Preliminary
200-OpRCCollide1-HFI-NOD	Operator causes low-speed collision between RC and facility SSCs	1	1	3.00E-03	5	Preliminary

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

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
200-OpRCIntCol01-HFI-NOD	Operator causes high-speed collision between RC and facility SSCs	1	1	1.0	N/A	Preliminary
200-OpRCIntCol02-HFI-NOD	Operator causes MAP to collide into RC	1	1	1.0	N/A	Preliminary
200-OpSDClose001-HFI-NOD	Operator closes shield door on conveyance	5	OA (1, 3, 5, 6)	1.0	N/A	Preliminary
200-OpSpurMove01-HFI-NOD	Operator causes spurious movement of CTT or ST during preparation or closure	2, 3, 7	2, 3, 5, 6	1.00E-04	10	Preliminary
200-OpSTCollide1-HFI-NOD	Operator causes low-speed collision of ST with SSC while moving to the Lid Bolting Room	7	5	3.00E-03	5	Preliminary
200-OpSTCollide2-HFI-NOD	Operator causes low-speed collision of ST with SSC while exporting the ST	8	5	3.00E-03	5	Preliminary
200-OpTCImpact01-HFI-NOD	Operator causes an impact between cask and SSC during upending and removal	2	2, 6	3.00E-03	5	Preliminary
200-OpTipover001-HFI-NOD	Operator causes cask to tip over during cask upending and removal	2	2, 6	1.00E-04	10	Preliminary
200-OpTipover002-HFI-NOD	Operator causes cask to tip over during cask preparation activities	3	3	1.00E-04	10	Preliminary
200-OpTipOver003-HFI-NOD	Operator causes tipover of ST	7	5	1.00E-04	10	Preliminary
200-OpTipOver3-HFI-NOD	Operator causes tipover of CTT during movement to the Cask Unloading Room	4	3	N/A[b]	N/A	Omitted from analysis
200-VCTO-DR00001-HFI-NOD	Operators open two or more vestibule doors in RF	HVAC	OA	1.00E-02	3	Preliminary
200-VCTO-HEPALK-HFI-NOD	Operator fails to notice HEPA filter leak in train A	HVAC	OA	1.0	N/A	Preliminary

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

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
200-VCTO-HFIA000-HFI-NOM	Human error exhaust fan switch wrong position	HVAC	OA	1.00E-01	3	Preliminary
Crane Drops (drop of cask or object onto cask)	Operator drops cask or drops object onto cask during crane operations	2, 3	OA (2, 3, 6)	N/A[a]	N/A	Historical data
Drop of object on AO	Operator drops heavy object on AO during AO closure	N/A	5	N/A[b]	N/A	Omitted from analysis
Gas Sampling	Operator improperly performs gas sampling	N/A	3	N/A[b]	N/A	Omitted from analysis
Load too Heavy	Operator causes drop of cask by attempting to lift a load that is too heavy for the crane	OA	OA (2, 3, 6)	N/A[b]	N/A	Omitted from analysis
Moderator	Operator introduces moderator into a moderator-controlled area of the RF	OA	OA	N/A[b]	N/A	Omitted from analysis
RC Derailment	Operator causes the RC to derail	1	1	N/A[a]	N/A	Historical data
Spurious Movement of CTT or ST during CTM Activities	Operator causes spurious movement of the CTT or ST during canister loading or unloading	6	4	N/A[b]	N/A	Omitted from analysis
ST Rollover	Operator causes rollover of ST during AO export	8	5	N/A[b]	N/A	Omitted from analysis
200-HCTT-Roll	Operator causes rollover of HCTT	9	6	N/A[b]	N/A	Omitted from analysis

NOTE: [a] Historical data was used to produce a probability of crane drops; this historical data is not included as part of the HRA, but is addressed in Attachment C, Section C1.3.

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

AO = aging overpack; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; ESD = event sequence diagram; HCTT = cask tractor and cask transfer trailer; HFE = human failure event; HTC = a transportation cask that is never upended; HVAC = heating, ventilation, and air conditioning; MAP = mobile access platform; N/A = not applicable; OA = over arching (applies to multiple HFE groups, see Section E6.0.2); RC = railcar; SSC = structure, system, or component; SSCs = structures, systems, and components; ST = site transporter; TAD = transportation, aging, and disposal; TTC = a transportation cask that is upended using a tilt frame.

Source: Original

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6.5 FIRE INITIATING EVENTS

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

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

6.5.1 Input to Initiating Events

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

Room dimensions (Section F5.2.1 and F5.4 of Attachment F) are utilized to determine individual room areas and the total building area. The area of the RF is utilized to evaluate the building ignition frequency. From methodology and equations presented in Section F4.3.1 of Attachment F, the building ignition frequency over the 50-year facility operation period of 2.6 is obtained for the RF. The results of this portion of the analysis are summarized in Table 6.5-1.

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

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

Table 6.5-1. Room Areas and Total Ignition Frequency

Room	Area (m^2)	Room	Area (m^2)	Room	Area (m^2)	Room	Area (m^2)
1001	167	1020	237	1207	68	2002D	87
1002	368	1020A	22	1208	51	2002E	182
1003A	40	1021	191	1209	54	2002F	60
1003B	76	1021A	349	1210	57	2002G	17
1003C	53	1021B	12	1211	35	2003	334
1003D	140	1022	51	1212	39	2004	259
1003E	133	1023	54	1212A	7	2005	333
1003F	67	1025	56	1213	13	2006	296
1003G	45	1026	40	1214	13	2007	1,444
1004	261	1027	30	1215	30	2008	267
1004A	99	1028	75	1216	16	2009	308
1005	235	1028A	51	1217	38	2010	334
1005A	20	1029	42	1218	21	2011	259
1011	98	1030	30	1219	21	2012	333
1012	296	1031	32	1220	32	2022	54
1013	175	1200	8	1221	48	2023	54
1014	141	1201A	47	1222	4	2025	55
1015	156	1201B	100	1223	34	2026	40
1016	126	1202	21	1224	73	2027	38
1017/1017A	1,993	1203	46	2001	167	2029	42
1018	256	1204	35	2002A	69	3001	24
1018A	51	1205	8	2002B	132	3026	40
1019	265	1206	36	2002C	17	3029	42
1019A	70	—	—	—	—	—	—
Total Area (m^2)					12,842	—	—
Ignition Frequency (per m^2/yr)					4.05E-06	—	—
Ignition Frequency (per yr)					5.20E-02	—	—
Ignition Frequency (50 years - preclosure period)					2.60E+00	—	—

Source: Attachment F, Table F5.2-1

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

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

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

The distribution and determination of ignition sources is further discussed in Section F5.4 of Attachment F, and summarized in Table 6.5-2. For the purposes of the summary, the "no equipment involved" category and the "heat-generating process equipment" category have been left out of Table 6.5-2. This was done because the values in the "no equipment involved" category are exactly equal to the square meters for each room (Table 6.5-1) and because there is no equipment for any of the facilities that falls under the "heat-generating process equipment" category (Section F5.4.4, Attachment F).

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

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

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

Room	Electrical	HVAC	Mechanical Equipment	Torches, welders, burners	Internal combustion engines	Office/ kitchen equipment	Portable Equipment
1001	—	—	—	—	7	—	—
1002	—	—	3	—	59	—	—
1004	—	4	—	5	—	—	4
1004A	—	4	—	—	—	—	2
1005	23	2	—	—	—	—	—
1005A	1	—	—	—	—	—	—
1012	—	—	—	5	—	—	—
1013	—	—	2	—	34	—	—
1014	—	—	4	5	—	—	—
1015	—	—	2.03	—	—	—	1
1017/1017A	—	—	8.97	400	35	—	4
1018	80	—	—	5	—	—	2
1018A	2	—	—	—	—	—	—
1019	—	4	—	—	—	—	4
1019A	—	4	—	—	—	—	2
1020	23	2	—	—	—	—	2
1020A	1	—	—	—	—	—	—
1021	—	—	1	—	33	—	—
1021A	—	2	2	—	32	—	—
1028	—	—	1	—	—	—	—
1207	—	—	—	—	—	1	—
1208	6	—	—	—	—	1	—
1209	—	—	—	—	—	2	—
1210	—	—	—	—	—	2	—
1212	—	—	—	—	—	1	—
1218	—	—	—	—	—	1	—
1219	—	—	—	—	—	1	—
1220	—	—	—	—	—	1	—
1223	—	—	1	—	—	—	—
2003	—	2	—	5	—	—	2
2004	—	1	—	—	—	—	2
2005	—	—	—	5	—	—	—
2006	—	6	—	—	—	—	2
2007	—	—	7	—	—	—	1
2008	—	2	—	—	—	—	2
2009	—	1	—	—	—	—	2
2010	—	2	—	5	—	—	2
2011	—	—	—	—	—	—	2
2012	21	—	—	5	—	—	—
TOTAL	**157**	**36**	**32**	**440**	**200**	**10**	**36**

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

Source: Attachment F, Table F5.5-1

Table 6.5-3. Residence Fractions

Initiating Event	**Residence Fraction**
Waste Form in AO in Vestibule/Lid Bolting Room (Diesel)	
TAD or DPC in AO (incl. TTC & VTC) in Vestibule/Lid Bolting Room (diesel present)	1.2E-05
Waste Form in AO in Loading Room (diesel)	
TAD or TC/DPC in AO (incl. TTC & VTC) in Loading Room (diesel present)	3.3E-06
Waste Form in Vestibule/Preparation Area (Diesel)	
TC/TAD on railcar in Vestibule/Preparation Area w/ SPM (diesel present)	2.1E-06
TC/DPC (TTC) on railcar in Vestibule/Preparation Area w/ SPM (diesel present)	2.1E-06
TC/DPC (VTC) in Vestibule/Preparation Area w/ SPM (diesel present)	2.1E-06
TC/DPC (HTC) in Vestibule/Preparation Area w/ SPM/truck (diesel present)	4.3E-06
Waste Form in Preparation Area (No Diesel)	
TC/TAD on railcar in Preparation Area (no diesel present)	1.6E-05
TC/DPC on railcar (TTC) in Preparation Area (no diesel present)	2.4E-05
TC/DPC on railcar (VTC) in Preparation Area (no diesel present)	1.3E-05
TC/DPC (HTC) on railcar in Preparation Area (no diesel present)	2.7E-05
Waste Form in Preparation Area	
TC/TAD on CTT in Preparation Area	6.4E-06
TC/DPC on CTT (VTC, incl. TTC) in Preparation Area	1.5E-05
Waste Form in Cask Unloading Room	
TC/TAD on CTT in Cask Unloading Room	3.5E-06
TC/DPC (TTC) on CTT in Cask Unloading Room	1.8E-06
TC/DPC (VTC) in Cask Unloading Room	1.8E-06
Waste Form in Transfer Room	
TAD or DPC (including TTC & VTC) in Transfer Room	1.2E-06
TC/TAD or TC/DPC (TTC & VTC) (diesel present)	2.1E-06
TC/TAD (No Diesel)	2.6E-05
TAD or DPC (TTC & VTC) in CTM	1.2E-06
TAD or DPC (TTC & VTC) in AO (diesel present)	1.5E-05
TC/DPC (TTC) in CTM (no diesel)	4.0E-05
TC/DPC (VTC) (no diesel)	3.0E-05
TC/DPC (HTC) (diesel present)	4.3E-06
TC/DPC (HTC) (no diesel)	2.7E-05

NOTE: AO = aging overpack; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; HTC = a transportation cask that is never upended; SPM = site prime mover; TAD = transportation, aging, and disposal canister; TC = transportation cask; TTC = a transportation cask that is upended using a tilt frame; VTC = a transportation cask that is upended on a railcar; WP = waste package.

Source: Attachment F, Tables F5.7-1, F5.7-2, F5.7-3, and F5.7-6

6.5.2 Initiating Event Frequencies

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

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

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

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

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

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

Initiating Event	Equipment	Mean	Median	97.5% Value	Error Factor	Type
Localized Fire Threatens Waste Form in AO in Vestibule/Lid Bolting Room (diesel present)	Site transporter	—	—	—	—	—
Localized Fire Threatens TAD or DPC (incl. TTC & VTC) in AO in Vestibule/Lid Bolting Room (diesel present)		8.1E-07	7.3E-07	1.80E-6	2.1	Lognormal
Localized Fire Threatens Waste Form in AO in Loading Room (diesel present)		—	—	—	—	—
Localized Fire Threatens TAD or DPC (incl. TTC & VTC) in AO in Loading Room (diesel present)		3.5E-07	3.2E-07	7.9E-07	2.0	Lognormal
Localized Fire Threatens Waste Form in Vestibule/Preparation Area (diesel present)	Site prime mover	—	—	—	—	—
Localized Fire Threatens TC/TAD in Vestibule/Preparation Area (diesel present)		4.6E-07	4.2E-07	1.0E-06	2.0	Lognormal
Localized Fire Threatens TC/DPC (TTC) in Vestibule/Preparation Area (diesel present)		4.6E-07	4.2E-07	1.0E-06	2.0	Lognormal
Localized Fire Threatens TC/DPC (VTC) in Vestibule/Preparation Area (diesel present)		4.6E-07	4.2E-07	1.0E-06	2.0	Lognormal
Localized Fire Threatens TC/DPC (HTC) in Vestibule/Preparation Area (diesel present)		9.3E-07	8.3E-07	2.1E-06	2.2	Lognormal
Localized Fire Threatens Waste Form in Preparation Area	Railcar	—	—	—	—	—
Localized Fire Threatens TC/TAD in Preparation Area (no diesel present)		3.1E-06	2.8E-06	6.9E-06	2.1	Lognormal
Localized Fire Threatens TC/DPC (TTC) in Preparation Area (no diesel present)		4.5E-06	4.0E-06	1.0E-05	2.2	Lognormal
Localized Fire Threatens TC/DPC (VTC) in Preparation Area (no diesel present)		2.5E-06	2.2E-06	5.5E-06	2.3	Lognormal
Localized Fire Threatens TC/DPC (HTC) in Preparation Area (no diesel present)		5.0E-06	4.5E-06	1.1E-05	2.1	Lognormal

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

Initiating Event	Equipment	Mean	Median	97.5% Value	Error Factor	Type
Localized Fire Threatens Waste Form in Preparation Area	Cask transfer trolley	—	—	—	—	—
Localized Fire Threatens TC/TAD in Preparation Area		9.1E-07	8.1E-07	2.1E-06	2.2	Lognormal
Localized Fire Threatens TC/DPC (VTC, including TTC) in Preparation Area		2.1E-06	1.9E-06	4.8E-06	2.1	Lognormal
Localized Fire Threatens Waste Form in Cask Unloading Room		—	—	—	—	—
Localized Fire Threatens TC/TAD in Cask Unloading Room		3.9E-07	3.5E-07	8.7E-07	2.1	Lognormal
Localized Fire Threatens TC/DPC (TTC) in Cask Unloading Room		2.0E-07	1.8E-07	4.4E-07	2.1	Lognormal
Localized Fire Threatens TC/DPC (VTC) in Cask Unloading Room		2.0E-07	1.8E-07	4.4E-07	2.1	Lognormal
Localized Fire Threatens Waste Form in Transfer Room	Canister transfer machine	—	—	—	—	—
Localized Fire Threatens TAD or DPC (including TTC & VTC) in Transfer Room		1.1E-07	9.9E-08	2.5E-07	2.1	Lognormal
Large Fire Threatens TC/TAD or TC/DPC (TTC & VTC) (diesel present)		8.6E-07	7.6E-07	2.0E-06	2.3	Lognormal
Large Fire Threatens TC/TAD (no diesel)		1.1E-05	9.5E-06	2.5E-05	2.4	Lognormal
Large Fire Threatens TAD or DPC (TTC & VTC) in CTM		4.9E-07	4.4E-07	1.1E-06	2.1	Lognormal
Large Fire Threatens TAD or DPC (TTC & VTC) in AO (diesel present)		6.1E-06	5.5E-06	1.4E-05	2.1	Lognormal
Large Fire Threatens TC/DPC (TTC) (no diesel)		1.6E-05	1.5E-05	3.8E-05	1.8	Lognormal
Large Fire Threatens TC/DPC (VTC) (no diesel)		1.2E-05	1.1E-05	2.9E-05	2.0	Lognormal
Large Fire Threatens TC/DPC (HTC) (diesel present)		1.8E-06	1.6E-06	4.1E-06	2.2	Lognormal
Large Fire Threatens TC/DPC (HTC) (no diesel)		1.1E-05	9.8E-06	2.6E-05	2.2	Lognormal

NOTE: AO = aging overpack; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; EF = error factor; HTC = a transportation cask that is never upended; TAD = transportation, aging, and disposal canister; TC = transportation cask; TTC = a transportation cask that is upended using a tilt frame; VTC = a transportation cask that is upended on a railcar.

Source: Attachment F, Table F5.7-7