generator supplies power to one division (A or B) of ITS systems. Each ITS diesel generator, its associate support systems, and the power distribution system are independent and electrically isolated from the other ITS diesel generator, its support systems and power distribution system.

The ITS loads within the WHF are powered via two ITS 480 V load centers and two ITS motor control centers (MCC) located within separate areas in the WHF. Each division of the AC power supply from the 13.8 kV ITS switchgears to the WHF passes through a 13.8 kV to 480 V transformer.

The ITS on site power portion of the ITS power supply system is intended to provide back-up power to selected buildings and operations in the event of a main transmission loss of power (i.e., LOSP). The primary components in each division include: a diesel generator, support systems for the diesel generator, and a load sequencer. Both ITS diesel generators are located in the Emergency Diesel Generator Facility (EDGF). Each is sized to provide sufficient 13.8 kV power to support all ITS loads in one division in six facilities (i.e., three CRCFs, the WHF, the RF, and the EDGF).

The ITS diesel generator starts upon detection of an undervoltage condition via an undervoltage relay of the diesel generator switchgear. Each ITS diesel generator is equipped with a complete independent set of support systems including HVAC systems, uninterruptible and DC power systems, a fuel oil system, diesel generator start subsystem, diesel generator cooling subsystem and lube oil subsystem.

The load sequencer controls sequence of events that occur after a LOSP and the ITS diesel generator starts. Upon a LOSP, the load sequencer opens the WHF ITS load center feed breaker. After the ITS diesel generator starts and reaches rated capacity, the load sequence connects the ITS diesel generator to the 13.8 kV ITS switchgear and then reconnects the WHF loads.

6.2.2.8.2 Operations

Under normal operating conditions, AC power is supplied from two 138 kV offsite power lines. Power is passed through the 138 kV to 13.8 kV switchyard to the two independent 13.8 kV ITS switchgear. From here, power is transmitted via separate lines to a 13.8 kV to 480 V transformers supporting divisions A and B of the WHF. Power to individual ITS components within each facility is provided via two ITS 480 V load centers and two ITS 480 V MCCs (one of each for division A and one of each for division B in each facility) powered through these transformers.

During a LOSP, both ITS diesel generators are required to start and accept loads in a timely manner. Upon a LOSP, the onsite power distribution system supporting ITS loads is disconnected from the switchyard; a circuit breaker between the 13.8 kV ITS switchgear and the switchyard 13.8 kV switchgear in each division automatically open. Both diesel generators start automatically and are connected to the 13.8 kV ITS switchgear when the connecting breaker is closed by the load sequencer. The load sequencer then reconnects the WHF loads to the 13.8 kV ITS switchgear. Both ITS diesel generators continue to supply AC power until normal power is restored.

Environmental systems are provided to maintain the temperature in the various EDGF rooms and WHF ITS electrical rooms within acceptable levels.

6.2.2.8.3 Control System

The ITS diesel generator starts upon detection of an undervoltage condition via an undervoltage relay of the 13.8 kV ITS switchgear. The 13.8 kV ITS switchgears are isolated from the main switchyard upon a loss of power in the switchyard. The loads in the WHF are shed upon a loss of power indication.

A load sequencer controls the loading of the ITS diesel generator onto the 13.8 kV ITS switchgear upon the ITS diesel generator reaching rated output. The same load sequencer controls reloading the WHF loads onto the AC power system.

6.2.2.8.4 System/Pivotal Event Success Criteria

Success criterion for the AC power system is defined in terms of its support function for the ITS HVAC confinement function. The AC power system must operate in support of the HVAC system for as long as necessary to successfully provide confinement after the potential release of radioactive material inside the WHF. There are two independent trains of HVAC and each of these must be supported by an independent AC power system. Therefore, the following success criteria apply to the respective AC power supply trains:

- Provide AC power from either the normal offsite power lines or from the ITS diesel generator (DG A) to the HVAC division powered through WHF ITS Load Center A and ITS MCC A1 for the mission time of 720 hours.

- Provide AC power from either the normal offsite power lines or from the ITS diesel generator (DG B) to the HVAC division powered through WHF ITS Load Center A and ITS MCC B1 for the mission time of 720 hours.

The respective trains of the ITS portions of the AC power system are essentially identical. Various design features are provided to achieve each of the success criteria for the respective trains.

The FTA for the AC power system includes separate analyses for the respective trains. The failure to achieve the success criterion defines the top event for the fault tree for each train of the AC power system.

6.2.2.8.5 Mission Time

The mission time for the ITS AC power system is the same as for the HVAC system, 720 hours for a canister breach event and radionuclide release (Attachment B, Section B8.2.5.1.1). For a sample line break during cask cooling, a mission of time for the ITS power system is the same as the HVAC system which is 24 hours.

6.2.2.8.6 Fault Tree Results

Two fault trees are developed for the AC power system, one for train A and one for train B. The respective top events are:

- "Loss of AC power at ITS Load Center A for the WHF," defined as a failure of the normal and ITS onsite power supplies to provide power to ITS Load Center A.

- "Loss of AC power at ITS Load Center B for the WHF," defined as a failure of the normal and ITS onsite power supplies to provide power to ITS Load Center B.

The results are the same (see Attachment B, Figures B8.4-1 and B8.4-3) for the trains:

For a mission time of 720 hours:

- The mean probability of failure is 3.2E-2
- The standard deviation is 7.8E-02.

For a mission time of 24 hours:

- The mean failure probability of failure is 1.3E-3
- The standard deviation is 6.3E-3 (Reference Attachment H).

6.2.2.9 Horizontal Cask Tractor and Trailer Fault Tree Analysis

The FTA for the horizontal cask tractor and trailer (HCTT) is detailed in Attachment B, Section B9. The following is a summary of the design, operations, success criteria, and results of the fault tree quantification. See Attachment B, Section B9 for sources of information on the physical and operational characteristics of the HCTT.

The tractor is a large, four-wheel drive, diesel tractor designed specifically for pulling the transfer trailer. The tractor has redundant brakes in addition to having a fail-safe emergency brake. The tractor has independently mounted non-driven hydraulic pendular axles with a minimum of four tires per axles that will ensure the cask remains level during transportation across uneven terrain. In addition to the pendular axles, the trailer has three other hydraulic systems: (1) stabilizing jacks, (2) cask support skid and positioning system, and (3) hydraulic ram.

6.2.2.9.1 Operation

After receipt in the Transportation Cask Vestibule, the entrance door from the Transportation Cask Vestibule to the Cask Preparation Area is opened to allow the HCTT to move to the receipt area within the Cask Preparation Area. There, the HCTT carrying the cask/waste form is moved into a position where the cask can be removed. The HCTT is then secured in place as required by procedures. The HCTT tractor is detached from the HCTT trailer and moved out of the Cask Preparation Area. The entrance door is closed and the vestibule door is opened to allow departure of the HCTT tractor.

Only activities associated with the HCTT while in the WHF are addressed in this document.

6.2.2.9.2 Control System

Once the HCTT is properly positioned in the WHF, the brakes on both the tractor and trailer are engaged. The brakes are spring applied with hydraulic release calipers. There is a backup system on the tractor consisting of a split master cylinder.

Stabilizing jacks provide vertical support during the loading and unloading of the cask on the HCTT.

6.2.2.9.3 System/Pivotal Event Success Criteria

The success criterion for the HCTT is the prevention of a collision with other vehicles, facility structures, or equipment.

Various design features are provided to achieve each of the success criteria. These include redundant braking systems in the tractor and parking brakes that fail safe. The failure to achieve each success criterion defines the top event for a fault tree for the HCTT.

6.2.2.9.4 Mission Times

A conservative mission time of one hour is used to account for the time it takes the HCTT loaded with a transportation cask to move through the Transportation Cask Vestibule doors to the Cask Preparation Area inside the WHF.

6.2.2.9.5 Fault Tree Results

The HCTT FTA is detailed in Attachment B, Section B9.

There is one fault tree associated with the HCTT that represent a potential initiating event:

> HCTT collision with other vehicles, WHF facility structures or equipment when loaded with a transportation cask.

The results of the analysis are summarized in Table 6.2-7.

Table 6.2-7. Summary of Top Event Quantification for the HCTT

Top Event	Mean Probability	Standard Deviation
HCTT Collision	4.6E-3	2.4E-2

NOTE: HCTT = horizontal cask tractor and trailer.

Source: Attachment B, Section B9, Figure B9.4-1

6.2.2.10 Potential Moderator Sources

6.2.2.10.1 Internal Floods

Internal floods are potential sources of moderator addition into a canister associated with pivotal events in the event sequences included in Section 6.1. Moderator addition into a canister can occur following a breach of the canister and a subsequent internal flood. The internal flooding analysis considers all waste handling facilities.

During most of its handling at the repository, a canister is surrounded by at least one other barrier to water intrusion: a transportation cask, a transportation cask within a CTT, an aging overpack, a waste package, a waste package within a WPTT, or a waste package within a TEV.

Each facility is equipped with a normally dry, double-preaction sprinkler system in areas where waste forms are handled ((Ref. 2.2.15), (Ref. 2.2.30), (Ref. 2.2.24), and (Ref. 2.2.38)). Such systems, which require both actuation of smoke and flame detectors to allow the preaction valve to open and heat actuation of a fusible link sprinkler head to initiate suppression, have a very low frequency of spurious operation. A 30-day period from the occurrence of the canister breach to the time definitive action can be taken to prevent introduction of water into the canister is reasonable and is the same as the period used to assess dose for a radiological release. The spurious actuation frequency over a 30 day mission time after a breach is calculated below.

An estimate of the probability of spurious actuation was developed using a simplified screening model that addressed the following cut sets that result in actuation:

- Spurious preaction valve opens before canister breach × failure of a sprinkler head during post-breach mission time (30 days)

- Failure of a sprinkler head during building evacuation × water left in dry piping after last test (first quarter following annual test).

The frequency of sprinkler failure is estimated using an individual sprinkler head failure frequency of 1.6E-6/yr (Ref. 2.2.12, Table 1), the estimated number of sprinklers (1 per 130 ft^2 based on NFPA 13 (Ref. 2.2.62, Table 8.6.2.2.1(b))) and the applicable area (Ref. 2.2.21, Table 10). At 130 ft^2 per sprinkler, 58 sprinklers are estimated. The failure of any sprinkler in the room is then estimated to be 58 × 1.6E-6/yr × 1/8760 hrs/yr, or 1.1E-8/hr.

The frequency of preaction valve spurious open is estimated using the solenoid valve spurious open data in Section 6.3 of 8.1E-07/hr. This is reasonable because a solenoid valve must open to relieve the air pressure from the diaphragm which keeps the valve closed.

The value of the first cut set is (1.6E-6/yr × 1/8760 hrs/yr × 720 hrs) × (8.1E-7/hr × 720 hrs) = 8E-11/sprinkler head. The second cut set is more significant: 0.025 (human error screening value) × (1.6E-6/yr × 1/8760 hrs/yr × 720 hrs) = 3E-9/sprinkler head.

Applying the sum of these values, 3E-9 per sprinkler head, to the number of sprinklers calculated for the waste handling areas of the four facilities results in the following estimates of the probability of spurious sprinkler actuation found in Table 6.2-8.

Table 6.2-8. Probability of Spurious Sprinkler Actuation

Facility	Waste Handling Area (ft^2) [a]	Number of Sprinkler Heads	Probability of Spurious Actuation in 30 Day Period in Waste Handling Areas
CRCF(ea)	42,000	330	1E-6
IHF	30,000	240	9E-7
RF	19,000	150	5E-7
WHF	28,000	215	6E-7

NOTE: [a]CRCF area based on room numbers 1005E, 1016-1026, 2004,2007, 2007A, and 2007B; IHF area based on room numbers 1001-1003, 1006-1008, 1011,1012, 1026, and 2004; RF area based on room numbers 1013, 1015, 1016, 1017, 1017A, and 2007; WHF area based on room numbers 1007-1010, 1016, 2004, 2006, and 2008. CRCF = Canister Receipt and Closure Facility; IHF = Initial Handling Facility; RF = Receipt Facility; WHF = Wet Handling Facility.

Source: Original

Piping carrying water is present in the waste form handling areas of the CRCF, IHF and WHF. Piping lengths in these areas of the CRCF and WHF are below 100 feet per facility (Ref. 2.2.86). The probability of a pipe crack in a 30 day period is estimated using the pipe leak data from NUREG/CR-6928 (Ref. 2.2.46, Table 5-1). Piping leaks and large break rates applicable to non-service water applications are used in the analysis. These values are considered appropriate for repository systems because the conditioning applied to the fluids in the systems is typical of commercial nuclear power plants:

External leak small (1 to 50 gpm): leak rate = 2.5E-10 $hr^{-1}ft^{-1}$

External leak large (> 50 gpm): leak rate = 2.5E-11 $hr^{-1}ft^{-1}$

Multiplying the sum of the small and large leak frequencies (2.8E-10 $hr^{-1}ft^{-1}$) by the length of piping in the waste handling areas of each facility, and the number of hours in a 30 day period (720 hr), a conditional probability of water leakage in all waste handling areas given a breach is approximated as follows:

CRCF = 2.8E-10 $hr^{-1}ft^{-1}$ × 100 ft × 720 hrs = 2.0E-05

IHF = < 2.8E-10 $hr^{-1}ft^{-1}$ × 6800 ft × 720 hrs = 1.4E-03

RF = 2.8E-10 $hr^{-1}ft^{-1}$ × 0 ft × 720 h = 0

WHF = 2.8E-10 $hr^{-1}ft^{-1}$ × 75 ft × 720 hrs = 1.5E-05.

It is appropriate to use the waste handling area piping lengths because they are separated by concrete walls from the non-waste handling areas of buildings.

The above applies to event sequences that do not involve fires as an initiating event. During fire initiating event sequences, fire suppression would actuate in the locations sufficiently heated by the fire. The fire initiating event analysis is described in Section 6.5, and the conditional probability of canister failure owing to fires is described in Section 6.3. The analysis is performed without the salutary effects of fire suppression in order to demonstrate large margins of safety during fire event sequences. Furthermore, the location of each fire is analyzed as around the outer shell of the overpack that surrounds the canister. The frequency of containment breach due to fire is significantly overestimated because of this conservative approach.

For fires that occur in locations that contain canisters sealed within bolted transportation casks, the fire location is floor level and the transportation casks rise as much as 20 ft above the floor. Casks are relatively thick walled compared to canisters and sustain a relatively small internal pressurization when compared to canisters. Therefore, if a fire is large enough, it will fail the internal canister first, as indicated in Attachment D. This will cause the bolted and sealed cask to bear the overpressure that is inside the canister. The cask bolts might act as elastic springs allowing the top to break the seal and relieve the internal pressure. This would be a mechanism that prevents cask breach. However, a hot fire may result in sufficient loss of strength of the bottom portion of the stainless steel cask such that it breaches. If failure occurs because of bolt stretching the cask lid remains on top of the cask preventing fire suppression water from entering. Commercial DPCs and TAD canisters will require at least 100 L of water to enter the canister if optimally distributed among the fuel rods (Ref. 2.2.35, Section 2.3.10.1). Casks are raised above the floor. They lay on top of railcars, are lifted from there by cranes, sit inside a CTT, or lay sideways on a pallet. They are at least 5 ft from the floor. If the bottom portion of the canister breaches, there is no physical mechanism for this much water to enter the cask and then the canister, remain as water (not boil off), and optimally mix with the fuel rods.

This latter situation also applies to canisters sealed within a welded waste package. The waste package sits inside a WPTT or is inside a TEV. In the former case it is more than three feet from the floor (Ref. 2.2.16) and in the latter case, about one foot from the floor (Ref. 2.2.17). In the latter case, however, the TEV offers an additional layer of protection against fires. In addition, it is physically unrealistic for a sufficient amount of available fire suppression water to cause 100 L to leak into a breached canister, but not extinguish the fire or at least reduce the severity of the fire such that a breach would not occur.

For a canister inside of an open transportation cask or waste package, the orientation of these is always vertical, and the cask and waste package are always elevated above the floor where the fire occurs. The occurrence of a fire of sufficient severity will fail the canister first as described above. An open transportation cask or waste package might allow fire suppression water to spray in from the top. The building configuration, however, precludes this occurrence. The cask lids are removed while in the upload cell below the CTM. The cask and waste package ports are above the casks and waste package. There is no fire suppression piping spanning the ports because the ports must be kept clear in order to perform lift and load operations. In the Cask Preparation Area and welding area, the lid is on the waste package and fire suppression piping can not be above an open waste package because of the welding machine. In the DPC cutting cell in which a cask is open (WHF only), there can be no fire suppression piping above an open cask because of the cutting equipment.

Upon failure of the canister inside the cask, the cask will not be susceptible to pressurization failures as above. Instead, water can only enter a cask (or waste package) if the cask body melts through. Fires capable of melting stainless steel or Alloy 22, however, have an occurrence frequency within the waste handling facilities of less than 1E-05 over the preclosure period (Attachment D). Thus, breach of the cask or waste package in a manner that would allow water to enter the canister is essentially not physically realizable.

When a canister is being lifted, transferred inside the shield bell, and lowered. It is not inside an outer cask. However, fires can not be severe enough to breach a canister while being moved, as described in more detail in Attachment D. Water intrusion, therefore, is not physically realizable for this situation.

It is concluded that moderator entry into breached canisters during fire event sequences is not physically realizable because of a combination of physical mechanisms, building and equipment configuration, and overpack material properties. Furthermore, the existence of water from fire suppression is inconsistent with the fire analyses performed to obtain the probability of containment failure owing to fire. If fire suppression were indeed available, the probabilities of canister breach would be far lower. However, in order to complete an event sequence quantification, the conditional probability of moderator entry into a canister after canister breach during a fire initiating event sequence is assessed as *extremely unlikely* and assigned a lognormal distribution with a median of 0.001 and an error factor of 10. This yields a mean value of 3E-03. The large error factor is assigned because of the potential of human error to defeat some of the reasons that water will not enter the cask or waste package (e.g., neglecting to place a lid on the waste package just before a severe fire). These assignments are consistent with the methodology on the use of judgment provided in Section 4.3.10.

For fires that occur in locations that contain uncanistered spent nuclear fuel sealed within bolted transportation casks, the fire location is floor level and the transportation casks rise as much as 20 ft above the floor. Again, the analysis is performed without the salutary effects of fire suppression in order to demonstrate large margins of safety during fire event sequences. Should fire suppression be available, then cask failure would not occur (i.e., it would be orders of magnitude lower in probability). Therefore, if fire suppression water or a flood has occurred before or during the fire, there would be no breach of containment for entry into the cask. (Note that cask seal failure takes approximately one hour during a severe fire to occur. Therefore, the breach analysis that ignores fire suppression is quite conservative.) The cask failure mode is from over-pressurization and degradation of the seals between the lid and the shell, therefore, the area of the seal provides a small target for fire suppression entry. If fire suppression actuates, the fire brigade arrives, or other unborated water becomes available after the cask has failed, then as long the cask is internally pressurized, water can not enter. Because of the heat source provided by the SNF (in addition to heat generated by the fire), there will always be a higher pressure on the inside of the cask than the atmosphere on the outside of the cask. As noted above, casks are raised above the floor and water sources other than fire suppression are incapable of reaching the elevation for entry into the cask.

6.2.2.10.2 Lubricating Fluid

Another source of moderation is lubricating fluid in cranes. Crane lube oil is of limited quantity (<150 gal) and housed in a welded gear box with a leak pan below it capable of capturing the entire gearbox fluid inventory. The facility operating life of the surface facilities is 50 years. An estimate of the leakage rate through the gear box and drip pan during the 50 year period is found by multiplying the gearcase motor failure frequency (all modes) of 0.88E-06 per hour (Ref. 2.2.42, Page 2-104 and Section 6.3) by 50 years times the conditional probability of oil pan failure. A loss of lubrication would fail the crane operation and also be detected by oil pressure indicators. The conditional probability of oil pan failure may be estimated by an analogy to receiver tank leakage during the interval between gearbox failure and detection. The interval is conservatively estimated to be 30 days. The all modes failure rate of a receiver tank is 0.34 E-06 per hour (Ref. 2.2.42, Page 2-213). Using an exposure interval of 50 years, the conditional probability of lubricating fluid entering a breached canister would be less than:

> 0.88E-06/hr × 50 yrs × 8760 hrs/yr × 0.34E-06/hr x 720 hrs/30days =
> 9E-05 over the preclosure period.

This probability is overstated because: (a) it does not account for inspections during the operating period of the facility, and (b) it does not account for the conditional probability that lubricating fluid can find its way into a breached canister. Therefore, lubricating fluid is eliminated as a potential moderator.

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6.3 DATA UTILIZATION

6.3.1 Active Component Reliability Data

The fault tree models described in Section 6.2 include random failures of active mechanical equipment as basic events. In order to numerically solve these models, estimates of the likelihood of failure of these equipment basic events are needed. The active component reliability estimates are developed by gathering and reviewing industry-wide data, and applying Bayesian combinatorial methods to develop mean values and uncertainty bounds that best represented the range of the industry-wide information.

6.3.1.1 Industry-wide Reliability Data for Active Components

While data from the facility being studied are the preferred source of equipment failure rate information, it is common in a safety analysis for information from other facilities in the same industry to be used when facility-specific data is sparse or unavailable. Because the YMP is a one-of-a-kind facility and has no operating history, it is necessary to develop the required data from experience of other nuclear and non-nuclear equipment operations. Industry-wide data sources are documents containing industrial or military experience on component performance. These sources are from previous safety/risk analyses and reliability studies performed nationally or internationally, and also standards or published handbooks. For the YMP PCSA, a database is constructed using a library of industry-wide data sources of reliability data from nuclear power plants, equipment used by the military, chemical processing plants and other facilities. The sources used are listed in Attachment C, Section C1.2.

The data source scope has to be sufficiently broad to cover a reasonable number of the equipment types modeled, yet with enough depth to ensure that the subject matter is appropriately addressed. For example, a separate source might be used for electronics data versus mechanical data, so long as the detail and the applicability of the information provided justify its use. Lastly, the quality of the data source is considered to be a measure of the source's credibility. Higher quality data sources are based on equipment failures documented by a facility's maintenance records. Lower quality sources use either abbreviated accounts of the failure event and resulting repair activity, or do not allow the user to trace back to actual failure events. Every effort is made in this analysis to use the highest quality data source available for each active component type and failure mode (TYP-FM).

A potential disadvantage of using industry-wide data is that a source may provide failure rates that are not realistic because the source environment, either physical or operational, may not correlate to the facility modeled. Part of the PCSA active component reliability analysis effort, therefore, is to evaluate the similarity between the YMP operating environment and that represented in each industry-wide data source to ensure data appropriateness. The evaluation process is described in Section C1.2.

Given the fact that the YMP is a relatively unique facility (although portions are similar to the spent fuel handling and storage areas of commercial nuclear plants), the data development perspective is to collect as much relevant failure estimate information as possible to cover the spectrum of equipment operational experience. It is reasonable to expect that the YMP equipment would fall within this spectrum (Section 3.2.1). The scope of the sources selected for this data set is therefore deliberately broad to take advantage of the combined experience of many facilities, not a single plant. It is then intended to provide a combined estimate that reflects as best as possible the uncertainty ranges of the individual estimates. This ensures that the data are not skewed towards the possibly atypical behavior of one particular plant, industry or operating environment. The combinatorial process, utilizing Bayes' Theorem, is discussed in the following subsection.

Among the active components whose reliability is quantified with industry-wide data are the 200-ton cranes, jib cranes, canister maneuvering cranes, and the spent fuel transfer machine (SFTM). The rationale for using such data for these estimates is that a significant amount of crane experience exists within the commercial nuclear power industry and other applications and that this experience can be used to bound the anticipated crane performance at YMP. Furthermore, the repository is expected to have training for crane operators and maintenance programs similar to those of nuclear power plants. Crane and SFTM handling incidents that result in a drop are included in the drop probability regardless of cause; they may be caused by equipment failures (including failures in the yokes and grapples), human error, or some combination of the two.

Every attempt was made to find more than one data source for each TYP-FM; multiple sources are not always available for a specific piece of equipment. When data was extracted from several sources it was combined using Bayesian estimation (as described further below), and compared by plotting the individual and combined distributions. However, the comparison process often resulted in one source being selected as most representative of the TYP-FM. Ultimately, 53% of the TYP-FMs were quantified with one data source, 8% with two data sources, 8% with three data sources, and 31% with four or more data sources.

6.3.1.2 Application of Bayes' Theorem to PCSA Database

The application of industry-wide data sources introduces uncertainty in the input parameters used in basic events and, ultimately, the quantification of probabilities of event sequences. Uncertainty is a probabilistic concept that is inversely proportional to the amount of knowledge, with less knowledge implying more uncertainty. Bayes' theorem is a common method of mathematically expressing a decrease in uncertainty gained by an increase in knowledge (for example, knowledge about failure frequency gained by in-field experience).

There are several approaches for applying Bayes' theorem to data management and combining data sources, as described in (Ref. 2.2.10). For the PCSA, the method known as "parametric empirical Bayes" is primarily used. This permits a variety of different sources to be statistically combined and compared, whether the inputs are expressed as the number of failures and exposure time or demands, or as means and lognormal error factors.

A typical application of Bayes' theorem is illustrated as follows. A failure rate for a given component is needed for a fault tree (e.g., a fan motor in the HVAC system). There is no absolute value for the failure rate, but there are several data sources for the same kind of fan and/or similar fans that may exhibit considerable variability for many reasons. Applying any or all of the available data to the YMP introduces uncertainty in the analysis of the reliability of the

HVAC system. Bayes' theorem provides a mechanism for systematically treating the uncertainty and applying available data sources using the following steps:

1. Initially, estimate the failure rate to be within some range with a probability distribution. This is termed the "prior" probability of having a certain value of the failure rate that expresses the state of knowledge before any new information is applied.

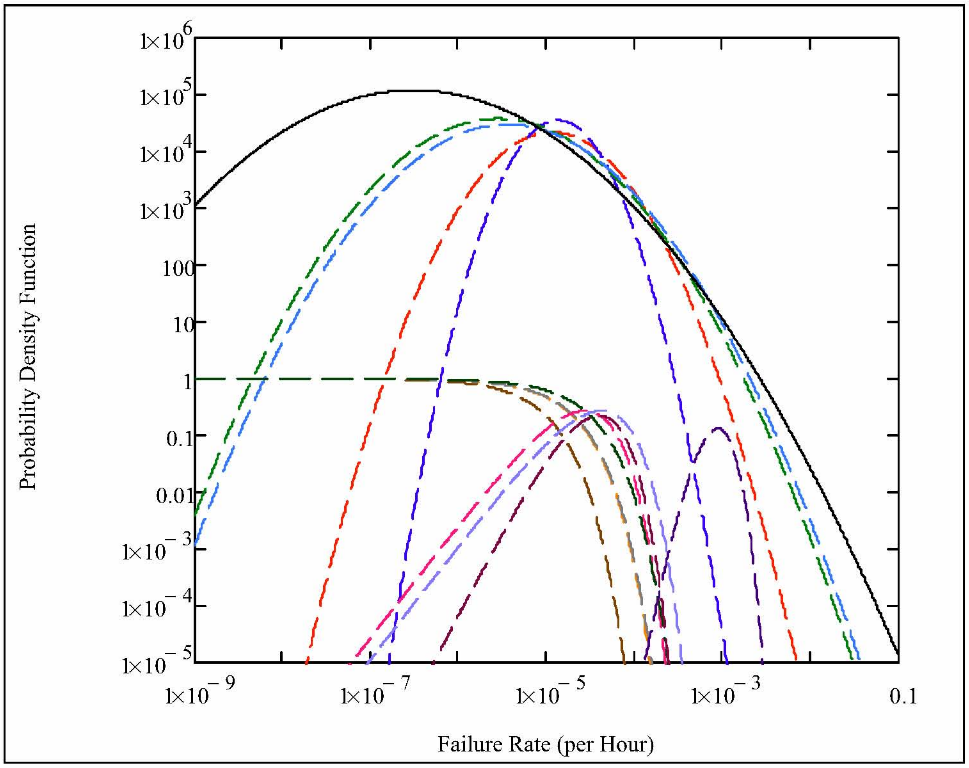
2. Characterize the test information, or evidence, in the form of a likelihood function that expresses the probability of observing the number of failures in the given number of trials if the failure rate is a certain value. The evidence comprises observations or test results on the number of failure events that occur over a certain exposure, operational, or test duration.

3. Update the probability distribution for the failure rate based on the new body of evidence.

The likelihood function is defined by the analyst in accordance with the kind of evidence. For time-based failure data, a Poisson model is used for the likelihood function. For demand-based failure data, a binomial model is used. The mathematical expression for applying Bayes' theorem to data analysis is described in Attachment C, Section C2, Equation C1.

For the analysis presented herein, MathCAD is used to calculate the population-variability (prior) distributions of active components. As described in Attachment C, Section C2.1, the method of "The Combined Use of Data and Expert Estimates in Population Variability Analysis" (Ref. 2.2.56, pp. 311–321) is used as the basis example for the combinations performed. In this method, the population-variability distribution of the failure rate is approximated by a lognormal distribution whose unknown parameters, v and τ, respectively the mean and standard deviation of the associated normal distribution, are determined. Calculating v and τ involves calculating the likelihood function associated with the reliability information in each data source. For a data source providing a failure rate point estimate, the likelihood function is a lognormal distribution, function of the failure rate x, and characterized by its median value and associated error factor. For a data source providing exposure data (given in the form of a number n of recorded failures over an exposure time t), the likelihood function is a Poisson distribution, expressing the probability that n failures are observed when the expected number of failures is x times t.

The maximum likelihood method is used to calculate v and τ. This involves maximizing the likelihood function for the entire set of data sources. This likelihood function is the product of the individual likelihood function for each data source because the data sources are independent from each other. It is equivalent and computationally convenient to find the maximum likelihood estimators for v and τ by using the sum of the log-likelihood (logarithm of the likelihood) of each data source. As a result, the likelihood functions from the individual data sources and a population-variability probability density function for the combination are produced and plotted for comparison, as in the example shown as Figure 6.3-1.



Source: Attachment C, Figure C2.1-1

Figure 6.3-1. Likelihood Functions from Data Sources (Dashed Lines) and Population-Variability Probability Density Function (Solid Line)

If only a single data source is considered applicable to a given TYP-FM combination and if the data source provides a mean and an error factor for the component reliability parameter, the probability distribution is modeled in SAPHIRE as a lognormal distribution with that mean and that error factor. However, if the data source does not readily provide a probability distribution, but instead exposure data, (i.e., a number of recorded failures over an exposure time for failure rates or over a number of demands for failure probabilities), the probability distribution for the reliability parameter is developed through a Bayesian update using Jeffreys' non-informative prior distribution (i.e., gamma for time-related failure modes and beta for demand based failure modes).

Example implementations of the methods used for these cases are provided in Attachment C, Section C2.2.

6.3.1.3 Common-Cause Failure Data

Dependent failures are modeled in event tree and fault tree logic models. When possible, potential dependent failures are modeled explicitly via the logic models. For example, failure of the HVAC system is explicitly dependent upon failure in the electrical supply system that is modeled in the fault trees. Similarly, the effects of erroneous calibration or other human failure events can be explicitly included in the system fault tree models and the basic event probabilities considered during the HRA. Otherwise, potential dependencies known as CCFs are included in fault tree logic, but their probabilities are quantified by an implicit, parametric method. Therefore, another subtask of the active component reliability data analysis is to estimate common-cause failure probabilities.

Surveys of failure events in the nuclear industry have led to several parameter models. Of these, three are most commonly used: the Beta Factor method (Ref. 2.2.51), the Multiple Greek Letter (MGL) method (Ref. 2.2.60), and the Alpha Factor Method (Ref. 2.2.61). In a parametric model, the probability of two or more components failing by a CCF is estimated by use of the equations provided in Section 4.3.3.3.

For the PCSA, CCF rates or probabilities are estimated using the Alpha Factor method NUREG/CR-5485 (Ref. 2.2.61) because it is a method that includes a self-consistent means for development of uncertainties.

The data analysis reported in the Alpha Factor method (Ref. 2.2.61) consisted of:

1. Identifying the number of redundant components in each subsystem being reported, (e.g., two, three, or four (termed the CCF group size)).

2. Partitioning the total number of reported failure events for a given component into the number of components that failed together, (i.e., one component at a time, two components at a time, and so on up to failure of all components in a given CCF group).

3. Calculating the alpha factor for a given component type to provide a basis for estimating the probability of CCFs involving two, three, etc., or all components (see equation in Attachment C, Section C3).

4. Performing statistical analysis and curve fitting to define the mean and uncertainty range for alpha factors for various CCF group sizes up to eight.

The data analysis also produces prior distributions for the alpha factors. The results are the mean, alpha factors, and uncertainty bounds, reported in NUREG/CR-5485 (Ref. 2.2.61, Table 5-11) and reproduced in Attachment C, Table C3-1.

These alpha-factors values are used for failure-on-demand events (e.g., pump failure to start) and by using the alpha factor divided by two for failure-to-operate events (e.g., pump fails to run). For example, for a two-out-of-two failure on demand event, the mean alpha factor of 0.047 (shown in the far right column of Table C3-1 associated with α_2) was used in conjunction with the mean failure probability for the appropriate component type and failure mode (from Table C4-1) as inputs to a compound event to yield the common-cause failure probability.

Similarly, for the two-out-of-two operational failure, the mean alpha factor identified above is divided by 2 (0.0235) and is used in conjunction with the mean failure probability for the appropriate component type and operational failure mode. In addition, the parameter *b* associated with the beta distribution function for the alpha factor (Table C3-1) is modified to reflect the change in the alpha factor mean value while preserving the coefficient of variation from the distribution described by the parameters presented in Table C3-1. To preserve the coefficient of variation, the variance associated with the distribution is reduced by a factor of 4 (the square of the reduction of the mean). (See Attachment C, Section C3 for the derivation of the value for the parameter *b*.) The parameter *b* for the operational α_2 is 21.03.

6.3.1.4 Input to SAPHIRE Models

Since the primary active component reliability data task objective is to support the quantification of fault tree models developed in SAPHIRE by the system analysts, the output data has to conform to the format appropriate for input to the SAPHIRE code.

SAPHIRE provides template data to the fault tree models in the form of three input comma delimited files:

1. .BEA – attributes to assign information to the proper SAPHIRE fields
2. .BED – descriptions of the component type name and failure mode
3. .BEI – information on the failure rate or probability estimates and distributions used.

Demonstration files for the .BEA, .BED and .BEI template data files provided with SAPHIRE were originally used to construct the PCSA template data files to ensure the proper formatting of the data for use by the fault tree models. In general, the .BEA file provides attribute designators for the code to implement such that the template data is properly assigned to the appropriate fields in SAPHIRE. The .BED file allows description information to be entered and linked to the template data name or designator (which in the PCSA case was the TYP-FM coding). Examples of descriptions used for the PCSA template data were: clutch failed to operate; relay spurious operation; position sensor fails on demand; and wire rope breaks. The .BEI file contains the actual active component reliability parameters, namely the mean value and uncertainty parameter, either the lognormal error factor, or the shape parameter of the beta or gamma distributions.

Geometric means of the input parameters from the data sources are initially used as screening values for each TYP-FM and are entered into the .BEI file, along with a default error factor of 10. Once the Bayesian combination process is completed for all of the TYP-FM combinations, mean and uncertainty parameter information are entered into the .BEI files, and tested in SAPHIRE before being distributed to the systems analysts.

The template data is utilized by the fault tree models by being imported into SAPHIRE using the MAR-D portion of the SAPHIRE code, then by using the modify event feature to link the template data to each basic event in the fault tree. This permits each active component of the same TYP-FM to utilize the same failure estimate and uncertainty information, based on the results of the data investigation and Bayesian combination process.

Attachment C, Section C4, presents a more thorough discussion of the active component reliability data development process, as well as a table of the template data that is imported into SAPHIRE.

6.3.1.5 Summary of Active Component Reliability Data in WHF Analysis

Table 6.3-1 summarizes the active component reliability data used in each basic event of the WHF models. Development of this table is discussed in detail in Attachment C, Section C4. Mission times are discussed in Section 6.2.

Table 6.3-1. Active Component Reliability Data Summary

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
050-#EEE-LDCNTRA-BUA-FOH	WHF Load Center A Fails	3	4.39E-04	6.10E-07	7.20E+02
050-#EEE-LDCNTRA-BUA-MTN [c]	ITS Load Center Train A OOS for Maintenance	3	1.03E-04	6.10E-07	1.68E+02
050-#EEE-LDCNTRA-BUA-ROE	Failure to Restore ITS Load Center Train A Post Maintenance	1	1.03E-05	—	—
050-#EEE-LDCNTRA-C52-FOD	Load Center A Feed Breaker Fails to Reclose	1	2.24E-03	—	—
050-#EEE-LDCNTRA-C52-SPO	Load Center A Feed Circuit Breaker Spurious Operation	3	3.82E-03	5.31E-06	7.20E+02
050-#EEE-LDCNTRB-BUA-FOH	WHF ITS Load Center B Fails	3	4.39E-04	6.10E-07	7.20E+02
050-#EEE-LDCNTRB-BUA-MTN [c]	ITS Load Center Train B OOS for Maintenance	3	1.03E-04	6.10E-07	1.68E+02
050-#EEE-LDCNTRB-BUA-ROE	Failure to Restore ITS Load Center Train B Post Maintenance	1	1.03E-05	—	—
050-#EEE-LDCNTRB-C52-FOD	13.8 ITS SWGR to WHF ITS LC B Circuit Breaker Fails on Demand	1	2.24E-03	—	—
050-#EEE-LDCNTRB-C52-SPO	WHF ITS Load Center Circuit Breaker (AC) Spur Op	3	3.82E-03	5.31E-06	7.20E+02
050-#EEE-LDCNTRS-C52-CCF	Common Cause Failure of the ITS Load Center Feed Breakers to Reclose	C	1.05E-04	—	—
050-#EEE-MCC0001-C52-SPO	WHF ITS MCC 0001 Feed Breaker Spurious Operation	3	3.82E-03	5.31E-06	7.20E+02
050-#EEE-MCC0001-MCC-FOH	WHF ITS MCC 00001 Fails	3	5.38E-03	7.49E-06	7.20E+02
050-#EEE-MCC0002-C52-SPO	WHF MCC-00002 Feed Breaker Spurious Operation	3	3.82E-03	5.31E-06	7.20E+02
050-#EEE-MCC0002-MCC-FOH	WHF ITS MCC00002 Failure	3	5.38E-03	7.49E-06	7.20E+02
050-#EEE-WHFITSA-XMR-CCF	WHF ITS Transformers CCF	C	4.92E-06	—	—
050-#EEE-WHFITSA-XMR-FOH	WHF ITS Transformer Train B Failure	3	2.10E-04	2.91E-07	7.20E+02
050--CTT--SV401--SV--FOH	Failure of Air Supply Solenoid Valve for Air Bags	3	4.87E-05	4.87E-05	1.00E+00

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
050-CCS-CQD1--QDV-FOH	Quick Disconnect CQD1 Fails	3	4.26E-06	4.26E-06	1.00E+00
050-CCS-CSKVLV1-CKV-FOD	Cask Check Valve 1 Fails to Check	1	6.62E-04	—	—
050-CCS-DRNHOSE-HOS-LEK	Cask Cooling Drain Hose Leaks	3	1.48E-05	1.48E-05	1.00E+00
050-CCS-DRNHOSE-HOS-RUP	Cask Cooling Drain Hose Ruptures	3	1.48E-06	1.48E-06	1.00E+00
050-CCS-DRNQD01-QDV-FOH	Cask Cooling QD Valve Fails	3	4.26E-06	4.26E-06	1.00E+00
050-CCS-DRNQD02-QDV-FOH	Cask Cooling QD 02 Valve Fails	3	4.26E-06	4.26E-06	1.00E+00
050-CCS-PIPBW03-PPL-RUP	Drain Piping Catastrophic - Line BW-0003	3	3.54E-06	4.42E-07	8.00E+00
050-CCS-PIPBW04-PPL-RUP	Drain Piping Catastrophic - Line BW-0004	3	3.54E-06	4.42E-07	8.00E+00
050-CCS-PIPBW05-PPL-RUP	Drain Piping Catastrophic - Line BW-0005	3	3.54E-06	4.42E-07	8.00E+00
050-CCS-PLCSPUR-PLC-SPO	PLC Spurious Operation Causes Pump Motor to Run Too Fast	3	2.92E-06	3.65E-07	8.00E+00
050-CCS-PMTRFST-MSC-FOH	Pump Motor Runs Too Fast	3	1.02E-03	1.28E-04	8.00E+00
050-CCS-PUMPINT-IEL-FOD	Positive Displace Pump Interlock Fails	1	2.75E-05	—	—
050-CCS-PUMPSTP-PMD-FTR	Pump P-00002 Fails to Run	3	2.76E-04	3.45E-05	8.00E+00
050-CCS-RLFVLVF-PRV-FOD	Pressure Relief Valve Fails on Demand	1	6.54E-03	—	—
050-CCS-THVLVFL-NZL-FOH	Throttle Valve to Pump Fails Open	3	2.28E-05	2.85E-06	8.00E+00
050-CCS-VNTPIPE-PPM-PLG	Pipe BW-0003 plugs	3	5.81E-06	7.26E-07	8.00E+00
050-CHC-CSKDROP-CRN-DRP	Cask Handling Crane Drop	1	3.16E-05	—	—
050-CHC-SLNGDRP-CRS-DRP	Cask handling Crane Sling Drop	1	1.17E-04	—	—
050-CHC-TWOBLCK-CRN-TBK	Cask Handling Crane Two Block Drop	1	4.41E-07	—	—
050-CR---IEL001--IEL-FOD	Interlock A From Slide Gate Fails	1	2.75E-05	—	—
050-CR---IEL002--IEL-FOD	Interlock B From Slide Gate Fails	1	2.75E-05	—	—
050-CR---IELCCF--IEL-FOH	Common Cause Failure of Interlocks From Slide Gate	C	1.29E-06	—	—
050-CR---PLC001--PLC-SPO	Inadvertent Signal Sent due to PLC Failure	3	3.65E-07	3.65E-07	1.00E+00

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
050-CRN-BRIDGMTR-MOE-FSO	CTM Bridge Motor (Electric) Fails to Shut Off	3	1.08E-07	1.35E-08	8.00E+00
050-CRN-HSTTRLMO-MOE-FSO	CTM Hoist Motor (Electric) Fails to Shut Off	3	1.35E-08	1.35E-08	1.00E+00
050-CRN-PLC0101--PLC-SPO	Crane bridge motor PLC spurious operation	3	3.65E-07	3.65E-07	1.00E+00
050-CRWT-BRK001--BRK-FOD	Tractor Brake A Fails	1	1.46E-06	—	—
050-CRWT-BRK002--BRK-FOD	Tractor Brake B Fails	1	1.46E-06	—	—
050-CRWT-BRK003--BRK-FOD	Trailer Brakes Fail	1	1.46E-06	—	—
050-CRWT-BRKCCF--BRK-FOD	CCF of Both Tractor Brakes	C	7.16E-08	—	—
050-CRWT-LPATH--ATH--CCF	CCF of Pendular Axle Hydraulics During Load/Unload	C	1.67E-04	—	—
050-CRWT-LPATH1--ATH-FOH	Pendular Axle Hydraulic 1 Failure	3	1.78E-03	8.91E-04	2.00E+00
050-CRWT-LPATH2--ATH-FOH	Pendular Axle Hydraulic 2 Failure	3	1.78E-03	8.91E-04	2.00E+00
050-CRWT-LPATH3--ATH-FOH	Pendular Axle Hydraulic 3 Failure	3	1.78E-03	8.91E-04	2.00E+00
050-CRWT-LPATH4--ATH-FOH	Pendular Axle Hydraulic 4 Failure	3	1.78E-03	8.91E-04	2.00E+00
050-CRWT-LPATH5--ATH-FOH	Pendular Axle Hydraulic 5 Failure	3	1.78E-03	8.91E-04	2.00E+00
050-CRWT-LPATH6--ATH-FOH	Pendular Axle Hydraulic 6 Failure	3	1.78E-03	8.91E-04	2.00E+00
050-CRWT-LPATH7--ATH-FOH	Pendular Axle Hydraulic 7 Failure	3	1.78E-03	8.91E-04	2.00E+00
050-CRWT-LPATH8--ATH-FOH	Pendular Axle Hydraulic 8 Failure	3	1.78E-03	8.91E-04	2.00E+00
050-CRWT-LSJATH1-ATH-FOH	Stabilizing Jack 1 Failure	3	1.78E-03	8.91E-04	2.00E+00
050-CRWT-LSJATH2-ATH-FOH	Stabilizing Jack 2 Failure	3	1.78E-03	8.91E-04	2.00E+00
050-CRWT-LSJATH3-ATH-FOH	Stabilizing Jack 3 Failure	3	1.78E-03	8.91E-04	2.00E+00
050-CRWT-LSJATH4-ATH-FOH	Stabilizing Jack 4 Failure	3	1.78E-03	8.91E-04	2.00E+00
050-CRWT-TRCT-STEER-FAIL	Tractor Steering System Failure	1	1.84E-05	—	—
050-CRWT-TRD0001-TRD-FOH	Front Portside Track Failure	3	5.89E-07	5.89E-07	1.00E+00
050-CRWT-TRD0002-TRD-FOH	Rear Portside Track Failure	3	5.89E-07	5.89E-07	1.00E+00

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
050-CRWT-TRD0003-TRD-FOH	Front Starboard Track Failure	3	5.89E-07	5.89E-07	1.00E+00
050-CRWT-TRD0004-TRD-FOH	Rear Starboard Track Failure	3	5.89E-07	5.89E-07	1.00E+00
050-CRWT-TRLR-STEER-FAIL	Trailer Steering System Failure	1	1.84E-05	—	—
050-CTM-##ZE0133-ECP-FOH	Bell/Grapple/Canister Alignment Position Encoder Fails	3	1.43E-05	1.79E-06	8.00E+00
050-CTM-##ZI0133-ALM-SPO	Bell/Grapple/Canister Alignment Position Ind Alarm Fails	3	4.74E-07	4.74E-07	1.00E+00
050-CTM-##ZS0133-#ZS-FOD	Bell/Grapple/Canister Alignment Limit Switch Fails	1	2.93E-04	—	—
050-CTM-#ZSH0112-1ZS-FOD	CTM Shield skirt position switch 0112 fails	1	2.93E-04	—	—
050-CTM--121122-ZS--CCF	CCF CTM Upper Limit Position Switches	C	1.38E-05	—	—
050-CTM--330121--ZS--FOD	CTM Hoist First Upper Limit Switch 0121 Failure on Demand	1	2.93E-04	—	—
050-CTM--330122--ZS--FOD	CTM Final Hoist Upper Limit Switch 0122 Failure on Demand	1	2.93E-04	—	—
050-CTM--CBL0001-WNE-BRK	CTM Hoist Wire Rope Breaks	1	2.00E-06	—	—
050-CTM--CBL0002-WNE-BRK	CTM Hoist Wire Rope Breaks	1	2.00E-06	—	—
050-CTM--CBL0102-WNE-CCF	CCF CTM Hoist wire ropes	C	9.40E-08	—	—
050-CTM--DRTRN-CT--FOD	Controller Failure	1	4.00E-06	—	—
050-CTM--DRUM001-DM--FOD	CTM Drum Failure on Demand	1	4.00E-08	—	—
050-CTM--DRUMBRK-BRP-FOD	CTM Drum Brake (Pneu-matic) Failure on Demand	1	5.02E-05	—	—
050-CTM--DRUMBRK-BRP-FOH	CTM Drum Brake (Pneumatic) Failure	3	2.01E-04	8.38E-06	2.40E+01
050-CTM--EQL-SHV-BLK-FOD	CTM Sheaves Failure on Demand	1	1.15E-06	—	—
050-CTM--GRAPPLE-GPL-FOD	CTM Grapple Failure on Demand	1	1.15E-06	—	—
050-CTM--HOISTMT-MOE-FTR	CTM Hoist Motor (Electric) Fails to Run	3	6.50E-06	6.50E-06	1.00E+00
050-CTM--HOLDBRK-BRK-FOD	CTM Holding Brake Failure on Demand	1	1.46E-06	—	—
050-CTM--HOLDBRK-BRK-FOH	CTM Holding Brake (Electric) Failure	3	3.52E-05	4.40E-06	8.00E+00

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
050-CTM--IMEC125-IEL-FOD	CTM Hoist Motor Control Interlock Failure on Demand	1	2.75E-05	—	—
050-CTM--LOWERBL-BLK-FOD	CTM Lower Sheaves Failure on Demand	1	1.15E-06	—	—
050-CTM--OVERSP--ZS--FOD	CTM Hoist Motor Speed Limit Switch Failure on Demand	1	2.93E-04	—	—
050-CTM--PORTGT1-MOE-SPO	Port Gate Motor 1 (Electric) Spurious Operation	3	6.74E-07	6.74E-07	1.00E+00
050-CTM--PORTGT1-PLC-SPO	Port Gage 1 PLC Spurious Operation	3	3.65E-07	3.65E-07	1.00E+00
050-CTM--PORTGT2-MOE-SPO	Port Gate Motor 2 (Electric) Spurious Operation	3	6.74E-07	6.74E-07	1.00E+00
050-CTM--PORTGT2-PLC-SPO	Port Gage 2 PLC Spurious Operation	3	3.65E-07	3.65E-07	1.00E+00
050-CTM--SLIDEGT-MOE-SPO	CTM Slide Gate Motor (Electric) Spurious Operation	3	6.74E-07	6.74E-07	1.00E+00
050-CTM--SLIDEGT-PLC-SPO	CTM Slide Gate PLC Spurious Operation	3	3.65E-07	3.65E-07	1.00E+00
050-CTM--SLIDGT2-IEL-FOD	CTM Slide Gate Interlock Failure	1	2.75E-05	—	—
050-CTM--TROLLY-MOE-SPO	Motor (Electric) Spurious Operation	3	6.74E-07	6.74E-07	1.00E+00
050-CTM--UPPERBL-BLK-FOD	CTM Upper Sheaves Failure on Demand	1	1.15E-06	—	—
050-CTM--WT0125--SRP-FOD	CTM Load Cell Pressure Sensor Fails on Demand	1	3.99E-03	—	—
050-CTM--WTSW125-ZS--FOD	CTM Load Cell Limit Switch Failure on Demand	1	2.93E-04	—	—
050-CTM--YS01129-ZS--FOD	CTM Drum Brake Control Circuit Switch Fail	1	2.93E-04	—	—
050-CTM--ZSH0111-ZS--SPO	CTM Grapple Engage Switch Spurious Operation	3	1.28E-06	1.28E-06	1.00E+00
050-CTM-ASD0122#-CTL-FOD	CTM Hoist ASD Controller Fails	1	2.03E-03	—	—
050-CTM-BIDGMTR-#TL-FOH	CTM Bridge Motor Torque Limiter Failure	3	2.86E-02	8.05E-05	3.60E+02
050-CTM-BRDGPSTN-PLC-SPO	CTM Canister Alignment PLC Spurious Operation	3	3.65E-07	3.65E-07	1.00E+00
050-CTM-BRIDGETR-#PR-FOH	Passive Restraint (Bumper) Failure	3	1.95E-06	4.45E-10	4.38E+03
050-CTM-BRIDGETR-MOE-FSO	CTM Shield Skirt-Bridge motor Interlock Failure	3	1.35E-08	1.35E-08	1.00E+00
050-CTM-BRIDGMTR-#CT-FOD	CTM bridge motor controller fails	1	4.00E-06	—	—

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
050-CTM-BRIDGMTR-IEL-FOD	CTM Shield Skirt-Bridge motor Interlock Failure	1	2.75E-05	—	—
050-CTM-BRIDGMTR-MOE-SPO	CTM Bridge Motor Fails to Shut Off	3	6.74E-07	6.74E-07	1.00E+00
050-CTM-BRIDGMTS-MOE-SPO	CTM Bridge Motor (Electric) Spurious Operation -shear	3	6.74E-08	6.74E-07	1.00E-01
050-CTM-HC0104##-#HC-FOD	CTM hand held radio remote controller fails	1	1.74E-03	—	—
050-CTM-HOISTMTR-MOE-FSO	CTM Hoist Motor (Electric) Fails to Shut Off	3	1.08E-07	1.35E-08	8.00E+00
050-CTM-HSTTRLLS-MOE-SPO	CTM Hoist Trolley Motor (Electric) Spurious Operation M- Shear	3	6.74E-08	6.74E-07	1.00E-01
050-CTM-HSTTRLLY-#TL-FOH	CTM Hoist Motor Torque limiter Failure	3	2.86E-02	8.05E-05	3.60E+02
050-CTM-HSTTRLLY-IEL-FOD	CTM Shield Skirt Hoist Trolley Motor Interlock Failure	1	2.75E-05	—	—
050-CTM-HSTTRLLY-MOE-SPO	CTM Hoist Trolley Motor Spurious Operation	3	6.74E-07	6.74E-07	1.00E+00
050-CTM-MISSPOOL--DM-MSP	CTM Mis-spool Event	1	6.86E-07	—	—
050-CTM-MISSPOOL-LRG-FOH	Lifting Rig Or Hook All Modes	3	7.45E-07	7.45E-07	1.00E+00
050-CTM-OPSENSOR-SRX-FOH	Canister Above CTM Slide Gate Optical Sensor Fails	3	4.70E-06	4.70E-06	1.00E+00
050-CTM-PLC0101#-PLC-SPO	CTM Bridge Motor PLC Spurious Operation	3	3.65E-07	3.65E-07	1.00E+00
050-CTM-PLC0101--PLC-SPO	CTM Bridge Motor PLC Spurious Operation	3	3.65E-07	3.65E-07	1.00E+00
050-CTM-PLC0101S-PLC-SPO	CTM Bridge Motor PLC Spurious Operation -shear	3	3.65E-08	3.65E-07	1.00E-01
050-CTM-PLC0102--PLC-SPO	CTM Shield Bell Trolley PLC Spurious Operation	3	3.65E-07	3.65E-07	1.00E+00
050-CTM-PLC0102S-PLC-SPO	CTM Shield Bell Trolley PLC Spurious Operation -Shear	3	3.65E-08	3.65E-07	1.00E-01
050-CTM-PLC0103--PLC-SPO	CTM Hoist Trolley PLC Spurious Operation	3	3.65E-07	3.65E-07	1.00E+00
050-CTM-PLC0103S-PLC-SPO	CTM Hoist Trolley PLC Spurious Operation -Shear	3	3.65E-08	3.65E-07	1.00E-01
050-CTM-SBELTRLS-MOE-SPO	CTM shield Bell trolley Motor (Electric) Spurious Operation-Shear	3	6.74E-08	6.74E-07	1.00E-01
050-CTM-SBELTRLY-#TL-FOH	CTM Shield Bell Motor Torque limiter Failure	3	2.86E-02	8.05E-05	3.60E+02
050-CTM-SBELTRLY-IEL-FOD	CTM Shield Bell Trolley Interlock Failure	1	2.75E-05	—	—

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
050-CTM-SBELTRLY-MOE-SPO	CTM Shield Bell Trolley Motor Spurious Operation	3	6.74E-07	6.74E-07	1.00E+00
050-CTM-SKRTCTCT-SRP-FOD	CTM Skirt Floor Contact Sensors Fail	1	3.99E-03	—	—
050-CTM-SLIDGT2-SRX-FOD	CTM Slide Gate Position Sensor Fails on Demand	1	1.10E-03	—	—
050-CTM-TROLLEYT-MOE-FSO	Motor (Electric) Fails to Shut Off	3	1.35E-08	1.35E-08	1.00E+00
050-CTM-TROLLYTR--PR-FOH	Passive Restraint (Bumper) Failure	3	1.95E-06	4.45E-10	4.38E+03
050-CTM-TROLYCNT-#HC-FOD	Hand Held Controller Failure to Stop (on Demand)	1	1.74E-03	—	—
050-CTM-ZSL0111-ZS--SPO	CTM Grapple Engage Switch Spurious Operation	3	1.28E-06	1.28E-06	1.00E+00
050-CTT--CT001---CT--SPO	Onboard Controller Spurious Operation	3	2.27E-05	2.27E-05	1.00E+00
050-CTT--DSW000--ESC-CCF	Common Cause Failure of Deadman Switches	C	1.18E-05	—	—
050-CTT--DSW001--ESC-FOD	Deadman Switch 1 Fails Closed	1	2.50E-04	—	—
050-CTT--DSW002--ESC-FOD	Deadman Switch 2 Fails Closed	1	2.50E-04	—	—
050-CTT--HC001---HC--SPO	Hand Held Radio Remote Controller Spurious Operation	3	5.23E-07	5.23E-07	1.00E+00
050-CTT--HC021---HC--FOD	Remote Stop Control Transmits Wrong Instruction	1	1.74E-03	—	—
050-CTT--SV301---SV--SPO	Solenoid Valve Spurious Operation	3	4.09E-07	4.09E-07	1.00E+00
050-CTT--SV601---SV--FOD	Main Air Supply Valve on CTT Fails to Close	1	6.28E-04	—	—
050-CTT--SV602---SV--FOD	Solenoid Valve Fails to Close	1	6.28E-04	—	—
050-CTT--ZS301---ZS--FOD	Pin Limit Switch #1 Fails	1	2.93E-04	—	—
050-CTT--ZS302---ZS--FOD	Pin Limit Switch #2 Fails	1	2.93E-04	—	—
050-CTT-FWDREVM1-SV--FOH	Failure of SV Providing Fwd/Rev to Motor 1	3	4.87E-05	4.87E-05	1.00E+00
050-CTT-FWDREVM2-SV--FOH	Failure of SV Providing Fwd/Rev to Motor 2	3	4.87E-05	4.87E-05	1.00E+00
050-CTT-PINLIMIT-ZS-CCF	Common Cause Failure of Limit Switches	C	1.38E-05	—	—
050-CTT-SVROTM1--SV--FOH	Failure of SV Providing Rotation to Motor 1	3	4.87E-05	4.87E-05	1.00E+00
050-CTT-SVROTM2--SV--FOH	Failure of SV Providing Rotation to Motor 2	3	4.87E-05	4.87E-05	1.00E+00

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
050-EXCESSIVE-WIND-SPEED	Sustained Wind Exceeds 40 mph and Gust to 90 mph	1	4.70E-03	—	—
050-FIRE-CSNF-PREP	Prep Area Fire Affects CSNF	1	5.40E-06	—	—
050-FIRE-CSNF-VEST	Fire Threatens CSNF in Entrance Vestibule	1	3.00E-06	—	—
050-FIRE-DPC-CTM	Fire Affects DPC in the CTM	1	8.30E-08	—	—
050-FIRE-DPC-DPCCUT	Fire Affects DPC at DPC Cutting	1	1.70E-05	—	—
050-FIRE-DPC-LARGE	Large fire affects DPC in facility	1	1.00E-04	—	—
050-FIRE-DPC-PREP	Fire affects DPC in Prep Area	1	8.90E-06	—	—
050-FIRE-DPC-UNLOAD	Fire affects DPC in Unload Room	1	4.90E-07	—	—
050-FIRE-DPC-VEST	Fire Affects DPC in Entrance Vestibule	1	1.20E-05	—	—
050-FIRE-LARGE-CSNF	Large Fire Affects CSNF	1	1.10E-05	—	—
050-FIRE-TAD-CLOSE	Fire Affects TAD in Closure Area	1	2.30E-05	—	—
050-FIRE-TAD-CTM	Fire Affect TAD in CTM	1	6.90E-08	—	—
050-FIRE-TAD-LARGE	Large Fire Affects TAD in WHF	1	6.70E-05	—	—
050-FIRE-TAD-LOAD	Fire Affects TAD in Loading Room	1	2.90E-07	—	—
050-FIRE-TAD-UNLOAD	Fire Affects TAD in Unload Room	1	3.30E-07	—	—
050-FIRE-TAD-VEST	Fire affects TAD in Entrance Vestibule (Bolting)	1	3.50E-07	—	—
050-FL---SC001---SC--FOH	Speed Control Failure	3	1.28E-04	1.28E-04	1.00E+00
050-HTTCOLLIDE---G65-FOH	Speed Limiter Fails	3	1.16E-05	1.16E-05	1.00E+00
050-JIBCRANE-CRJ-DRP	Jib Crane Drop	1	6.41E-05	—	—
050-LLW-RECIRC-PPM-RUP	LLW Recirculation Piping Ruptures	3	7.67E-06	8.75E-10	8.76E+03
050-OIL-MODERATOR	Oil Moderator Sources in WHF (Gear Boxes)	1	9.00E-05	—	—
050-OPEXPOSESAMP-HOS-RUP	Hose Ruptures During Sampling	3	1.48E-06	1.48E-06	1.00E+00
050-OTHER-WATER	Water Moderator From Other Sources	1	1.50E-05	—	—
050-PHC-OBJDROP-CRN-DRP	Pool Handling Crane Drop	1	3.16E-05	—	—

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
050-PHC-TWOBLCK-CRN-TBK	Pool Handling Crane Two Block Drop	1	4.41E-07	—	—
050-PMTT-CBP002-CBP--OPC	PMTT Power Cable - Open Circuit	3	9.13E-08	9.13E-08	1.00E+00
050-PMTT-CBP003--CBP-SHC	PMTT Power Cable - Short Circuit	3	1.88E-08	1.88E-08	1.00E+00
050-PMTT-CT000---CT--FOD	PMTT Primary Stop Switch Fails	1	4.00E-06	—	—
050-PMTT-HC001--HC--FOD	Remote Control Transmits Wrong Signal	1	1.74E-03	—	—
050-PMTT-MOE000--MOE-FSO	PMTT Lock Mode State Fails on Loss of Power	3	1.35E-08	1.35E-08	1.00E+00
050-PMTT-PLC001--PLC-FOD	On-Board Controller Fails to Respond	1	3.69E-04	—	—
050-PMTT-SC021---SC--FOH	Speed Controller on PMTT Pendant Fails	3	1.28E-04	1.28E-04	1.00E+00
050-PORTSLIDEGTE-IEL-FOD	Port Slide gate interlock Fails	1	2.75E-05	—	—
050-PWR-LOSS	Loss of Site Power	1	4.10E-06	—	—
050-PWR-LOSS-2	Loss of Power	1	5.70E-06	—	—
050-SD---PLC001--PLC-SPO	Spurious Signal From PLC Closes Door	3	3.65E-07	3.65E-07	1.00E+00
050-SD---SRU001--SRU-FOH	Ultrasonic Obstruction Sensor Fails	7	2.16E-03	9.62E-05	4.50E+02
050-SD---TL000---TL--CCF	Common Cause Failure of Over Torque Sensors	C	3.37E-04	—	—
050-SD---TL001---TL--FOH	Motor #1 over Torque Sensor Fails	7	1.44E-02	8.05E-05	3.60E+02
050-SD---TL002---TL--FOH	Motor #2 over Torque Sensor Fails	7	1.44E-02	8.05E-05	3.60E+02
050-SFTM-FUELDRP-SFT-DRP	Spent Fuel Transfer Machine (SFTM) Drop	1	5.15E-06	—	—
050-SFTM-TOOHIGH-SFT-RTH	Spent Fuel Transfer Machine Fuel Raised Too High	1	7.36E-07	—	—
050-SLDGATE-IEL-FOD	Slide gate interlock fails	1	2.75E-05	—	—
050-SPMRC--CT001--CT-FOD	On-Board Controller Fails to Respond	1	4.00E-06	—	—
050-SPMRC-BRK001-BRP-FOD	SPMRC Brake Failure on Demand	1	5.02E-05	—	—
050-SPMRC-BRP000-BRP-FOD	Brake (Pneumatic) Failure on Demand	1	5.02E-05	—	—
050-SPMRC-BRP000-BRP-FOH	PMRC Fails to Stop on Loss of Power	3	8.38E-06	8.38E-06	1.00E+00
050-SPMRC-CBP001-CBP-OPC	Power Cable to SPMRC - Open Circuit	3	9.13E-08	9.13E-08	1.00E+00

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
050-SPMRC-CBP001-CBP-SHC	SPMRC Power Cable - Short Circuit	3	1.88E-08	1.88E-08	1.00E+00
050-SPMRC-CPL000-CPL-FOH	Railcar Automatic Coupler System Fails	3	1.91E-06	1.91E-06	1.00E+00
050-SPMRC-CT000--CT--FOD	SPMRC Primary Stop Switch Fails	1	4.00E-06	—	—
050-SPMRC-CT002--CT--FOH	Pendant Direction Controller Fails	3	6.88E-05	6.88E-05	1.00E+00
050-SPMRC-CT003-CT-SPO	On-Board Controller Initiates Spurious Signal	3	2.27E-05	2.27E-05	1.00E+00
050-SPMRC-DERAIL-PERMILE	Derailment Failure per Mile	1	1.18E-05	—	—
050-SPMRC-G65000-G65-FOH	PMRC Speed Control (Governor) Fails	3	1.16E-05	1.16E-05	1.00E+00
050-SPMRC-HC001--HC--FOD	Pendant Control Transmits Wrong Signal	1	1.74E-03	—	—
050-SPMRC-HC001--HC--SPO	Spurious Command from Pendant Controller	3	5.23E-07	5.23E-07	1.00E+00
050-SPMRC-IEL011-IEL-FOD	Failure of Mobile Platform Anti-Collision Interlock	1	2.75E-05	—	—
050-SPMRC-MOE000-MOE-FSO	SPMRC Lock Mode State Fails on Loss of Power	3	1.35E-08	1.35E-08	1.00E+00
050-SPMRC-SC021--SC--FOH	Speed Controller on SPMRC Pendant Fails	3	1.28E-04	1.28E-04	1.00E+00
050-SPMRC-SEL021-SEL-FOH	Speed Selector on SPMRC Pendant Fails	3	4.16E-06	4.16E-06	1.00E+00
050-SPMRC-STU001-STU-FOH	RC End Stops Fail	3	2.11E-04	4.81E-08	4.38E+03
050-SPMTT--CT001--CT-FOD	On-board Controller Fails to Respond	1	4.00E-06	—	—
050-SPMTT--CT001-CT--SPO	On-Board Controller Spurious Operation	3	2.27E-05	2.27E-05	1.00E+00
050-SPMTT-BRK001-BRP-FOD	SPMTT Pneumatic Brakes Fail	1	5.02E-05	—	—
050-SPMTT-BRP000-BRP-FOD	Brake (Pneumatic) Failure on Demand	1	5.02E-05	—	—
050-SPMTT-CBP001-CBP-OPC	Power cable to SPMTT - Open Circuit	3	9.13E-08	9.13E-08	1.00E+00
050-SPMTT-CBP001-CBP-SHC	SPMTT Power Cable - Short Circuit	3	1.88E-08	1.88E-08	1.00E+00
050-SPMTT-CPL000-CPL-FOH	Truck Trailer Automatic Coupler System Fails	3	1.91E-06	1.91E-06	1.00E+00
050-SPMTT-CT001--CT-FOD	On-Board Controller Fails to Respond	1	4.00E-06	—	—
050-SPMTT-CT002--CT--FOH	Controller Failure	3	6.88E-05	6.88E-05	1.00E+00

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
050-SPMTT-G65000-G65-FOH	PMTT Speed Control (Governor) Fails	3	1.16E-05	1.16E-05	1.00E+00
050-SPMTT-HC002--HC--SPO	Spurious Signal from Pendant Controller	3	5.23E-07	5.23E-07	1.00E+00
050-SPMTT-IEL102-IEL-FOD	Failure of Mobile Platform Anti-Collision Interlock	1	2.75E-05	—	—
050-SPMTT-MOE000-MOE-FSO	SPMTT Lock Mode State Fails on Loss of Power	3	1.35E-08	1.35E-08	1.00E+00
050-SPMTT-SC021--SC--FOH	Speed Controller on SPMTT Pendant Fails	3	1.28E-04	1.28E-04	1.00E+00
050-SPMTT-SEL021-SEL-FOH	Speed Selector on SPMTT Pendant Fails	3	4.16E-06	4.16E-06	1.00E+00
050-SPMTT-STU001-STU-FOH	SPMTT End Stops Fail	3	2.11E-04	4.81E-08	4.38E+03
050-ST---BRK001--BRK-FOD	ST Fails to Stop on Loss of Power	1	1.46E-06	—	—
050-ST---CBP004-CBP--OPC	ST Power Cable - Open Circuit	3	9.13E-08	9.13E-08	1.00E+00
050-ST---CBP004-CBP--SHC	ST Power Cable Short Circuit	3	1.88E-08	1.88E-08	1.00E+00
050-ST---CT000---CT--FOD	ST Primary Stop Switch Fails	1	4.00E-06	—	—
050-ST---CT002---CT--FOH	Direction Controller Fails	3	6.88E-05	6.88E-05	1.00E+00
050-ST---HC000--HC--SPO	Spurious Commands from Remote Control	3	5.23E-07	5.23E-07	1.00E+00
050-ST---HC001--HC--FOD	Remote Control Transmits Wrong Signal	1	1.74E-03	—	—
050-ST---HC002---HC--SPO	Spurious Command to Lift/Lower AO or STC	3	5.23E-07	5.23E-07	1.00E+00
050-ST---MOE000--MOE-FSO	ST Lock Mode State Fails on Loss of Power	3	1.35E-08	1.35E-08	1.00E+00
050-ST---MOE021--MOE-FSO	Drive System on Primary Propulsion Fails	3	1.35E-08	1.35E-08	1.00E+00
050-ST---SC002--SC--FOH	Speed Control on ST Pendant Control Fails	3	1.28E-04	1.28E-04	1.00E+00
050-ST---SC021---SC--FOH	Speed Controller on ST Pendant Fails	3	1.28E-04	1.28E-04	1.00E+00
050-ST---SC021---SC--SPO	On-Board Controller Initiates Spurious Signal	3	3.20E-05	3.20E-05	1.00E+00
050-ST---SEL021--SEL-FOH	Speed Selector on ST Pendant Fails	3	4.16E-06	4.16E-06	1.00E+00
050-TADDRY-HOS-RUP	Hose Ruptures	3	1.48E-06	1.48E-06	1.00E+00
050-VCTO-AHU0001-FAN-FTR	AHU 0001 fan fails to run	3	5.06E-02	7.21E-05	7.20E+02
050-VCTO-AHU0002-FAN-FTR	AHU 0002 fan fails to run	3	5.06E-02	7.21E-05	7.20E+02

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
050-VCTO-AHU0003-FAN-FTR	AHU 0003 fan fails to run	3	2.56E-02	7.21E-05	3.60E+02
050-VCTO-AHU0003-FAN-FTS	AHU 0003 fan fails to start	1	2.02E-03	—	—
050-VCTO-BDMP00A-UDM-FOH	Train A fan discharge backdraft damper fails closed	3	1.61E-02	2.26E-05	7.20E+02
050-VCTO-BDMP00B-DMP-FOD	Train B backdraft damper fails to open when fan starts	1	8.71E-04	—	—
050-VCTO-BDMP00B-UDM-FOH	Train B fan discharge backdraft damper fails closed	3	8.10E-03	2.26E-05	3.60E+02
050-VCTO-DCT0A-DTC-RUP	Train A Duct Ruptures	3	2.68E-03	3.72E-06	7.20E+02
050-VCTO-DCT0B-DTC-RUP	Train B Duct Ruptures	3	1.34E-03	3.72E-06	3.60E+02
050-VCTO-DMP000A-DMP-FRO	Train A fan discharge manual isolation damper fails closed	3	6.03E-05	8.38E-08	7.20E+02
050-VCTO-DMP000B-DMP-FRO	Train B fan discharge manual isolaton damper fails closed	3	3.02E-05	8.38E-08	3.60E+02
050-VCTO-DMPF00A-DMP-FRO	Train A fan inlet manual isolation damper fails to remain open	3	6.03E-05	8.38E-08	7.20E+02
050-VCTO-DMPF00B-DMP-FRO	Train B fan inlet manual isolation damper fails to remain open	3	3.02E-05	8.38E-08	3.60E+02
050-VCTO-FAN00A-FAN-FTR	Exhaust Fan in Train A Fails	3	5.06E-02	7.21E-05	7.20E+02
050-VCTO-FAN00A-PRM-FOH	Train A exhaust fan fails due to ASD malfunction	3	3.87E-04	5.38E-07	7.20E+02
050-VCTO-FAN00B-FAN-FTR	Train B exhaust fan fails to run	3	2.56E-02	7.21E-05	3.60E+02
050-VCTO-FAN00B-FAN-FTS	Train B exhaust fan fails to start	1	2.02E-03	—	—
050-VCTO-FAN00B-PRM-FOH	Train B exhaust fan fails due to ASD malfunction	3	1.947E-04	5.38E-07	3.60E+02
050-VCTO-FANBASD-CTL-FOD	Train B ASD start logic signal fails	1	2.03E-03	—	—
050-VCTO-HEPA-CCF	CCF of 2 of 3 filter plenums	C	9.53E-05	—	—
050-VCTO-HEPAB-CCF	Common Cause Failure of HEPA Filters (2 of 3)	C	4.77E-05	—	—
050-VCTO-HEPALK-HFI-NOD	Operator fails to shift trains when alarm occurs	1	1.00E+00	—	—
050-VCTO-HFIA000-HFI-NOM	HVAC Train B control switch in wrong position	1	1.00E-01	—	—
050-VCTO-PLEN01-DMS-FOH	Train A plenum 01 moisture seperator/demi ster plugs	3	6.55E-03	9.12E-06	7.20E+02

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
050-VCTO-PLEN01-HEP-LEK	Train A Plenum 01 HEPA filters leak	3	2.16E-03	3.00E-06	7.20E+02
050-VCTO-PLEN01-HEP-PLG	Train A Plenum 01 HEPA filters plug	3	3.07E-03	4.27E-06	7.20E+02
050-VCTO-PLEN01I-DMP-FRO	Train A filter plenum 01 inlet damper fails to remain open	3	6.03E-05	8.38E-08	7.20E+02
050-VCTO-PLEN01O-DMP-FRO	Train A filter plenum 01 outlet damper fails to remain open	3	6.03E-05	8.38E-08	7.20E+02
050-VCTO-PLEN02-DMS-FOH	Train A plenum 02 moisture seperator/demi ster plugs	3	6.55E-03	9.12E-06	7.20E+02
050-VCTO-PLEN02-HEP-LEK	Train A Plenum 02 HEPA filters leak	3	2.16E-03	3.00E-06	7.20E+02
050-VCTO-PLEN02-HEP-PLG	Train A Plenum 02 HEPA filters plug	3	3.07E-03	4.27E-06	7.20E+02
050-VCTO-PLEN02I-DMP-FRO	Train A filter plenum 02 inlet damper fails to remain open	3	6.03E-05	8.38E-08	7.20E+02
050-VCTO-PLEN02O-DMP-FRO	Train A filter plenum 02 outlet damper fails to remain open	3	6.03E-05	8.38E-08	7.20E+02
050-VCTO-PLEN03-DMS-FOH	Train A plenum 03 moisture seperator/demi ster plugs	3	6.55E-03	9.12E-06	7.20E+02
050-VCTO-PLEN03-HEP-LEK	Train A Plenum 03 HEPA filters leak	3	2.16E-03	3.00E-06	7.20E+02
050-VCTO-PLEN03-HEP-PLG	Train A Plenum 03 HEPA filters plug	3	3.07E-03	4.27E-06	7.20E+02
050-VCTO-PLEN03I-DMP-FRO	Train A filter plenum 03 inlet damper fails to remain open	3	6.03E-05	8.38E-08	7.20E+02
050-VCTO-PLEN03O-DMP-FRO	Train A filter plenum 03 outlet damper fails to remain open	3	6.03E-05	8.38E-08	7.20E+02
050-VCTO-PLEN05-DMS-FOH	Train B plenum 05 moisture seperator/demi ster plugs	3	3.28E-03	9.12E-06	3.60E+02
050-VCTO-PLEN05-HEP-LEK	Train B Plenum 05 HEPA filters leak	3	1.08E-03	3.00E-06	3.60E+02
050-VCTO-PLEN05-HEP-PLG	Train B Plenum 05 HEPA filters plug	3	1.54E-03	4.27E-06	3.60E+02
050-VCTO-PLEN05I-*MP-FRO	Train B filter plenum 05 inlet damper fails to remain open	3	3.02E-05	8.38E-08	3.60E+02
050-VCTO-PLEN05O-DMP-FRO	Train B filter plenum 05 outlet damper fails to remain open	3	3.02E-05	8.38E-08	3.60E+02
050-VCTO-PLEN06-DMS-FOH	Train B plenum 06 moisture seperator/demi ster plugs	3	3.28E-03	9.12E-06	3.60E+02
050-VCTO-PLEN06-HEP-LEK	Train B Plenum 06 HEPA filters leak	3	1.08E-03	3.00E-06	3.60E+02

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
050-VCTO-PLEN06-HEP-PLG	Train B Plenum 06 HEPA filters plug	3	1.54E-03	4.27E-06	3.60E+02
050-VCTO-PLEN06I-DMP-FRO	Train B filter plenum 06 inlet damper fails to remain open	3	3.02E-05	8.38E-08	3.60E+02
050-VCTO-PLEN06O-DMP-FRO	Train B filter plenum 06 outlet damper fails to remain open	3	3.02E-05	8.38E-08	3.60E+02
050-VCTO-PLEN07-DMS-FOH	Train B plenum 07 moisture seperator/demi sterplugs	3	3.28E-03	9.12E-06	3.60E+02
050-VCTO-PLEN07-HEP-LEK	Train B Plenum 07 HEPA filters leak	3	1.08E-03	3.00E-06	3.60E+02
050-VCTO-PLEN07-HEP-PLG	Train B Plenum 07 HEPA filters plug	3	1.54E-03	4.27E-06	3.60E+02
050-VCTO-PLEN07I-DMP-FRO	Train B filter plenum 07 inlet damper fails to remain open	3	3.02E-05	8.38E-08	3.60E+02
050-VCTO-PLEN07O-DMP-FRO	Train B filter plenum 07 inlet damper fails to remain open	3	3.02E-05	8.38E-08	3.60E+02
050-VCTO-RSH114-SRR-FOH	Exhaust high rad alarm fails	3	2.00E-05	2.00E-05	1.00E+01
050-VCTO-SUPPLY-FAN-CCF	CCF of both operating supply fans	C	1.19E-03	—	—
050-VCTO-TDMP00A-DTM-FOH	Train A tornado damper fails closed when tornado conditions don't exist	3	1.61E-02	2.26E-05	7.20E+02
050-VCTO-TDMP00B-DTM-FOH	Train B tornado damper fails closed when tornado conditions don't exist	3	8.10E-03	2.26E-05	3.60E+02
050-VCTO-TRATRIP-CTL-FOD	Signal from train A tripped logic fails	1	2.03E-03	—	—
050-VCT0-AHU0001-AHU-FTR	WHF ITS Elec AHU 00001 Fails to run	3	2.73E-03	3.80E-06	7.20E+02
050-VCT0-AHU0001-CTL-FOD	WHF ITS Elec AHU 00001 Controller Fails	1	2.03E-03	—	—
050-VCT0-AHU0002-AHU-FTR	WHF ITS Elec AHU 00002 Fails to Run	3	2.73E-03	3.80E-06	7.20E+02
050-VCT0-AHU0002-CTL-FOD	WHF ITS Elec AHU 00002 Controller Fails	1	2.03E-03	—	—
050-VCT0-AHU0002-FAN-FTS	WHF ITS Elec AHU 00002 Fails to Start	1	2.02E-03	—	—
050-VCT0-AHU0003-AHU-FTR	WHF ITS Elec AHU 00003 Fails to Run	3	2.73E-03	3.80E-06	7.20E+02
050-VCT0-AHU0003-CTL-FOD	WHF ITS Elec AHU 00003 Controller Fails	1	2.03E-03	—	—
050-VCT0-AHU0004-AHU-FTR	WHF ITS Elec AHU 00004 Fails to Run	3	2.73E-03	3. 80E-06	7.20E+02
050-VCT0-AHU0004-CTL-FOD	WHF ITS Elec AHU 00004 Controller Fails	1	2.03E-03	—	—

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
050-VCT0-AHU0004-FAN-FTS	WHF ITS Elec AHU 00004 Fails to Start	1	2.02E-03	—	—
050-VCT0-AHU0103-AHU-CCR	CCF of the running WHF ITS Elec AHUs to Continue to Run	C	6.42E-05	—	—
050-VCT0-AHU0202-AHU-CCR	CCF of Standby WHF ITS Elec AHUs to Run	C	6.42E-05	—	—
050-VCT0-AHU0202-AHU-CCS	CCF of Standby WHF ITS Elec AHUs to Start	C	9.49E-05	—	—
050-VCT0-EXH-004-CTL-FOD	WHF ITS Elec Exh Fan 00004 Controller Fails	1	2.03E-03	—	—
050-VCT0-EXH-004-FAN-FTR	WHF ITS Elec Exhaust Fan 00004 Fails to Run	3	5.06E-02	7.21E-05	7.20E+02
050-VCT0-EXH-005-CTL-FOD	WHF ITS Elec Exh Fan 00005 Controller Fails	1	2.03E-03	—	—
050-VCT0-EXH-005-FAN-FTR	WHF ITS Elec Exhaust Fan 00005 Fails to Run	3	5.06E-02	7.21E-05	7.20E+02
050-VCT0-EXH-005-FAN-FTS	WHF ITS Elec Exh Fan 00005 Fails to Start	1	2.02E-03	—	—
050-VCT0-EXH-006-CTL-FOD	WHF ITS Elec Exh Fan 0006 Controller Fails	1	2.03E-03	—	—
050-VCT0-EXH-006-FAN-FTR	WHF ITS Elec Exh. Fan Fails to Run	3	5.06E-02	7.21E-05	7.20E+02
050-VCT0-EXH-007-CTL-FOD	WHF ITS Elec Exh fan 00007 Controller Fails	1	2.03E-03	—	—
050-VCT0-EXH-007-FAN-FTR	WHF ITS Elec Exhaust Fan 00007 Fails to Run	3	5.06E-02	7.21E-05	7.20E+02
050-VCT0-EXH-007-FAN-FTS	WHF ITS Elec Exh Fan 00007 Fails to Start	1	2.02E-03	—	—
050-VCT0-EXH0406-FAN-CCR	CCF of running Exh Fans for WHF ITS Elec.	C	1.19E-03	—	—
050-VCT0-EXH0507-FAN-CCF	CCF to Run: Standby Exh fans for the WHF ITS Elec	C	1.19E-03	—	—
050-VCT0-EXH0507-FAN-CCS	CCF to Start: Standby Exh fans for the WHF ITS Elec	C	9.49E-05	—	—
050-VSCO-HEPA-CCF	Common Cause Failure of HEPA Filters (2 of 3)	C	4.77E-05	—	—
050-WATER-FIRE-SUPPRESS	Water Moderator From Fire Suppression Failure	1	6.00E-07	—	—
26D-##EG-DAYTNKA-TKF-FOH	ITS DG A Day Tank (00002A) Fails	3	1.58E-04	4.40E-07	3.60E+02
26D-##EG-DAYTNKB-TKF-FOH	ITS DG B Day Fuel Tank Fails	3	1.58E-04	4.40E-07	3.60E+02
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	—	—

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
26D-##EG-FTP1DGA-PMD-FTR	ITS DG A Fuel Transfer Pump Fails to Run	3	1.23E-02	3.45E-05	3.60E+02
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	3.60E+02
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	3.60E+02
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	3.60E+02
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	3.60E+02
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	3.60E+02
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	3.60E+02
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	3.60E+02
26D-##EG-HVACFN4-FAN-FTS	ITS DG B Room Fan 4 (Motor-Driven) Fails to Start	1	2.02E-03	—	—

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
26D-##EG-STRTDGA-C72-SPO	ITS Switchgear A Battery Circuit Breaker (DC) Spur Op	3	3.85E-04	1.07E-06	3.60E+02
26D-##EG-STRTDGB-C72-SPO	13.8kV ITS SWGR Battery B Circuit Breaker (DC) Spur Op	3	3.85E-04	1.07E-06	3.60E+02
26D-##EG-WKTNK_A-TKF-FOH	ITS DG A Bulk Fuel Tank (00001A) Fails	3	1.58E-04	4.40E-07	3.60E+02
26D-##EG-WKTNK_B-TKF-FOH	ITS DG B Bulk Fuel Tank Fails	3	1.58E-04	4.40E-07	3.60E+02
26D-##EGBATCHRGA-BYC-FOH	ITS Switchgear A Battery: Battery Charger Failure	3	1.28E-03	7.60E-06	1.68E+02
26D-##EGBATCHRGB-BYC-FOH	ITS DG B Battery Charger Failure	3	1.28E-03	7.60E-06	1.68E+02
26D-#EEE-SWGRDGA-BUA-FOH	13.8kV ITS Switchgear A Failure	3	4.39E-04	6.10E-07	7.20E+02
26D-#EEE-SWGRDGB-AHU-FTR	EDGB Switchgear Room Air Handling Unit Failure to Run	3	2.73E-03	3.80E-06	7.20E+02
26D-#EEE-SWGRDGB-BUA-FOH	13.8kV ITS Switchgear B Bus Failure	3	4.39E-04	6.10E-07	7.20E+02
26D-#EEESWGRDGA-AHU-FTR	13.8kV ITS Switchgear room Air Handling Unit Fails	3	2.73E-03	3. 80E-06	7.20E+02
26D-#EEG-HVACFA1-FAN-FTR	ITS DG A room Fan 1 (Motor-Driven) Fails to Run	3	2.56E-02	7.21E-05	3.60E+02
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	3.60E+02
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	3.60E+02
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	3.60E+02
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	3.60E+02
26D-#EEU-208_DGB-BUD-FOH	ITS DG B DC Panel Failure	3	8.64E-05	2.40E-07	3.60E+02
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	—	—

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
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	—	—
26D-#EEY-ITSDG-A-#DG-FTR	ITS Diesel Generator A Fails to Run	3	7.70E-01	4.08E-03	3.60E+02
26D-#EEY-ITSDG-A-#DG-FTS	Diesel Generator Fails to Start	1	8.38E-03	—	—
26D-#EEY-ITSDG-A-#DG-MTN	ITS DG A OOS Maintenance	1	1.95E-03	—	—
26D-#EEY-ITSDG-B-#DG-MTN	ITS DG B OOS Maintenance	1	1.95E-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	3.60E+02
26D-#EEY-OB-SWGA-C52-FOD	13.8kV ITS SWGR Feed Breaker (AC) Fails to Open	1	2.24E-03	—	—
26D-#EEY-OB-SWGA-C52-SPO	13.8kV ITS SWGR A Feed Breaker Spurious Operation	3	3.82E-03	5.31E-06	7.20E+02
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	7.20E+02
26D-#EEY-OB-SWGS-C52-CCF	Common Cause Failure of 13.8kV 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	13.8kV ITS Switchgear Feed Breaker Lockout Relay Fails to Open CB	3	3.15E-03	8.77E-06	3.60E+02
26D-#EG-LDSQNCRB-SEQ-FOD	ITS DG B Load Sequencer Fails	1	3.33E-03	—	—
26D-#EG-LOCKOUTB-RLY-FTP	13.8 ITS SWGR Lockout Relay (Power) Fails to Open CB	3	3.15E-03	8.77E-06	3.60E+02
26D-#EGLDSQNCRA-SEQ-FOD	DG A Load Sequencer Fails	1	3.33E-03	—	—
26D-EG-BATTERYA-BTR-FOD	ITS Switchgear A Battery No Output Given Challenge	1	8.20E-03	—	—
27A-#EEE-BUS2DGA-C52-SPO	13.8kV Open Bus 2 ITS Load Breaker Spurious Operation	3	3.82E-03	5.31E-06	7.20E+02

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

Basic Event Name	Basic Event Description	Calc. Type[a]	Basic Event Mean Probability[b]	Mean Failure Rate	Mission Time (Hours)
27A-#EEE-BUS3DGB-C52-SPO	Circuit Breaker (AC) Spurious Operation	3	3.82E-03	5.31E-06	7.20E+02
27A-#EEN-OPENBS2-BUA-FOH	13.8kV Open Bus 2 Bus Failure	3	4.39E-04	6.10E-07	7.20E+02
27A-#EEN-OPENBS4-BUA-FOH	13.8kV Open Bus 4 Bus Failure	3	4.39E-04	6.10E-07	7.20E+02
27A-#EEN-OPNBS1A-SWP-SPO	13.8kV Open Bus 2 to ITS Div A Electric Power Switch Spur. Transfer	3	1.12E-04	1.55E-07	7.20E+02
27A-#EEN-OPNBS3B-SWP-SPO	13.8kV Open Bus 4 to ITS B Electric Power Switch Spur Transfer	3	1.12E-04	1.55E-07	7.20E+02

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. Calc Type 7 is 1 + (exp(-lambda * tau) – 1.0)/(lambda * tau) : lambda is presented in the mean failure rate column and tau is presented in the mission time column.

[c]Template data BUA-FOH was applied to BUA-MTN since the range of generic data was considered to capture a spectrum of maintenance actions.

AHU = air handling unit; AO = aging overpack; ASD = adjustable speed drive; CB = circuit breaker; CCF = common-cause failure; CSNF = commercial spent nuclear fuel; CTM = canister transfer machine; CTT = cask transfer trolley; DG = diesel generator; EDGB = Emergency Diesel Generator Building (Facility); Elec = electrical; Exh = exhaust; HEPA = high-efficiency particulate air; HVAC = heating, ventilation, and air conditioning; ITS = important to safety; LC = Load Center; LLW = low-level radioactive waste; MCC = motor control center; OOS = out of service; Op = operation; PLC = programmable logic controller; PMRC = prime mover railcar; PMTT = prime mover truck trailer; QD = quick disconnect; RC = railcar; SPMRC = site prime mover railcar; SPMTT = site prime mover truck trailer; Spur = spurious; ST = site transporter; STC = shielded transfer cask; SV = solenoid valve; SWGR = switchgear; TAD = transport, aging, and disposal (canister); WHF = Wet Handling Facility.

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) loss of shielding 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 shielding.

6.3.2.1 Probability of Loss of Containment

An overview of the methodology for calculating the probability of failure of passive equipment from drops and impact loads is presented in Section 4.3.2.2. Consistent with HLWRS-ISG-02 (Ref. 2.2.73), the methodology essentially consists of comparing the demand upon the equipment to a capacity curve. The probability of failure is the value of the cumulative distribution function for the capacity curve, evaluated at the demand upon the container. More detailed discussion is presented in Attachment D, Section D1. The methodology is applicable to all of the waste containers that are processed in the WHF, including transportation casks, aging overpacks, canisters, and waste packages. As described in Section 4.3.2.2, the condition at which a passive component is said to fail depends on the success criteria defined for the component in the WHF 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 Section 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 this parameter. Therefore, the calculation of the probability of passive failures is based on the response or resistance characteristics of the container, given the conservative point value for the drop or impact load defined for a given event sequence.

6.3.2.2 Probability of Loss of Containment for Drops and Impacts

Calculation of the probability of failure of the various containers is based on the variability in the strength (resistance) of the container as derived from tests and structural analysis, including finite element analysis (FEA), detailed in Attachment D, Section D1. Loss of containment probability analysis has been evaluated for various containers by three different studies:

1. *Seismic and Structural Container Analysis for the PCSA* (Ref. 2.2.36)
2. *Structural Analysis Results of the DOE SNF Canisters Subjected to the 23-foot Vertical Repository Drop Event to Support Probabilistic Risk Evaluations* (Ref. 2.2.82) and *Qualitative Analysis of the Standardized DOE SNF Canister for Specific Canister-on-Canister Drop Events at the Repository* (Ref. 2.2.81)
3. *Naval Long Waste Package Vertical Impact on Emplacement Pallet and Invert* (Ref.2.2.23).

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

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. 2.2.36). If a probability for the event sequence is less than of 1.0×10^{-8}, additional conservatism is incorporated in the PCSA by using a failure probability of 1.0×10^{-5}, which is 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 is 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. 2.2.36). For these canisters, only flat-bottom drops are considered to model transfers by a CTM. This is justified because these canisters fit sufficiently tightly within the CTM and potential dropped canisters are guided by the canister guide sleeve of the CTM to remain in a vertical position.

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

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

Package	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 foot drop	1.0×10^{-5}	LLNL, adjusted, no impact limiters
Representative canister	32.5	1.0×10^{-5}	Flat bottomed, LLNL, adjusted
Aging overpack	3	1.0×10^{-5}	LLNL, adjusted

NOTE: [a]Also applies to shielded transfer casks used on-site and horizontal transfer casks.
[b]For transfers by the CTM, this drop height is greater than the maximum drop height (except for CTM transfers in the IHF).
LLNL = Lawrence Livermore National Laboratory.

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-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: ft = feet; 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 mph or ft/min is converted to 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:

> Energy from drop = $mgh \propto Fs$ and $F \propto mg$, therefore, $s \propto h$, where s = strain, F = local force on container from drop, m = mass of container, h = drop height, and g = acceleration of gravity.

For drop heights other than those for the modeled situations presented in Table 6.3-2, failure probabilities can be estimated by shifting capacity curve to match the conservative failure probabilities listed in Table 6.3-2. The mean failure drop height, H_m, is found so that the probability of failure, P, is the value listed in Table 6.3-2 for the drop height, H_d, listed in Table 6.3-2.

$$P = \int_{-\infty}^{x} N(t)\,dt \quad and \quad x = \frac{H_d / H_m - 1}{COV} \qquad \text{(Eq. 27)}$$

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 is 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 it probability cannot be inferred from comparison with other structural challenges to the canister.

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

Collision Scenario	Speed	Velocity (ft/sec)	Equivalent Drop Height (ft)[a]	Failure Probabilities for Various Container Types	
				Transportation Cask	Canister
Railcar	2.5 (mph)	3.67	0.21	1.00E-08	N/A
Truck trailer	2.5 (mph)	3.67	0.21	1.00E-08	N/A
Crane	20 (ft/min)	0.33	0.00	1.00E-08	N/A
CTT	10 (ft/min)	0.17	0.00	1.00E-08	1.00E-08
Site transporter	2.5 (mph)	3.67	0.21	N/A	1.00E-08
CTM	20 (ft/min)	0.33	0.00	N/A	1.00E-08
CTM	40 (ft/min)	0.67	0.01	N/A	1.00E-08
Two-blocking	—	—	—	1.00E-05	1.00E-05

NOTE: [a]Values that are less than 0.005 are reported as 0.00.
CTM = canister transfer machine; CTT = cask transfer trolley; ft = feet.

Source: Attachment D

6.3.2.3 Probability of Canister Failure in a Fire

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

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

In response to a fire, the temperature of the waste form container under consideration increases as a function of the fire duration. The maximum temperature is calculated using a heat transfer model that is simplified to allow a probabilistic analysis to be performed that accounts for the variability of key parameters. The model accounts for radiative and convective heat transfers from the fire, and also for the decay heat from the waste form inside a container. The temperature evolution of waste form containers is analyzed based on a simplified geometry with a wall thickness that, for the range of waste form containers of interest in the PCSA, is representative or conservatively small. Specifically, two characteristic canister wall thicknesses are modeled: 0.5 in. and 1.0 in., characteristic of a range of DPCs. 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[a]	Failure Probability	
	Mean	Standard Deviation
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]Configurations not addressed in this table include any canister in an aging overpack. In this configuration, the canister is protected from the fire by the massive concrete overpack. Calculations have shown that the temperatures experienced by the canister in this configuration are well below the canister failure temperature, so that failures for these configurations can be screened. For conservatism, a screening conditional probability of 1×10^{-6} could be used.

Source: Attachment D, Table D2.1-8

Note that no failure probability is provided for a bare canister configuration. The reason for this is that the canister is outside of a 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 three inches wide, but is approximately 27 ft long. Given this configuration, it is unlikely that there is sufficient inflow of air to sustain a large fire that could heat a significant portion of the canister wall. There may be sufficient inflow to sustain a localized fire, but such a fire would not be adequate to heat the canister to failure.

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

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

6.3.2.4 Probability of Loss of Containment from Heatup

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

A series of bounding calculations was performed to determine the maximum temperature that could be reached by a canister following loss of HVAC cooling (Ref. 2.2.13). These calculations consider a range of decay heat levels and a loss of cooling for 30 days. These analyses indicate that the canister temperature would remain well below 500°C (773 K) (Ref. 2.2.13). This temperature is hundreds of degrees below the temperature at which the canister would fail (see Attachment D, Figure D2.1-4). For that reason, canister failure due to a loss of HVAC is physically unrealizable and considered Beyond Category 2.

6.3.2.5 Probability of Loss/Degradation of Shielding

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

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

A structural challenge may cause shielding degradation or shielding loss. Loss of shielding occurs when an SSC fails in a manner that leaves a direct path for radiation to stream, for example as a result of a breach. Degradation of shielding occurs when a shielding SSC is not breached but its shielding function is degraded. In the PCSA, a shielding degradation probability after a structural challenge is derived for those transportation casks that employ lead for shielding. Finite element analyses on the behavior of transportation casks subjected to impacts associated with various collision speeds, reported in NUREG/CR-6672 (Ref. 2.2.83), indicate that lead slumping after an end impact could result in a reduction of shielding; transportation casks without lead are not susceptible to such shielding degradation. This information is used in Attachment D to derive the shielding degradation probability of a transportation cask at drop heights characteristic of crane operations. The distribution is developed for impacts on surfaces made of concrete, which compare to the surfaces onto which drops could occur at the GROA. No impact limiter is relied upon to limit the severity of the impact. Conservatively, the distribution is applied to transportation casks and also shielded transfer casks, regardless of whether or not they use lead for shielding. Thus, for containers that have both a containment and shielding function, the PCSA considers a probability of containment failure (which is considered to result in a concurrent loss of shielding), and also a probability of shielding degradation (which is associated with those structural challenges that are not sufficiently severe to cause loss of containment). Table 6.3-6 displays the resulting shielding degradation probabilities for transportation casks and shielded transfer casks after a structural challenge. Given that there is significant conservatism in the calculation of strain and the uncertainty associated with the fragility (strength), the resulting estimates include uncertainties and are considered conservative.

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

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

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

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

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

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

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

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

	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.
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.
Shielded loss by fire for aging overpacks and CTM shield bell	0	Type of concrete used for aging overpacks is not sensitive to spallation; Uranium used in CTM shield bell shielding does not lose its shielding function as a result of a fire.

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

Source: Attachment D, Table D3.4-1

6.3.2.6 Probability of Other Fire-Related Passive Failures

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

6.3.2.7 Application to Event Sequence Models

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

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

Table 6.3-7. Summary of Passive Event Failure Probabilities

	10 Tons Dropped on Container	Container Vertical Drop from Normal Operating Height	Container 30-ft Vertical Drop	Container 45-ft Vertical Drop	6-ft Horizontal Drop, Rollover	2.5 mph Flat Side Impact/ Collision	2.5 mph Localized Side Impact/ Collision	9 mph Flat Side Impact/ Collision	2.5 mph End-to-End Collision	9 mph End-to-End Collision	Slapdown (Bounds Tip Over)	Thin-Walled Canister Fire	Thick-Walled Canister Fire
Loss of Containment													
Canister in Transportation 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
Transportation 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	1.E-05	N/A	N/A	N/A	N/A	N/A	N/A	1.E-05	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 Aging Overpack	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													
Transportation 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
Canister Transfer Machine	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
ft = foot; mph = miles per hour; N/A = not applicable, no scenarios identified.

Source: Attachment D

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

Basic Event ID	Basic Event Description	Basic Event Value
AO-SHIELD-FAIL-DROP	Failure of aging overpack shield due to drop	5.00E-06
AO-SHIELD-FAIL-DROPON	Failure of aging overpack shield due to drop on	1.00E-05
AO-SHIELD-FAIL-IMPACT	Aging overpack shield fails due to impact	1.00E-05
BARE-FUEL-FAIL-FIRE	Bare fuel in cask fails due to fire	5.00E-02
CANISTER-AO-DROP-FAIL	Canister in aging overpack fails due to drop	1.00E-05
CANISTER-AO-IMPACT-FAIL	Failure of canister in aging overpack due to impact	1.00E-08
CANISTER-FAIL-FIRE-AO	Canister in aging overpack fails due to fire	1.00E-06
CANISTER-FAIL-IMPACT	Canister fails due to impact	1.00E-08
CANISTER-FAIL-TWOBLOCK	Canister fails due to two blocking	1.00E-05
CANISTER-FAILS-DROP	Canister fails due to drop	1.00E-05
CANISTER-FIRE-FAIL-CTM	Canister in CTM fails in fire	1.40E-04
CANISTER-IN-AO-IMPACT	Canister in aging overpack fails	1.00E-05
CANISTER-IN-CASK-FAIL	Canister inside cask fails	1.00E+00
CANISTER-IN-CASK-FIRE	Canister in a cask fails in fire	2.00E-06
CANISTER-SHEAR-CTM	Canister shear in canister transfer machine	1.00E+00
CASK-DROP-OPERATIONAL	Failure of cask due to drop from operational height	1.00E-05
CASK-DROP-TWOBLOCK	Cask failure due to two block event	1.00E-05
CASK-FAIL-IMPACT	Cask failure due to impact	1.00E-08
CASK-FAILS	Cask fails on impact or drop	1.00E+00
CASK-SHIELDING-DROP	Shielding failure due to drop	1.00E-05
CASK-SHIELDING-IMPACT	Cask shielding fails due to impact	1.00E-08

NOTE: Refer to Attachment D for discussion.

Source: Original

6.3.3 Miscellaneous Data

Data that is not defined as Active Component Reliability Data (Section 6.3.1) or Passive Equipment Failure Data (Section 6.3.2), but are used in the reliability analysis for this facility are listed in the Table 6.3-9.