- CPC "Available Time": It is anticipated there is some time pressure to successfully perform this task so that load out can proceed. The CPC for temporarily inadequate available time for an observation task is 1.0.

- CPC "Adequacy of Training/Preparation": This is a task that is clearly trained, and the risks of loadout is emphasized in training. Because it is performed frequently, there is a high level of experience. The CPC for adequate training and high experience for an observation task is 0.8.

Applying these factors yields the following:

$$\text{Crew member fails to notice that loadout is occurring} = 0.001 \times 2.0 \times 1.0 \times 0.8 = 0.002 \qquad \text{(Eq. E-48)}$$

Crew Member Fails to Exit the Room in Time to Avoid Exposure—Training indicates the need for action in such a case. A few minutes are available to exit through clearly marked doors. This can be represented by NARA GTT C1, adjusted for the following EPCs:

- GTT C1: Simple response to a range of alarms/indications providing clear indication of situation (simple diagnosis required). Response might be direct execution of simple actions or initiating other actions separately assessed. The baseline HEP is 0.0004.

- EPC 3: Time pressure. The full effect is ×11, which corresponds to the operator having just enough time. In this case, there are some minutes left to act. The APOA anchor for 0.5 is that the operator must work at a fast pace. The situation is judged to be between these two anchors, and thus the APOA is set to 0.75.

Using the NARA HEP equation yields the following:

$$\text{Crew member fails to exit the room in time to avoid exposure} = 0.0004 \times [(11\text{-}1) \times 0.75 + 1] = 0.003 \qquad \text{(Eq. E-49)}$$

HEP Calculation for Scenario 1(a)—The events in the HEP model for Scenario 1(a) are presented in Table E6.7-4.

Table E6.7-4. HEP Model for HFE Group #7 Scenario 1(a) for 060-OpDirExpose3-HFI-NOD

Designator	Description	Probability
A	A crew member remains on the second floor of the Waste Package Loadout Room after evacuation ordered	0.01
B	WPTT operator fails to order evacuation	0.008
C	Radiation protection worker fails to check if room is empty	0.04
D	Radiation protection worker fails to recognize that someone is still in room	0.27
E	Crew member fails to notice that loadout is occurring	0.002
F	Crew member fails to exit the room in time to avoid exposure	0.003

NOTE: WPTT = waste package transfer trolley.

Source: Original

The Boolean expression for this scenario follows:

$$(A + B) \times (C + D) \times (E + F) = (0.01 + 0.008) \times (0.04 + 0.27) \times (0.002 + 0.003) = (0.018) \times (0.31) \times (0.005) = 3E{-}5 \qquad \text{(Eq. E-50)}$$

E6.7.3.4.2.2 HFE Group #7 Scenario 1(b) for 060-OpDirExpose3-HFI-NOD

1. Crew member requests reentry into enter the Waste Package Loadout Room
2. Supervisor agrees to allow access.

Crew Member Requests Reentry into the Waste Package Loadout Room—TEV loading is a normal part of operations that takes less than a few hours and is performed about twice a week. Workers are trained not to enter the Waste Package Loadout Room unless necessary for a prescheduled activity. There is a posted schedule which all the workers, including the supervisor, are aware of. Also, during loadout, there are indicators in the CRCF Control Room and outside both the personnel access door and the shield door that turn on when TEV loading is in progress. These indicators, however, are non-ITS equipment, and no credit is given for their function.

Entry would have to be for some perceived urgent need in order to countermand training. This is believed to be best represented by NARA GTT A4, adjusted for the following EPCs:

- GTT A4: Judgment needed for appropriate procedure to be followed, based on interpretation of a situation which is covered by training at appropriate intervals. The baseline HEP is 0.006.

- EPC 14: Conflict between immediate and long-term objectives. The full effect is ×2.5, which corresponds to deciding between two extremely significant problems, one of which is clearly more urgent than the other. The APOA anchor for 0.5 can be interpreted as suggesting situations of balancing an urgent plant need with an urgent personal need. The APOA anchor for 0.1 is that an individual has immediate personal needs, but there is an obvious safety task which requires completion. Other reasons for reducing from full effect include training and procedures that dictate a hierarchy of goals (which, in this case, may or may not actually help). The situation in this case is judged to be between 0.1 and 0.5, and thus the APOA is set to 0.3.

Using the NARA HEP equation yields the following:

$$\text{Crew member requests reentry into the Waste Package Loadout Room} = 0.006 \times [(2.5\text{-}1) \times 0.3 + 1] = 0.009 \qquad \text{(Eq. E-51)}$$

Supervisor Agrees to Allow Access—The supervisor believes that the reason for reentry is sufficiently compelling to stop the operation and allow the reentry to take place. The supervisor tells the WPTT operator to stop the operation, which does not prevent exposure upon reentry.

The supervisor knows that the TEV is being loaded and is aware of the consequences associated with entering the Waste Package Loadout Room during TEV loading. However, if the need is legitimate, the supervisor may choose to grant access. Given that the supervisor understands the consequences associated with direct exposure to the waste package, granting access to the Waste Package Loadout Room while the WPTT is being tilted down requires an act of great negligence; the likelihood of this was assessed to be very low and corresponds to NARA GTT A5; and adjusted by the following EPCs:

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

- EPC 14: A conflict between immediate and long-term objectives. The full effect would be × 2.5. This EPC is applicable because there is a conflict between getting the worker in and out safely and keeping on schedule. To reduce the full affect of this EPC, training and clear procedures must dictate the hierarchy of goals and make operators aware of the dangers of 'short-termism.' Safety is expected to be a much higher priority in this case because the consequences are high and immediate and training emphasizes prioritizing safety over schedule. However, the paperwork associated with stopping the TEV loading operation provides the supervisor an additional incentive to violate the procedure if the supervisor believes it can be safely done. Therefore, the APOA is assessed to be 0.5.

$$\text{Supervisor agrees to allow access} = 0.0001 \times [(2.5\text{-}1) \times 0.5 + 1] = 0.0002 \qquad \text{(Eq. E-52)}$$

It should be noted that there are other possible unsafe actions for this scenario, such as the supervisor either failing to request stop of the loadout operation, failing to verify that the operation has stopped before opening the door, or prematurely restarting the operation while the worker is still in the Waste Package Loadout Room. In addition, it is possible that the WPTT operator could fail to stop the loadout operation as requested. However, these actions were considered much less likely than the primary unsafe actions cited above and, further, would only serve to drive down the overall scenario HEP value. Therefore, the analysts decided to conservatively constrain the analysis to the unsafe actions quantified above.

HEP Calculation for Scenario 1(b)—The event in the HEP model for Scenario 1(b) is presented in Table E6.7-5.

Table E6.7-5. HEP Model for HFE Group #7 Scenario 1(b) for 060-OpDirExpose3-HFI-NOD

Designator	Description	Probability
A	Crew member requests reentry into the Waste Package Loadout Room	0.009
B	Supervisor agrees to allow access	0.0002

Source: Original

The Boolean expression for this scenario follows:

$$A \times B = 0.009 \times 0.0002 = 2E{-}06 \quad \text{(Eq. E-53)}$$

E6.7.3.4.2.3 HFE Group #7 Scenario 1(c) for 060-OpDirExpose3-HFI-NOD

1. Personnel access shield door left open
2. Interlock or load sensor fails and WPTT enters the Waste Package Loadout Room.

Personnel Access Door Left Open—Before the WPTT is moved from the Waste Package Positioning Room to the Waste Package Loadout Room, a designated radiation protection worker checks that the area is free from personnel and ensures that all the personnel access doors are closed and locked. (Note: if the personnel access doors are left unlocked, a person could potentially enter the room and incur direct exposure, but this is bounded by the current scenario.)

In this scenario, the unsafe action that occurs is that one of the shield doors is left open (i.e., the shield is not fully in place). This scenario also includes radiation protection worker being successful in assuring that all personnel have left the room (the unsafe action of failing to assure the room is empty is addressed in Scenario 1(a)).

The failure to recognize that an access door is left open is believed to be best represented by NARA GTT B3:

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

In addition, the WPTT operator would have to fail to verify by camera that the door was left open and fail to check the tag in/tag out board to address accountability for the location of personnel. This error is presumed to have medium dependency. Based on Table 20-21 of THERP (Ref. E8.1.26), for a baseline HEP of <.01 and medium dependence, the appropriate dependence value would be Item (3)(a) or 0.15.

$$\text{Personnel access shield door left open} = 0.0007 \times 0.15 = 0.0001$$

Interlock or Load Cell Fails and WPTT Enters the Loadout Room—There is an interlock between the personnel access shield doors and the Waste Package Positioning Room shield door.

If there is a loaded WPTT in the Waste Package Positioning Room (load sensor), in order for the Waste Package Positioning Room shield door to open (to allow the WPTT to move into the Waste Package Loadout Room), the personnel access doors must be closed and locked. A direct exposure would occur if the interlock fails since nothing would stop the WPTT operator from moving the WPTT into the Waste Package Loadout Room, and nothing would prevent radiation from escaping the room. The following mechanical failures are discussed in Section E6.7.3.4.1.

The mechanical failure probability for an interlock, from Attachment C, Table C4-1, is approximately 2.7E−5/demand.

$$\text{Interlock fails} = 2.7\text{E}{-5}$$

The mechanical failure probability for a load cell, represented by a pressure sensor from Attachment C, Table C4-1, is approximately 4.0E−03/demand.

$$\text{Load cell fails} = 4.0\text{E}{-03}$$

$$\text{Interlock or load cell fails} = 2.7\text{E}{-05} + 4.0\text{E}{-03} = 0.004$$

HEP Calculation for Scenario 1(c)—The events in the HEP model for Scenario 1(c) are presented in Table E6.7-6.

Table E6.7-6. HEP Model for Group #7 Scenario 1(c) for 060-OpDirExpose3-HFI-NOD

Designator	Description	Probability
A	Personnel access shield door left open	0.0001
B	Interlock or Load Cell fails and WPTT enters the Waste Package Loadout Room	4E−03

NOTE: WPTT = waste package transfer trolley.

Source: Original

The Boolean expression for this scenario follows:

$$A \times B = 0.0001 \times 4\text{E}{-03} = 4\text{E}{-07} \qquad \text{(Eq. E-54)}$$

E6.7.3.4.2.4 HEP for HFE 060-OPDIREXPOSE3-HFI-NOD

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

$$\begin{aligned}\text{060-OPDIREXPOSE3-HFI-NOD} &= \text{HEP 1(a)} + \text{HEP 1(b)} + \text{HEP 1(c)} = \\ &3\text{E}{-05} + 2\text{E}{-06} + 4\text{E}{-07} = 3\text{E}{-05}\end{aligned} \qquad \text{(Eq. E-55)}$$

E6.7.4 Results of Detailed HRA for HFE Group #7

The final HEPs for the HFEs that required detailed analysis in HFE Group #7 are presented in Table E6.7-7 (with the original preliminary value shown in parentheses).

Table E6.7-7. Summary of HFE Detailed Analysis for HFE Group #7

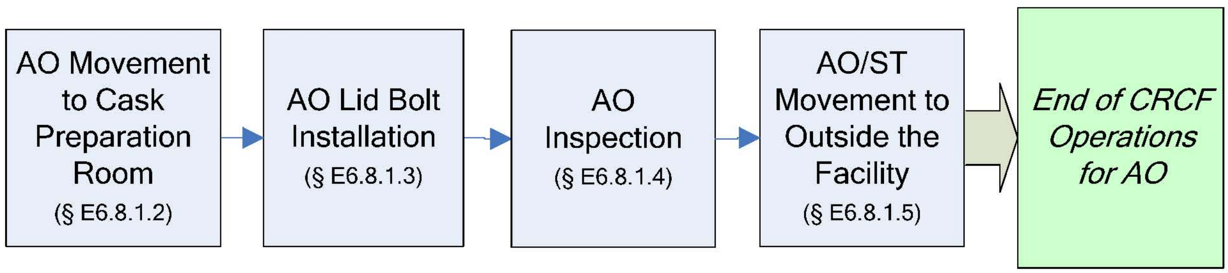
HFE	Description	Final Probability
060-OpDirExpose3-HFI-NOD	Operator causes direct exposure while loading TEV	3E−05 (1E−3)

NOTE: TEV = transport and emplacement vehicle.

Source: Original

E6.8 ANALYSIS OF HUMAN FAILURE EVENT GROUP #8: CLOSURE AND EXPORT OF AN AGING OVERPACK

HFE group #8 corresponds to the operations and initiating events associated with the ESD and HAZOP evaluation nodes listed in Table E6.0-1, covering closure and export of aging overpacks. The operations covered in this HFE group are shown in Figure E6.8-1. This operation begins after the canister has been placed into the aging overpack by the CTM, the aging overpack is located below the cask port, and the cask port is closed. The operation proceeds with the site transporter operator moving the aging overpack under the preparation platform in the preparation area from the Cask Unloading Room. The aging overpack lid is bolted on and the aging overpack is exported from the CRCF through the Site Transporter Entrance Vestibule. This operation ends once the site transporter/aging overpack has exited the facility and the exterior entrance vestibule door is closed.



NOTE: § = Section; AO = aging overpack; CRCF = Canister Receipt and Closure Facility; HFE = human failure event; ST = site transporter.

Source: Original

Figure E6.8-1. Activities Associated with HFE Group #8

E6.8.1 Group #8 Base Case Scenario

E6.8.1.1 Initial Conditions and Design Considerations Affecting the Analysis

The following conditions and design considerations were considered in evaluating HFE group #8 activities:

1. The aging overpack (secured on a site transporter) is in the Cask Unloading Room, loaded with a TAD canister or DPC with a lid on top, unbolted.

2. The site transporter is off with forks lowered.

3. There is an interlock between the port slide gates and the Cask Unloading Room shield doors. The port slide gate cannot be open while the shield doors to the Cask Unloading Room are also open.

The following personnel are involved in this set of operations:

- Crew members (two people)
- Supervisor

- Site transporter operator
- Radiation protection worker[12].

Section E5.1.2 provides a more detailed description of the duties performed by each of these personnel.

E6.8.1.2 Aging Overpack Movement to Cask Preparation Room

A crew member opens the Cask Unloading Room shield door, and the site transporter operator turns on the site transporter, raises the site transporter forks and moves the loaded aging overpack out of the Cask Unloading Room to the Cask Preparation Room on the site transporter. The site transporter operator performs this task visually and also receives confirmatory hand signals from the crew member. Once the site transporter is cleared out of the Cask Unloading Room, the crew member closes the shield door.

E6.8.1.3 Aging Overpack Lid Bolt Installation

Using the cask preparation platform, shield plate and common tools, a crew member(s) closes the shield plate, emplaces and tightens all the aging overpack lid bolts according to the proper procedure and then verifies on the checklist that all the bolts have been properly installed.

E6.8.1.4 Aging Overpack Inspection

Once the cask is ready to leave the facility, the crew conducts a visual inspection and radiological survey of the exterior of the cask.

E6.8.1.5 Aging Overpack Movement from Cask Preparation Room to Outside

Movement of Loaded Site Transporter out of Cask Preparation Room—Once the site transporter is in the Cask Preparation Room and ready for export, the overhead door to the vestibule is opened and the site transporter proceeds to the Site Transporter Vestibule and stops. The inside door (shield door) is then closed by a crew member. A checklist is signed to indicate that the inside door has been closed.

Movement of Loaded Site Transporter out of Site Transporter Vestibule—Once the door to the Cask Preparation Room has been closed, a crew member opens the outside door of the Site Transporter Vestibule and the site transporter operator proceeds to move the site transporter to the outside. Once the site transporter has cleared the outside overhead door, a crew member closes the door.

[12]The radiation protection worker, or health physicist, is not mentioned specifically in each step of this operation; however, there is always at least one radiation protection worker present during this step.

E6.8.2 HFE Descriptions and Preliminary Analysis

This section defines and screens the HFEs that are identified for the base case scenario that can affect the probability of initiating events occurring, and that could lead to undesired consequences. Descriptions and preliminary analysis for the HFEs of concern during closure and export of an aging overpack are summarized in Table E6.8-1. The analysis presented here includes the assignment of preliminary HEPs in accordance with the methodology described in Section E3.2 and Appendix E.III of this analysis. Section E4.2 provides details on the use of expert judgment in this preliminary analysis.

Table E6.8-1. HFE Group #8 Descriptions and Preliminary Analysis

HFE ID	HFE Brief Description	ESD	Preliminary Value	Justification
060-OpSTCollide3-HFI-NOD	*Operator Causes Low-Speed Collision of ST with SSC while Moving from the Cask Unloading Room to the Cask Preparation Room*: Operator causes collision of ST with facility structure or equipment while moving the ST under the platform from the Cask Unloading Room.	14	3E−03	This operation is identical to site transporter collision while moving into the Cask Unloading Room (060-OpSTCollide2-HFI-NOD; Section E6.4, HFE Group #4: Site Transporter Receipt and Movement into the Cask Preparation Room; Aging Overpack Preparation and Movement to the Canister Transfer Room) and was therefore assigned the same preliminary value: this failure is "highly unlikely" (one in a thousand or 0.001) but was adjusted because there are several ways for a collision to occur (×3).
060-OpImpact0000-HFI-NOD	*Operator Causes Impact of Cask during Transfer from Cask Unloading room to Cask Preparation Room*: While moving from the Cask Unloading Room to the Cask Preparation Room, the ST can impact the crane hook or rigging if it is improperly stowed.	14	N/A	While moving from the Cask Unloading Room to the Cask Preparation Room, the site transporter can impact the crane hook or rigging if it is improperly stowed. The shield plate is closed at the end of every operation involving the preparation platform. It is unlikely, then, that the crane rigging can be improperly stowed such that it can impact the site transporter while it is moving out of the Cask Unloading Room; it is more likely that rigging will impact the cask while the crane is actually in use. Therefore, any crane interference with the site transporter is already covered by 060-OpAOImpact01-HFI-NOW (operator causes aging overpack impact during aging overpack closure) and 060-OpTipover003-HFI-NOD (Operator Causes Tipover of Site Transporter). This failure is identical to Operator Causes Impact of Cask during Transfer from Cask Unloading Room to Cask Preparation Room (060-OpImpact0000-HFI-NOD; Section E6.4, HFE Group #4: Site Transporter Receipt and Movement into Cask Preparation Room; Aging Overpack Preparation and Movement to the Cask Unloading Room).
060-OpSDClose001-HFI-NOD	*Operator Closes Shield Door on Conveyance*: Once the CTM activities are over, an operator opens the shield door, turns on the ST, lifts the forks and moves the cask from the Cask Unloading Room to the Cask Preparation Room. There is a shield door between the Cask Preparation Room and the Cask Unloading Room. Also, while exporting the ST, the ST must pass through the shield door between the Cask Preparation Room and the ST Entrance Vestibule. The operator can impact the cask by inadvertently closing the shield door on the ST as the ST passes through the door.	7	1.0	The site transporter passes through a shield door as it moves from the Cask Preparation Room into the Cask Unloading Room. During this transfer, the operator can cause the site transporter to collide into the shield door or close the shield door on the site transporter. See Section E6.0.2.3.3 for a justification of this preliminary value.
060-OpCTCollide1-HFI-NOD	*Operator Causes Low-Speed Collision of Auxiliary Vehicle with ST during Closure Activities*: While the ST is parked under the preparation platform for closure activities, the operator of an auxiliary vehicle can collide into the ST. If the speed governor is functioning, this is a low-speed collision.	12	3E−03	In this step the site transporter is loaded and parked under the preparation platform. The speed of auxiliary vehicles is slow, the site transporter is very visible and procedural controls are expected to limit the number of other vehicles in the Cask Preparation Room during cask operations. This HEP was assigned the same preliminary value as railcar collision HFE (060-OpRCCollide1-HFI-NOD; Section E6.1, HFE Group #1: Receipt of SNF in the Railcar Entrance Vestibule and Movement into the Cask Preparation Room) because the dominant mechanism of both failures is collision with an auxiliary vehicle. In this case, the preliminary value is conservative because the site transporter is staged under the platform and the railcar/truck trailer collision HFE has additional failure modes associated with movement of the site prime mover which are not applicable here. This failure is identical for the preparation activities in a CTT or site transporter (060-OpCTCollide1-HFI-NOD; Section E6.3, HFE Group #3: Cask Preparation Activities and Movement to Cask Unloading Room and Section E6.4, HFE Group #4: Site Transporter Receipt and Movement into the Cask Preparation Room; Aging Overpack Preparation and Movement to the Canister Transfer Room)
060-OpFLCollide1-HFI-NOD	*Operator Causes High-Speed Collision of ST with SSC*: Operator can cause an auxiliary vehicle to collide into a loaded ST while the conveyance is parked in the Cask Preparation Room. If the collision is due to the auxiliary vehicle speed governor malfunctioning, this is a high-speed collision.	12	1.0	The operator can cause an auxiliary vehicle (i.e., forklift) to over speed, resulting in collision with the site transporter while the site transporter is parked under the preparation platform or in transit to or from the platform. In order to accomplish this, the speed governor of the auxiliary vehicle must fail. The site transporter itself is limited by design from going too fast. To be conservative, unsafe actions that require an equipment failure to cause an initiating event are generally assigned an HEP of 1.0.
060-OpTipOver003-HFI-NOD	*Operator Causes Tipover of ST*: If the operator improperly stows the crane rigging, during AO preparation it can catch the ST or cask. If the crane becomes attached to the ST or cask and the operator continues to move the ST (i.e., exiting the Cask Preparation Room) or crane, the ST could tip over.	12	1E−04	In this step the site transporter is moved from the Cask Unloading Room to the Cask Preparation Room, the aging overpack lid bolts are installed, and then the site transporter is exported from the facility through the Site Transporter Entrance Vestibule. This operation is identical (but reverse) to receipt and preparation of the aging overpack and thus was given the same name and preliminary value as the site transporter tipover during receipt and preparation of the aging overpack (060-OpTipover003-HFI-NOD; Section E6.4, HFE Group #4: Site Transporter Receipt and Movement into the Cask Preparation Room; Aging Overpack Preparation and Movement to the Canister Transfer Room).
060-OpAOImpact01-HFI-NOW	*Operator Causes Impact of AO during AO Closure*: During AO closure the AO lid is bolted. If the lid bolts are installed with the crane, it is possible that AO/ST can be impacted by the crane hook due to improper crane operations.	12	3E−03	In this step, the aging overpack lid bolts are installed. If the crane is used to move the lid bolts, it is possible that the crane can impact the side of the site transporter/aging overpack. This operation is identical, but in reverse, of the preparation of the aging overpack and thus was given the same name and preliminary value as impact during preparation of the aging overpack (060-OpAOImpact01-HFI-NOD; Section E6.4, HFE Group #4: Site Transporter Receipt and Movement into the Cask Preparation Room; Aging Overpack Preparation and Movement to the Canister Transfer Room). This failure was assessed as "highly unlikely" (one in a thousand or 0.001) but is adjusted because there are several ways for an impact to occur (×3).

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Table E6.8-1. HFE Group #8 Descriptions and Preliminary Analysis (Continued)

HFE ID	HFE Brief Description	ESD	Preliminary Value	Justification
Drop of Object on AO	*Operator Drops Heavy Object on the AO during AO Closure*: During AO closure the AO lid is bolted. If the lid bolts are removed with the crane, it is possible that they can be dropped onto the cask.	N/A	N/A	Aging overpack closure activities simply entail installing the lid bolts. In this step the lid bolts or the tools used to install the lid bolts can be dropped onto the aging overpack. This failure was omitted from analysis because the bolts and tools were not considered to be "heavy objects."
060-OpSpurMove01-HFI-NOD	*Operator Causes Spurious Movement of ST during Closure Activities*: The ST is supposed to be turned off, with the control pendant stored during this operation. However, if the ST is not in the proper configuration for AO closure, the operator can inadvertently cause the ST to move. This spurious movement can cause the ST to collide into the preparation platform.	12	1E−04	In this step the site transporter is parked under the preparation platform; the power is off, with the control pendant stored. For operations in this step there are several crew members on the preparation platform and no operators below the platform. This error was considered to be extremely unlikely (0.0001) because it requires multiple human errors: it would require the site transporter to be left on, the observers (the crane operator, two crew members or the radiation protection worker) would have to fail to notice or fail to stop operations and turn off the site transporter, and an operator would have to access the pendent and signal the site transporter to move. This failure is identical for the preparation activities in a CTT or site transporter (060-OpSpurMove01-HFI-NOD; Section E6.3, HFE Group #3: Cask Preparation Activities and Movement to Cask Unloading Room and Section E6.4, HFE Group #4: Site Transporter Receipt and Movement into the Cask Preparation Room; Aging Overpack Preparation and Movement to the Canister Transfer Room).
060-Liddisplace1-HFI-NOD	*Operator Inadvertently Displaces Lid*: The operator can improperly store the crane rigging such that it catches the lid lift fixture and pulls off the AO lid when bolts are installed, resulting in a direct exposure.	17	N/A	In this step the aging overpack lid is bolted with, perhaps, the use of the crane. Due to design changes to the preparation platform, improperly stowed rigging during this operation does not catch the lid lift fixture. These design changes include raising the platform and adding a shield plate so the cask is recessed underneath the platform and protected by the shield plate. Therefore this failure was omitted from analysis.
060-OpLoadDrop-HFI-NOD	*Operator Causes ST to drop AO*: The ST is like a forklift, carrying the AO several inches above the ground on its forks. If the AO is improperly secured onto the ST, it can fall off the forks while in transit or during closure activities.	16	N/A	The aging overpack is not purposefully lifted in this step. The only way for an aging overpack to be dropped is if it falls off the site transporter. The site transporter is like a fork lift which holds the aging overpack raised several inches above the ground while in transit. The site transporter cannot lift the aging overpack greater than one foot, so a drop greater than a foot is not plausible in this step. The aging overpack is prevented from moving on or falling off the site transporter by a securing mechanism which locks the aging overpack into place. The site transporter has traveled from the aging pad to the facility. It is highly unlikely that the aging overpack can drop in the facility due to human error given it has not dropped in transit to the facility because the aging overpack is not removed from the site transporter in the CRCF. Also, there are interlocks which prevent the site transporter from moving if the aging overpack is not properly secured. Therefore, drop of an aging overpack due to human failure was omitted from the analysis.
060-OpSTCollide4-HFI-NOD	*Operator Causes Low-Speed Collision of ST with SSC while Exporting the ST*: Operator causes collision of ST with facility structure or equipment while moving through the Cask Preparation Room to the ST Vestibule and then outside the facility. This is a separate HFE from 060-OpSTCollide3-HFI-NOD because this movement of the ST is temporally separate from ST movement to the Cask Preparation Room. Movement is separated by lid bolting activities.	16	3E−03	This operation is identical to (but reverse of) site transporter collision while moving into the facility (060-OpSTCollide1-HFI-NOD; Section E6.4, HFE Group #4: Site Transporter Receipt and Movement into the Cask Preparation Room; Aging Overpack Preparation and Movement to the Canister Transfer Room) and therefore has the same preliminary value.
ST Rollover	*Operator Causes ST to Rollover*: Operator drives over a significantly uneven surface while exporting the ST, causing the ST to rollover.	16	N/A	Although the center of mass for the site transporter is higher than that of the truck trailer, this failure mode was omitted from analysis for the same reasons as the truck rollover (Section E6.1). For a site transporter to rollover, the center of mass has to shift laterally. This can be done by traversing a significantly uneven surface or running over a very large object. There are no significantly uneven surfaces in the CRCF Entry Vestibule or Cask Preparation Room. It is incredible for the site transporter to run over an object large enough necessary to shift its center of mass.
060-OpFailStop-HFI-NOD	*Operator Fails to Stop ST if Tread Fails*: If the tread of the ST fails, it is possible the ST can rollover if the operator continues to operate the ST while trying to exit the facility.	16	1.0	If the tread of the site transporter fails, it is possible the site transporter can rollover if the operator continues to operate the site transporter. While it is unlikely that an operator would continue to operate a site transporter if such a significant and visible failure occurred, to be conservative, unsafe actions that require an equipment failure to cause an initiating event are assigned an HEP of 1.0.

NOTE: AO = aging overpack; CRCF = Canister Receipt and Closure Facility; CTT = cask transfer trolley; ESD = event sequence diagram; HEP = human error probability; HFE = human failure events; N/A = not applicable; SSC = structure, system, or component; ST = site transporter.

Source: Original

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E6.8.3 Detailed Analysis

There are no HFEs in this group that require detailed analysis; the preliminary values in the facility model do not result in any Category 1 or Category 2 event sequences that fail to comply with the performance objectives of 10 CFR 63.111, therefore, the preliminary values were sufficient to demonstrate compliance with 10 CFR Part 63 (Ref. E8.2.1).

E7 RESULTS: HUMAN RELIABILITY ANALYSIS DATABASE

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

Table E7-1. HFE Data Summary

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
060-#EEE-LDCNTRA-BUA-ROE	Operator fails to restore ITS load center Train-A post maintenance	Electrical	OA (Pre-Initiator)	1.03E−05	10	Preliminary
060-#EEE-LDCNTRB-BUA-ROE	Operator fails to restore ITS load center Train-B post maintenance	Electrical	OA (Pre-Initiator)	1.03E−05	10	Preliminary
060-Liddisplace1-HFI-NOD	Operator inadvertently displaces cask lid during platform activities	17	3, 4, 8	N/A [b]	N/A	Omitted from Analysis
060-OpAOImpact01-HFI-NOW	Operator causes AO impact during AO platform activities (preparation or closure)	5, 12	4, 8	3.00E−03	5	Preliminary
060-OpCaskDrop01-HFI-NOD	Operator drops cask during cask preparation activities	4	3	N/A [b]	N/A	Omitted from Analysis
060-OpClCTMGate1-HFI-NOD	Operator inappropriately closes slide or port gate during vertical canister movement and continues lifting	9	5	1.00E−03	5	Preliminary
060-OpCollide001-HFI-NOD	Operator causes low-speed collision of auxiliary vehicle with RC, TT, CTT, or TTC	3	2	3.00E−03	5	Preliminary
060-OpCraneIntfr-HFI-NOD	Operator causes WP handling crane to interfere with TEV or WPTT	15	7	1.00E−04	10	Preliminary
060-OpCTCollide1-HFI-NOD	Operator causes low-speed collision of auxiliary vehicle with ST/CTT	4, 5, 12	3, 4, 8	3.00E−03	5	Preliminary
060-OpCTCollide2-HFI-NOD	Operator causes low-speed collision of CTT with SSC during transfer from preparation station to Unloading Room	6	3	1.00E−03	5	Preliminary
060-OpCTMDirExp1-HFI-NOD	Operator causes direct exposure during CTM activities (Second Floor)	18	5	8E−06	10	Detailed

Table E7-1. HFE Data Summary (Continued)

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
060-OpCTMDrInt01-HFI-COD	Operator lifts object or canister too high with CTM (two-block)	9	5	1.0	N/A	Preliminary
060-OpCTMdrop001-HFI-COD	Operator drops object onto canister during CTM operations	9	5	4.00E−07	10	Detailed
060-OpCTMdrop002-HFI-COD	Operator drops canister during CTM operations	9	5	5.00E−07	10	Detailed
060-OpCTMImpact1-HFI-COD	Operator moves the CTM while canister or object is below or between levels	9	5	4.00E−08	10	Detailed
060-OpCTMImpact2-HFI-COD	Operator causes canister impact with lid during CTM operations (non-DPC)	9	5	N/A [b]	N/A	Omitted from Analysis
060-OpCTMImpact3-HFI-COD	Operator causes two CTMs to collide.	9	5	1.00E−01	3	Preliminary
060-OpCTMImpact5-HFI-COD	Operator causes canister Impact with SSC during CTM operations	9	5	1.0	N/A	Preliminary
060-OpCTTImpact1-HFI-NOD	Operator causes an impact between cask and SSC due to crane operations	4	3	3.00E−03	5	Preliminary
060-OpDirExpose1-HFI-NOD	Operator causes direct exposure during CTM activities (first floor)	18	5	1.00E−01	3	Preliminary
060-OpDirExpose2-HFI-NOD	Operator causes direct exposure during CTM activities (transfer into an AO)	18	5	1.00E−04	10	Preliminary
060-OpDirExpose3-HFI-NOD	Operator causes direct exposure during TEV loading	19	7	3.00E−05	10	Detailed
060-OpDPCShield1-HFI-NOW	Operator causes loss of shielding while installing DPC lift fixture	17	3	4.00E−04	10	Detailed
060-OpDSNFLoad-HFI-NOD	Operator misloads DSNF	N/A	5	1.00E−03	5	Preliminary
060-OpFailRstInt-HFI-NOM	Operator fails to restore interlock after maintenance	18	5, 7	1.00E−02	3	Preliminary
060-OpFailSG-HFI-NOD	Operator fails to close the CTM slide gate moving CTM with canister inside bell (direct exposure)	18	5	1E−03	5	Preliminary

Table E7-1. HFE Data Summary (Continued)

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
060-OpFailStop-HFI-NOD	Operator fails to stop ST if tread fails	2, 16	4, 8	1.0	N/A	Preliminary
060-OpFLCollide1-HFI-NOD	Operator causes high-speed collision of auxiliary vehicle with RC, TT, ST, CTT or TTC	3, 4, 5, 12	2, 3, 4, 8	1.0	N/A	Preliminary
060-OpImpact0000-HFI-NOD	Operator causes impact of cask during transfer between preparation station and Unloading room	6, 14	3, 4, 8	N/A [b]	N/A	Omitted from Analysis
060-OpLoadDrop-HFI-NOD	Operator causes ST to drop AO	2, 16	4, 8	N/A [b]	N/A	Omitted from Analysis
060-OpNoDiscoAir-HFI-NOD	Operator fails to disconnect air supply from CTT in the Unloading Room	9	5	1.00E−03	5	Preliminary
060-OpNoUnBolt00-HFI-NOD	Operator fails to fully unbolt the cask lid before moving CTT into the Unloading Room (non-DPC)	9	5	1.00E−03	5	Preliminary
060-OpNoUnBoltDP-HFI-NOD	Operator fails to fully unbolt the cask lid before moving CTT into the Unloading Room (DPC)	9	5	N/A [b]	N/A	Omitted from Analysis
060-OpNoUnplugST-HFI-NOD	Operator fails to disconnect the power supply from the ST in the Unloading Room	9	5	1.00E−03	5	Preliminary
060-OpRCCollide1-HFI-NOD	Operator causes low-speed collision between RC and facility SSCs	1	1	3.00E−03	5	Preliminary
060-OpRCIntCol01-HFI-NOD	Operator causes high-speed collision between RC and facility SSCs	1	1	1.0	N/A	Preliminary
060-OpRCIntCol02-HFI-NOD	Operator causes MAP to collide into RC	1	1	1.0	N/A	Preliminary
060-OpSDClose001-HFI-NOD	Operator closes shield door on conveyance	7	OA (1, 3, 4, 7, 8)	1.0	N/A	Preliminary
060-OpShieldRing-HFI-NOD	Operator fails to install WP shield ring in WPTT (direct exposure)	19	7	1.00E−04	10	Preliminary
060-OpSpurMove01-HFI-NOD	Operator causes spurious movement of CTT or ST in the preparation area	3, 4, 5, 12	2, 3, 4, 8	1.00E−04	10	Preliminary

Table E7-1. HFE Data Summary (Continued)

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
060-OpStageRack1-HFI-NOD	Operator causes direct exposure during canister staging	18	5	3.00E−05	10	Detailed
060-OpSTCollide1-HFI-NOD	Operator causes low-speed collision of ST with SSC while moving to the Cask Preparation Room	2	4	3.00E−03	5	Preliminary
060-OpSTCollide2-HFI-NOD	Operator causes low-speed collision of ST with SSC while moving to the Cask Unloading Room	6	4	3.00E−03	5	Preliminary
060-OpSTCollide3-HFI-NOD	Operator causes low-speed collision of ST with SSC while moving from the Cask Unloading Room to the Cask Preparation Room	14	8	3.00E−03	5	Preliminary
060-OpSTCollide4-HFI-NOD	Operator causes low-speed collision of ST with SSC while exporting the ST	16	8	3.00E−03	5	Preliminary
060-OpTCImpact01-HFI-NOD	Operator causes an impact between cask and SSC during upending and removal	3	2	3.00E−03	5	Preliminary
060-OpTEVDrClosd-HFI-NOD	Operator begins WP extraction before TEV doors open	15	7	1.00E−03	5	Preliminary
060-OpTiltDown01-HFI-NOD	Operator causes premature tilt-down of the WPTT	9, 10, 13	5, 6, 7	1.0	N/A	Preliminary
060-OpTipover001-HFI-NOD	Operator causes cask to tip over during cask upending and removal	3	2	1.00E−04	10	Preliminary
060-OpTipover002-HFI-NOD	Operator causes cask to tip over during cask preparation activities	4	3	1.00E−04	10	Preliminary
060-OpTipOver003-HFI-NOD	Operator causes tipover of ST	5, 12	4, 8	1.00E−04	10	Preliminary
060-OpTipOver3-HFI-NOD	Operator causes tipover of ST or CTT during movement between the Cask Unloading Room and Cask Preparation Area	6	3, 4	N/A [b]	N/A	Omitted from Analysis
060-OpTTCollide1-HFI-NOD	Operator causes low-speed collision between TT and facility SSCs	1	1	3.00E−03	5	Preliminary

Table E7-1. HFE Data Summary (Continued)

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
060-OpTTIntCol01-HFI-NOD	Operator causes high-speed collision between TT and facility SSCs	1	1	1.0	N/A	Preliminary
060-OpTTIntCol02-HFI-NOD	Operator causes MAP to collide into TT	1	1	1.0	N/A	Preliminary
060-OpTTRollover-HFI-NOD	Operator causes rollover of TT	1	1	N/A [b]	N/A	Omitted from Analysis
060-OpWPCollide1-HFI-NOD	Operator causes low-speed collision of WPTT into SSC	10, 13	6, 7	3.00E−03	5	Preliminary
060-OpWPInnerLid-HFI-NOD	Operator fails to install WP inner lid (direct exposure)	19	6	6.00E−06	10	Detailed
060-OpWPTiltUp01-HFI-NOD	Operator prematurely tilts up the WPTT	15	7	1.0	N/A	Preliminary
060-OpWPTTSpur01-HFI-NOD	Operator causes spurious movement of WPTT during canister loading	9	5	1.00E−03	5	Preliminary
060-VCTO-DR00001-HFI-NOD	Operators open 2 or more Vestibule Doors in CRCF	HVAC	OA (Pre-Initiator)	1.00E−02	3	Preliminary
060-VCTO-HFIA000-HFI-NOM	Human error exhaust fan switch wrong position	HVAC	OA (Pre-Initiator)	1.00E−01	3	Preliminary
060-VCTO-HEPALK-HFI-NOD	Operator fails to notice HEPA filter leak in train A	HVAC	OA (Pre-Initiator)	1.0	N/A	Preliminary
26D-#EEY-ITSDG-A-#DG-RSS	Operator fails to restore Diesel Generator A to service	Electrical	OA (Pre-Initiator)	1.95E−04	10	Preliminary
26D-#EEY-ITSDG-B-#DG-RSS	Operator fails to restore Diesel Generator B to service	Electrical	OA (Pre-Initiator)	1.95E−04	10	Preliminary
Crane Drops (drop of cask or object onto cask)	Operator drops cask or drops object onto cask during crane operations	Various (3, 4, 11, 15)	OA (2, 3, 6, 7)	N/A[a]	N/A	Historical Data
Gas Sampling	Operator improperly performs gas sampling	N/A	3	N/A [b]	N/A	Omitted from Analysis
Improper WP Closure	Operator damages canister or fails to properly weld the WP	11	6	N/A [b]	N/A	Omitted from Analysis
Load too Heavy	Operator causes drop of cask by attempting to lift a load that is too heavy for the crane	N/A	OA	N/A [b]	N/A	Omitted from Analysis

Table E7-1. HFE Data Summary (Continued)

Basic Event Name	HFE Description	ESD	HFE Group	Basic Event Mean Probability	Error Factor	Type of Analysis
Moderator	Operator introduces moderator into a moderator-controlled area of the CRCF	N/A	OA	N/A [b]	N/A	Omitted from Analysis
RC Derailment	Operator causes the RC to derail	1	1	N/A[a]	N/A	Historical Data
Spurious Movement of CTT/ST during CTM Activities	Operator causes spurious movement of the CTT or ST during canister loading and unloading	9	5	N/A [b]	N/A	Omitted from Analysis
ST Rollover	Operator causes rollover of ST	2, 16	4, 8	N/A [b]	N/A	Omitted from Analysis
TEV_Collision	Operator causes TEV to collide with WP or WPTT	15	7	N/A [b]	N/A	Omitted from Analysis
WPTT Derailment	Operator causes WPTT to derail	10, 13	6, 7	N/A[a]	N/A	Historical Data
WPTT Uncontrolled Tilt-down	Operator causes an uncontrolled tilt-down of the WPTT	10, 15	6, 7	N/A [b]	N/A	Omitted from Analysis

NOTE: [a] Historical data was used to produce a probability of crane drops; this historical data is not included as part of the HRA, but is addressed in Attachment C.
[b] These HFEs were initially identified, but omitted from analysis for various reasons, including a design change precluding the human failure, or the failure would require a series of unsafe actions in combination with mechanical failures, such that the event is no longer credible. See the appropriate HFE group in Attachment E for a case-by-case justification for these omissions.

AO = aging overpack; CRCF = Canister Receipt and Closure Facility; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; DSNF = U.S. Department of Energy spent nuclear fuel; ESD = event sequence diagram; HFE = human failure event; HVAC = heating, ventilation, and air conditioning; MAP = mobile access platform; MCC = motor control center; N/A = not applicable; OA = over arching (applies to multiple HFE groups, see Section 6.0.2); RC = railcar; SSC = structure, system, or component; SSCs = structures, systems, and components; ST = site transporter; TEV = transport and emplacement vehicle; TTC = a transportation cask that is upended using a tilt frame; TT = truck trailer; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

E8 REFERENCES

E8.1 DESIGN INPUTS

The PCSA is based on a snapshot of the design. The reference design documents are appropriately documented as design inputs in this section. Since the safety analysis is based on a snapshot of the design, referencing subsequent revisions to the design documents (as described in EG-PRO-3DP-G04B-00037, *Calculations and Analyses* (Ref. 2.1.1, Section 3.2.2.F)) that implement PCSA requirements flowing from the safety analysis would not be appropriate for the purpose of the PCSA.

The inputs in this section noted with an asterisk (*) indicate that they fall into one of the designated categories described in Section 4.1, relative to suitability for intended use. The inputs noted with a dagger (†) indicate cancelled or superseded documents for which the snapshot has not yet been updated.

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E8.1.2* ASME (American Society of Mechanical Engineers) NOG-1-2004. 2005. *Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder).* New York, New York: American Society of Mechanical Engineers. TIC: 257672. ISBN: 0-7918-2939-1

E8.1.3* ASME NUM-1-2004. 2005. *Rules for Construction of Cranes, Monorails, and Hoists (with Bridge or Trolley or Hoist of the Underhung Type).* New York, New York: American Society of Mechanical Engineers. TIC: 259317. ISBN: 0-7918-2938-3.

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E8.1.5* Benhardt, H.C.; Eide, S.A.; Held, J.E.; Olsen, L.M.; and Vail, R.E. 1994. *Savannah River Site Human Error Data Base Development for Nonreactor Nuclear Facilities (U).* WSRC-TR-93-581. Aiken, South Carolina: Westinghouse Savannah River Company, Savannah River Site. ACC: MOL.20061201.0160.

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POW-J032, Report No. 2, Issue 5. Leatherhead, England: Corporate Risk Associates. TIC: 259873.

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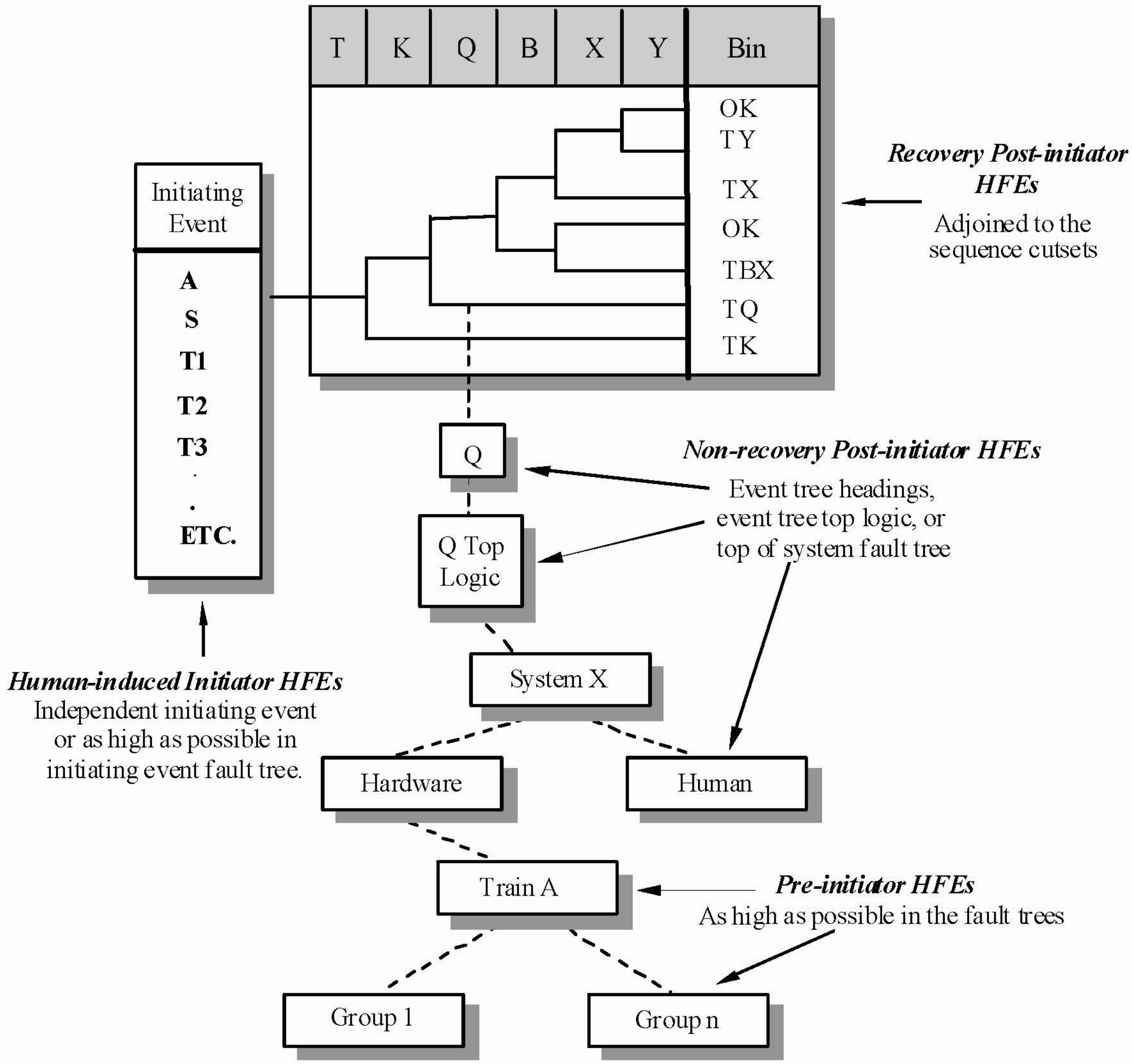
E8.2 DESIGN CONSTRAINTS

E8.2.1 10 CFR (Code of Federal Regulations) Part 63. 2007. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. U.S. Nuclear Regulatory Commission.

APPENDIX E.I
RECOMMENDED INCORPORATION OF HUMAN FAILURE EVENTS IN THE YMP PCSA

Figure E.I-1 provides a graphical illustration of how HFEs are incorporated into the PCSA.

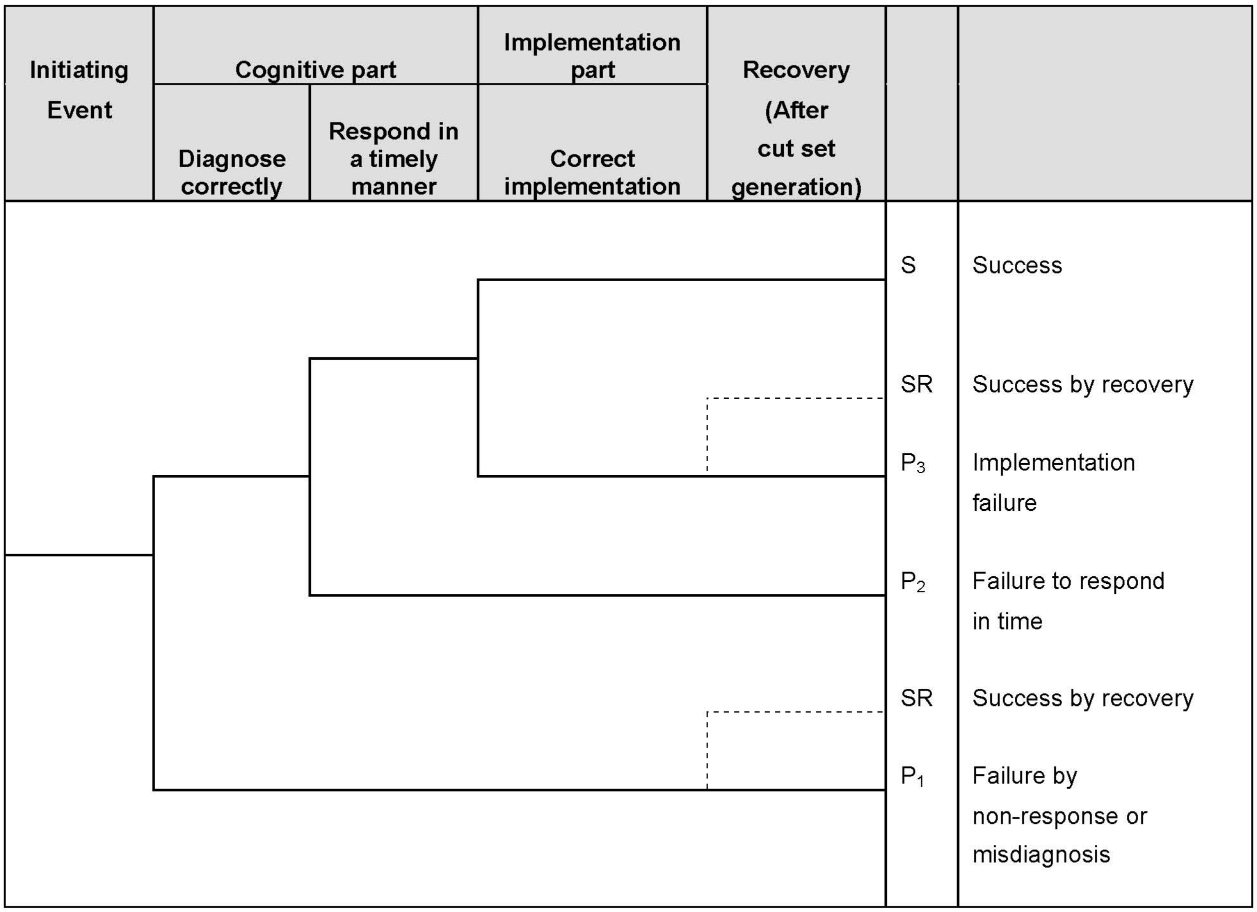


NOTE: HFE = human failure event.

Source: Original

Figure E.I-1. Incorporation of Human Reliability Analysis within the PCSA

APPENDIX E.II
GENERAL STRUCTURE OF POST-INITIATOR HUMAN ACTIONS



Source: Original

Figure E.II-1.Post Initiator Operator Action Event Tree

The representation in Figure E.II-1 consists of two elements, corresponding to a cognitive part (detection, diagnosis, and decision making) and an implementation (i.e., action) part.

P_1 represents the probability that operators make an incorrect diagnosis and decision and do not realize that they have done so. Some of the reasons for such mistakes are: incorrect interpretation of the procedures, incorrect knowledge of the plant state owing to communication difficulties, and instrumentation problems.

Given that the crew decides what to do correctly, there is still a possibility of failure to respond in time (represented by P_2) or making an error in implementation (represented by P_3).

However, it may be probable in certain scenarios that a recovery action can be taken. This consideration is taken into account after the initial quantification is completed and is applied as appropriate to the dominant cut sets.

APPENDIX E.III
PRELIMINARY (SCREENING) QUANTIFICATION PROCESS FOR HUMAN FAILURE EVENTS

The preliminary quantification process consists of the following:

Step 1—Complete the Initial Conditions Required for Quantification.

The preliminary quantification process requires the following:

- The baseline scenarios are available.
- The HFEs and their associated context have been defined.
  - Collect any additional information that is not already collected and that is needed to describe and define the HFEs (and associated contexts).
  - Review all information for clarity, completeness, etc.
  - Interpret and prioritize all information with respect to relevance, credibility, and significance.

Table E.III-1 provides examples of information normally identified using the ATHEANA method (*Technical Basis and Implementation Guidelines for a Technique for Human Event Analysis* (Ref. E8.1.22) that serve as inputs to the quantification process. The HFE/context descriptions in Table E.III-1 touch briefly on the information that is relevant to the screening-level quantification of the HFE. Since the baseline scenario generally touches on much of this information, the point of including the HFE/context descriptions is to summarize the information that pertains to the specific HFE to minimize the need for the analysts to refer back to the baseline scenario, except to obtain additional detail.

Table E.III-1. Examples of Information Useful to HFE Quantification

Information Type	Examples
Facility, conditions, and behavior for possible deviations of the scenarios	Reasonably possible unusual plant behavior and failures of systems; equipment, and indications, especially those that may be unexpected or difficult to detect by operators. Includes presence of interlocks that would have to fail to promote the deviation.
Operating crew characteristics (i.e., crew characterization)	Crew structure, communication style, emphasis on crew discussion of the "big picture."
Features of procedures	Structure, how implemented by operating crews, opportunities for "big picture" assessment and monitoring of critical safety functions, emphasis on relevant issue, priorities, any potential mismatches with deviation scenarios.
Relevant informal rules	Experience, training, practice, ways of doing things—especially those that may conflict with informal rules or otherwise lead operators to take inappropriate actions.
Timing	Plant behavior and requirements for operator intervention versus expected timing of operator response in performing procedure steps, etc.

Table E.III-1. Examples of Information Useful to HFE Quantification (Continued)

Information Type	Examples
Relevant vulnerabilities	Any potential mismatches between the scenarios and expected operator performance with respect to timing, formal and informal rules, biases from operator experience, and training, etc.
Error mechanisms	Any that may be particularly relevant by plant context or implied by vulnerabilities; applicable mechanisms depend upon whether HFE is a slip or mistake. Examples include: failures of attention, possible tunnel vision, conflicts in priorities, biases, missing or misleading indications, complex situations, lack of technical knowledge, timing mismatches and delays, workload, and human–machine interface concerns.
Performance-shaping factors	Those deemed associated with, or triggered by, the relevant plant conditions and error mechanisms.

NOTE: HFE = human failure event.

Source: Original

In Step 1, interpreting and prioritizing all information with respect to relevance, credibility, and significance is especially important if:

- Some information is applicable only to certain scenarios, HFEs, or contexts
- There are conflicts among information sources
- Information is ambiguous, confusing, or incomplete
- Information must be extrapolated, interpolated, etc.

Completion of the "lead-in" initial conditions is primarily performed by a single individual, using the results of the YMP HAZOP evaluation process and reviews of other relevant information sources. Discussions are also held with the Operations Department to augment that information, and the resulting write-ups are reviewed by the PCSA facility leads and the HRA team. The initial conditions are refined as part of an open discussion among the experts (in this case, the HRA team for the study) involved in the expert opinion elicitation process. The goal of this discussion is not to achieve a consensus but, rather, to advance the understanding of all the experts through the sharing of distributed knowledge and expertise. In each case, the scenario (or group of similar scenarios) and the HFE in question are described and the vulnerabilities and strong points associated with taking the right action are discussed openly among the HRA team.

Step 2—Identify the Key or Driving Factors of the Scenario Context.

The purpose of Step 2 is to identify the key or driving factors on operator behavior/performance for each HFE and associated context. Each expert participating in the elicitation process individually identifies these factors based on the expert's own judgment. Usually, these factors are not formally documented until Step 4.

Typically, there are multiple factors deemed most important to assessing the probability for the HFE in question. This is due to the focus of the ATHEANA search process on combinations of factors that are more likely to result in an integrated context (Ref. E8.1.22). When there is only a single driving factor, it is usually one that is so overwhelming that it alone can easily drive the estimated probability. For example, if the time available is shorter than the time required to perform the actions associated with the HFE, quantification becomes much simpler and other factors need not be considered.

Step 3—Generalize the Context by Matching it With Generic, Contextually Anchored Rankings, or Ratings.

In Step 3, each expert participating in the elicitation process must answer the following question for each HFE: based upon the factors identified in Step 2, how difficult or challenging is this context relative to the HFE being analyzed?

Answering this question involves independent assessments by each expert. In order to perform this assessment, the specifics of the context defined for an HFE must be generalized or characterized. These characterizations or generalizations then must be matched to general categories of failures and associated failure probabilities.

To assist the experts in making their judgments regarding the probability of events, some basic guidance is provided. In thinking about what a particular HEP associated with an HFE may be, they are encouraged to think about similar situations or experiences and use that to help estimate how many times out of 10, 100, 1,000, etc., would they expect crews to commit the HFE, given the identified conditions. The following examples of what different probabilities mean are provided to the experts to help them scale their judgments:

"Likely" to fail (extremely difficult/challenging)	~0.5	(5 out of 10 would fail)
"Infrequently" fails (highly difficult/challenging)[13]	~0.1	(1 out of 10 would fail)
"Unlikely" to fail (somewhat difficult/challenging)	~0.01	(1 out of 100 would fail)
"Highly unlikely" to fail (not difficult/challenging)	~0.001	(1 out of 1000 would fail)

The experts are allowed to select any value to represent the probability of the HFE. That is, other values (e.g., 3E−2, 5E−3) can be used. The qualitative descriptions above are provided initially to give analysts a simple notion of what a particular probability means. For exceptional cases, the quantification approach allows an HEP of 1.0 to be used when failure was deemed essentially certain. The following general guidance in Table E.III-2 is also provided to help calibrate the assessment by providing specific examples that fall into each of the above bins, and is based on the elicited judgment and consensus of the HRA team based on their past experience. This guidance applies to contexts where generally optimal conditions exist during performance of the action. Therefore, the experts should modify these values if they believe that the action may be performed under non-optimal conditions or under extremely favorable conditions. Values may also be adjusted to take credit for design features, controls and interlocks, or procedural safety controls[14,15]. Examples of such adjustments are also provided below; however

[13] The default value is 0.1. This value is used if no preliminary assessment is performed.

[14] As an initial preliminary value, unsafe actions that are backed up by interlocks are assigned a human error probability of 1.0 such that no credit for human performance is taken (i.e., only the interlocks are relied upon to demonstrate 10 CFR Part 63 (Ref. E8.2.1) compliance). If this proves insufficient, a more reasonable preliminary value is assigned to the unsafe action in accordance with this Appendix.

these values are not taken to be firm in any sense of the word, but rather simply as examples of where in general terms HEPs may fall and how they may relate to each other. Types of HFEs not listed here can be given values based on being "similar to" HFEs that are listed. Whatever value is selected, the basis is briefly documented.

Table E.III-2. Types of HFEs

PRE-INITIATOR HFEs	
Fail to properly restore a standby system to service	0.1
Failure to properly restore an operating system to service when the degraded state is not easily detectable	0.01
Failure to properly restore an operating system to service when the degraded state is easily detectable	0.001
Calibration error	0.01
HUMAN-INDUCED INITIATOR HFEs	
Failure to properly conduct an operation performed on a daily basis	0.001
Failure to properly conduct an operation performed on a very regular basis (on the order of once/week)	0.01
Failure to properly conduct an operation performed only very infrequently (once/month or less)	0.1
Operation is extremely complex OR conducted under environmental or ergonomic stress	×3
Operation is extremely complex AND conducted under environmental or ergonomic stress	×10
NON-RECOVERY POST-INITIATOR HFEs	
Not trained or proceduralized, time pressure	0.5
Not trained or proceduralized, no time pressure	0.1
Trained and/or proceduralized, time pressure	0.1
Trained and/or proceduralized, no time pressure	0.01

Source: Original

Step 4—Discuss and Justify the Judgments Made in Step 3

In Step 3, each expert independently provides an estimate for each HFE. Once all the expert estimates are recorded, each expert describes the reasons why they chose a particular failure probability. In describing their reasons, each expert identifies what factors (positive and negative) are thought to be important to characterizing the context and how this characterization fit the failure category description and the associated HEP estimate.

[15] Note that if such credit is taken, then it may be necessary (based on the PCSA results) to include these items in the nuclear safety design basis or the procedural safety controls for the YMP facilities.

After the original elicited estimates are provided, a discussion is held that addresses not only the individual expert estimates but also differences and similarities among the context characterizations, key factors, and failure probability assignments made by all of the experts. This discussion allows the identification of any differences in the technical understanding or interpretation of the HFE versus differences in judgment regarding the assignment of failure probabilities. Examples of factors important to HFE quantification that might be revealed in the discussion include:

- Differences in key factors and their significance, relevance, etc., based upon expert-specific expertise and perspective.
- Differences in interpretations of context descriptions.
- Simplifications made in defining the context.
- Ambiguities and uncertainties in context definitions.

A consensus opinion is not required following the discussion.

Step 5—Refinement of HFEs, associated contexts, and assigned HEPs (if needed)

Based upon the discussion in Step 4, the experts form a consensus on whether or not the HFE definition must be refined or modified, based upon its associated context. If the HFE must be refined or redefined, this is done in Step 5. If such modifications are necessary, the experts "reestimate" based upon the newly defined context for the HFE (or new HFEs, each with an associated context).

The experts participating in the elicitation process are also allowed to change their estimate after the discussion in Step 4 based on the discussions during that step, whether or not the HFE definition and context are changed. Once again, a consensus is not required.

Step 6—Determine final preliminary HEP for HFE and associated context

The final preliminary value to be incorporated into the PCSA for each HFE is determined in Step 6.

The failure probabilities assigned in the preliminary HRA quantification are based on the context outlined in the base case scenarios and deemed to be "realistically conservative." To help ensure this conservatism, if a consensus value could not be reached, the final failure probability that was assigned to each HFE was determined by choosing the highest assigned probability among the final estimates of the experts participating in the expert elicitation process.

APPENDIX E.IV
SELECTION OF METHODS FOR DETAILED QUANTIFICATION

There are a number of methods available for the detailed quantification of HFEs (preliminary quantification is discussed in Appendix E.III of this analysis). Some are more suited for use for the YMP PCSA than others. A number of methods were considered, but many were rejected as inapplicable or insufficient for use in quantification. Several sources were examined as part of the background analysis for selecting a method for detailed quantification (Ref. E8.1.17; Ref. E8.1.13; Ref. E8.1.24; and Ref. E8.1.21). As discussed in Section E3.2 the following four were chosen:

- ATHEANA expert judgment (Ref. E8.1.22).
- CREAM (Ref. E8.1.18)
- HEART (Ref. E8.1.28)/NARA (Ref. E8.1.11)
- THERP (Ref. E8.1.26).

This appendix discusses the selection process.

Basis for Selection—The selection process was conducted with due consideration of the HRA quantification requirements set forth in the ASME Level 1 PRA standard (Ref. E8.1.4) to the extent that those requirements, which were written for application to NPP PRA, apply to the types of operations conducted at the YMP. Certainly, all of the high level HRA quantification requirements were considered to be applicable. Further, all of the supporting requirements to these high level requirements were considered applicable, at least in regards to their intent. In some cases, the specifics of the supporting requirements are only applicable to NPP HRA and some judgment is needed on how to apply them. This was particularly true of those supporting requirements that judged certain specific quantification methods acceptable. This appendix lays out the specific case for the methods selected for use at the YMP (or, more to the point, the exclusion of certain methods that would normally be considered acceptable under the standard, but are deemed inappropriate for use for the YMP PCSA).

Differences between NPP and the YMP Relevant to HRA Quantification—There are a number of contrasts between the operations at the YMP and the operations at a NPP that affect the selection of approaches to performing detailed HRA quantification (Table E.IV-1).

Table E.IV-1. Comparison between NPP and YMP Operations

NPP	YMP
Central control of operations maintained in control room.	Decentralized (local), hands on control for most operations.
Most important human actions are in response to accidents.	Most important human actions are initiating events.
Post-accident response is important and occurs in minutes to hours. Short time response important to model in HRA.	Post-accident response evolves more slowly (hours to days). Short time response not important to model.
Multiple standby systems are susceptible to pre-initiator failures.	Standby systems do not play major role in the YMP safeguards, therefore few opportunities for pre-initiator failures.
Auxiliary operators sent by central control room operators to where needed in the plant.	Local control reduces time to respond.
Most actions are controlled by automatic systems.	Most actions are controlled by operators.
Reliance on instrumentation /gauges as operators' "eyes."	Most actions are local, either hands on or televised. Less reliance on man–machine interface.
High complexity of systems, interactions, and phenomena. Actions may be skill, rule, or knowledge based.	Relatively simple process with simple actions. Actions are largely skill based.
Many in operation for decades; HRA may include walk-downs and consultation with operators.	First of a kind; HRA performed for construction application, therefore walk-downs and consultation with operators not feasible.

NOTE: HRA = human reliability analysis; NPP = nuclear power plant; YMP = Yucca Mountain Project.

Source: Original

Assessment of Available Methods—There are essentially four general types of quantification approaches available:

1. Procedure focused methods:

   A. Basis: These methods concentrate on failures that occur during step-by-step tasks (i.e., during the use of written procedures). They are generally based on observations of human performance in the completion of manipulations without much consideration of the root causes or motivations for the performance (e.g., how often does an operator turn a switch to the left instead of to the right).

   B. Methods considered: THERP (Ref. E8.1.26).

   C. Applicability: This method is of limited use for the YMP because important actions are not procedure driven. Many operations are skill-based and/or semi-automated (e.g., crane operation, trolley operation, CTM operation, TEV operation). However, there are some instances where such an approach would be applicable to certain unsafe actions within an HFE. In addition, the THERP dependency model is adopted by NARA as being appropriate to use within a context-based quantification approach.

D. Assessment: THERP is retained as an option in the detailed quantification for its dependency model and for limited use when simple, procedure-driven unsafe actions are present within an HFE.

2. Time-response focused methods:

A. Basis: These methods focus on the time available to perform a task, versus the time required, as the most dominant factor in the probability of failure. They are, for the most part, based on NPP control room observations, studies, and simulator exercises. They also tend to be correlated with short duration simulator exercises (i.e., where there is a clear time pressure in the range of a few minutes to an hour to complete a task in response to a given situation).

B. As discussed in *Human Reliability Analysis: A Systems Engineering Approach with Nuclear Power Plant Applications* (Ref. E8.1.13), examples of time-response methods include: HCR (Ref. E8.1.13) and TRCs (Ref. E8.1.15).

C. Applicability: These methods are not applicable to the YMP because most actions do not occur in a control room and, in addition, are generally not subject to time pressure. This is particularly true of the most important HFEs, those that are human-induced initiators. Other than a desire to complete an action in a timely fashion to maintain production schedules, time is irrelevant to these actions, especially in the context of the type of time pressure considered by these methods. Even those actions at the YMP that may take place in a control room in response to an event sequence and have time as a factor would only require response in the range of hours or days, which is outside the credible range for these methods.

D. Assessment: No use can be identified for these methods within the YMP PCSA. None of them are retained.

3. Context and/or cognition driven methods:

A. Basis: These methods focus on the context and motivations behind human performance rather than the specifics of the actions, and as such are independent of the specific facility and process. To the extent that some of the methods are data-driven (i.e., they collect and use observations of human performance) the data utilized is categorized by GTT rather than by the type of facility or equipment where the human failure occurred. This makes them more broadly applicable to various industries, tasks, and situations, in large part because they allow context-specific PSFs to be considered. This allows for them to support a variety of contexts, individual performance factors (e.g., via PSFs) and human factor approaches.

B. Methods considered: HEART (Ref. E8.1.28; Ref. E8.1.29)/NARA (Ref. E8.1.11), CREAM (Ref. E8.1.18), and ATHEANA expert judgment (Ref. E8.1.22).

C. Applicability: The broad applicability of these methods and their flexibility of application make them most suited for application at the YMP. The use of information from a broad range of facilities and other performance regimes (e.g., driving, flying) support their use as facility-independent methods. The generic tasks considered can be applied to the types of actions of most concern to the YMP (i.e., human-induced initiators) as opposed to the more narrow definitions used in other approaches that make it difficult to use them for other than post-initiator or pre-initiator actions.

D. Assessment: Optimally it would be convenient to use only one of the three methods of this type for all the detailed quantification. However, HEART (Ref. E8.1.28)/NARA (Ref. E8.1.11) and CREAM (Ref. E8.1.18) approach their GTTs slightly differently and also use different PSFs and adjustment factors. There are unsafe actions within the YMP HFEs that would best fit the HEART (Ref. E8.1.28)/NARA (Ref. E8.1.11) approach and others that would best fit the CREAM (Ref. E8.1.18) approach. In addition, the union of the two approaches still has some gaps that would not cover a small subset of unsafe actions for the YMP (primarily in the area of unusual acts of commission). One gap relates to dependencies between actions, but in this case NARA (Ref. E8.1.11) specifically endorses the THERP (Ref. E8.1.26) approach and so this is used. However, other gaps exist. For these cases, the ATHEANA (Ref. E8.1.22) expert judgment approach provides a viable and structured framework for the use of judgment to establish the appropriate HEP values in a manner that would meet the requirements of the ASME RA-S-2002 (Ref. E8.1.4) standard. Therefore, all three of these methods are retained for use and the selection of one versus the other is made based on the specific unsafe action being quantified. This is documented as appropriate in the actual detailed quantification of each HFE.

4. Simplified methods:

A. Basis: These methods use the results of past PRAs to focus attention on those HFEs that have dominated risk. These are essentially PRA results from NPPs. As such, they presuppose NPP situations and actions, and define important PSFs based on these past NPP PRAs. They have very limited (if any) ability to investigate context, individual and human factors that are beyond NPP experience. The HEPs that result from applying these methods are calibrated to other NPP methods.

B. Methods considered: ASEP (Ref. E8.1.25), SPAR-H (Ref. E8.1.14).

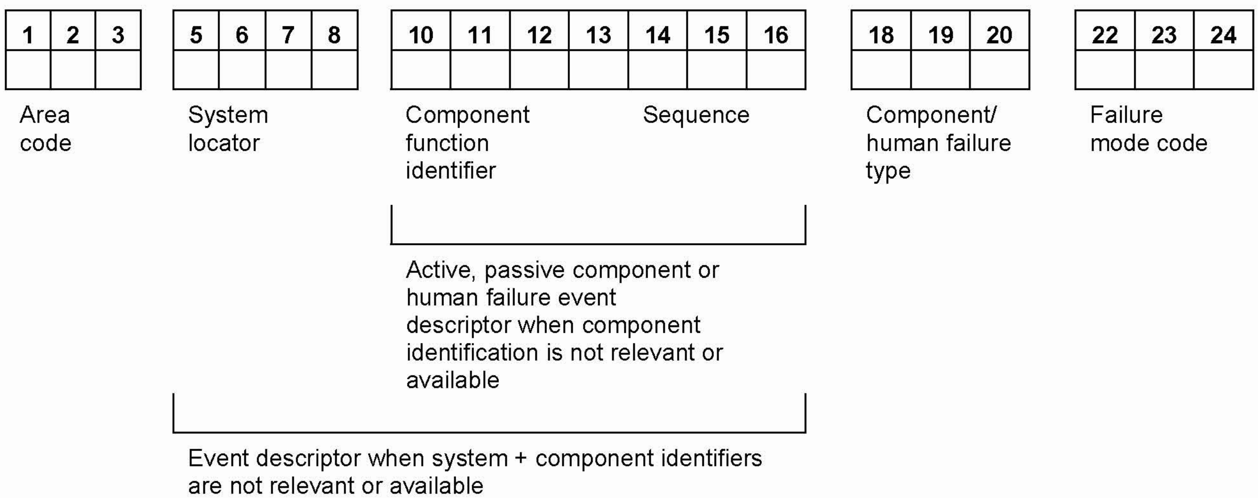
C. Applicability: These methods are clearly biased by their very close dependence on the results of past NPP PRAs. They are too limited for application beyond the NPP environment. They are not simply inappropriate for this application, but it would be extremely difficult to make a sound technical case regarding technical validity.

D. Assessment: No use can be identified for these methods within the YMP PCSA or any technical case made supporting them for a non-NPP application. None of them are retained.

APPENDIX E.V
HUMAN FAILURE EVENTS NAMING CONVENTION

Event names for HFEs in the YMP PCSA model follow the general structure of the naming convention for fault tree basic events. This is true whether the HFE is modeled in a fault tree, directly on an event tree, or as an initiating event. The convention, as adapted for HFEs, is as follows:

This basic event naming convention in Figure E.V-1 below is provided to ensure consistency with project standards and to permit this information to fit into a 24-character SAPHIRE field such that each basic event can be correlated to a unique component or human failure.



Source: Original

Figure E.V-1. Basic Event Naming Convention

The area code defines the physical design or construction areas where a component would be installed. Area codes are listed in *Engineering Standard for Repository Area Codes,* (Ref. E8.1.8). These codes are used rather than the facility acronyms to maintain consistency with Engineering. In this system, the CRCF is designated by area code 060, the Wet Handling Facility is 050, the Receipt Facility is 200, the Initial Handling Facility is 51A, and Subsurface is 800. Intra-Site Operations could fall under one of several repository area codes and therefore the most appropriate code to use was the repository general area code. However, this code was insufficient for the purposes of this analysis, and a designator of ISO was substituted instead. For the majority of cases, the area coding of HFEs in Attachment E reflects the location of the operations being evaluated, such as ISO for Intra-Site Operations. However, for certain HFEs, the coding corresponds to the location of the systems impacted by the human failure, such as HVAC, which is specific to the CRCF and therefore retains the 060 coding, and AC power, which retains the 26x and 27x coding. For these specific instances, such coding provides better traceability of the HFE back to the affected equipment.

The system locator code identifies operational systems and processes. System locator codes (four characters) are listed in Table 1 of *Repository System Codes* (Ref. E8.1.9). These are generally three or four characters long, such as VCT for tertiary confinement HVAC.

The component function identifiers identify the component function and are listed in the *Engineering Standard for Repository Component Function Identifiers* (Ref. E8.1.7). These are generally three or four characters long. Some BSC component function identifiers for typical components are shown in Table E.V-1, but in cases where there is not an equivalent match, the most appropriate PCSA type code should be used (also given in Table E.V-1).

The sequence code is a numeric sequence and train assignment (suffix), if appropriate, that uniquely identifies components within the same area, system, and component function.

If an HFE is related to the failure of an individual component with an existing component function identifier and sequence code, the naming scheme should utilize these codes in the event name. If an HFE is such that these codes do not apply, the basic event name can be a free form field for describing the nature of the event, such as HCSKSCF for operator topples cask during scaffold movement or HFCANLIDAJAR for operator leaves canister lid ajar, utilizing either seven characters when there is a relevant system locator code, or 12 characters when no system codes are applicable.

The human failure type and failure mode codes are three characters each, consistent with the coding provided in Table E.V-1 below.

For HFEs, the type code always begins with HF and continues with a one letter designator for the HFE temporal phase: P for pre-initiator, I for human-induced initiator, N for non-recovery post-initiator, R for recovery post-initiator (this latter code is not used during preliminary analysis).

Table E.V-1. Human Failure Event Type Codes and Failure Mode Codes

PRE-INITIATOR HFEs; TYP=HFP		**FMC=**
Fail to properly restore a standby system to service		RSS
Failure to properly restore an operating system to service when the degraded state is not easily detectable		ROH
Failure to properly restore an operating system to service when the degraded state is easily detectable		ROE
Calibration error		CAL
HUMAN-INDUCED INITIATOR HFEs; TYP=HFI		
Failure to properly conduct an operation	Operation is performed on a daily basis.	NOD
	Operation is performed on a very regular basis (on the order of once per week)	NOW
	Operation is performed only very infrequently (once per month or less)	NOM
Operation is extremely complex OR conducted under environmental or ergonomic stress	Operation is performed on a daily basis.	COD
	Operation is performed on a very regular basis (on the order of once per week)	COW
	Operation is performed only very infrequently (once per month or less)	COM

Table E.V-1. Human Failure Event Type Codes and Failure Mode Codes (Continued)

PRE-INITIATOR HFEs; TYP=HFP		**FMC=**
Operation is extremely complex AND conducted under environmental or ergonomic stress	Operation is performed on a daily basis.	CSD
	Operation is performed on a very regular basis (on the order of once per week)	CSW
	Operation is performed only very infrequently (once per month or less)	CSM
NON-RECOVERY POST-INITIATOR HFEs; TYP=HFN		
Not trained or proceduralized, time pressure		NPT
Not trained or proceduralized, no time pressure		NPN
Trained and/or proceduralized, time pressure		TPT
Trained and/or proceduralized, no time pressure		TPN
RECOVERY POST-INITIATOR HFEs; TYP=HFR		
Not trained or proceduralized, time pressure		NPT
Not trained or proceduralized, no time pressure		NPN
Trained and/or proceduralized, time pressure		TPT
Trained and/or proceduralized, no time pressure		TPN

NOTE: FMC = failure mode code; HFE = human failure event; HFI = human-induced initiator HFE; HFN = human failure non-recovery post-initiator HFE; HFP = pre-initiator HFE; HFR = human failure recovery post-initiator HFE; TYP = type.

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ATTACHMENT F
FIRE ANALYSIS

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TABLES (Continued)

ACRONYMS

CRCF	Canister Receipt and Closure Facility
DCMIS	digital control and management information system
DOE	U.S. Department of Energy
HEPA	high-efficiency particulate air
HLW	high-level radioactive waste
HVAC	heating, ventilation, and air conditioning
MCC	motor control center
NFPA	National Fire Protection Association
PCSA	preclosure safety analysis
PRA	probabilistic risk assessment
RF	Receipt Facility
RWF	residence weighting factor
SNF	spent nuclear fuel
TAD	transportation, aging, and disposal
WPTT	waste package transfer trolley
YMP	Yucca Mountain Project

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F1 INTRODUCTION

This document describes the work scope, definitions and terms, method, and results for the fire analysis performed as a part of the Yucca Mountain Project (YMP) preclosure safety analysis (PCSA). Fire analysis is divided into four major areas:

- Initiating event identification
- Initiating event quantification (including both ignition frequency and propagation probability)
- Fragility analysis (including convolution of fragility and hazard curves)
- Fire analysis model development and quantification.

Within the task, the internal events PCSA model is evaluated, with respect to fire initiating events, and modified as necessary to address fire-induced failures that lead to exposures. The lists of fire-induced failures that are included in the model are evaluated as to fire vulnerability, and fragility analyses are conducted as needed.