Table E6.5-12. HEP Model for HFE Group #5 Scenario 3(a) for 060-OpCTMImpact1-HFI-COD

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

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

Source: Original

The Boolean expression for this scenario follows:

$$A \times B \times \{[C \times (E2 + F1)] + [D \times (E1 + F2)]\} \times G =$$
$$0.0007 \times 0.07 \times \{[0.01 \times (0.5 + 0.001)] + [0.001 \times (0.01 + 0.5)]\} \times 2.7\text{E}{-05} =$$
$$0.0007 \times 0.07 \times 0.006 \times 2.7\text{E}{-05} = (<1\text{E}{-8}) \qquad \text{(Eq. E-26)}$$

E6.5.3.4.4.2 HFE Group #5 Scenario 3(b) for 060-OpCTMImpact1-HFI-COD

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

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

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

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

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

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

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

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

- CFF I3: Faulty diagnosis (either a wrong diagnosis or an incomplete diagnosis). The baseline HEP is 0.2.
- CPC "Working Conditions": The operator has optimal working conditions in the control room. The CPC for an interpretation task with advantageous working conditions is 0.8.
- CPC "Available Time": The operator clearly has adequate time before beginning the next steps in the process to realize that the amount of time spent in the lift is not reasonable for a canister lift. The CPC for an interpretation task with adequate available time is 0.5.
- CPC "Adequacy of Training/Preparation": Training is adequate with high experience. The CPC for an observation task with adequate training and high experience is 0.8.

Applying these factors yields the following:

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

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

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

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

Applying these factors yields the following:

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

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

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

Using the NARA HEP equation yields the following:

$$\text{Operator fails to notice that port slide gate does not fully close} = 0.0004 \times [(11-1) \times 0.1 + 1] \times [(3-1) \times 0.1 + 1] = 0.001 \qquad \text{(Eq. E-27)}$$

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

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

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

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

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

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

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

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

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

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

This is a mechanical failure of the interlock. This event is quantified in Section E6.5.3.4.1.

CTM slide gate interlock fails = 2.7E−5

HEP Calculation for Scenario 3(b)—The events in the HEP model for Scenario 3(b) are presented in Table E6.5-13.

Table E6.5-13. HEP Model for HFE Group #5 Scenario 3(b) for 060-OpCTMImpact1-HFI-COD

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

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

Source: Original

The Boolean expression for this scenario follows:

$$A \times B \times \{[C \times (E2 + F1)] + [D \times (E1 + F2)]\} \times G = 0.005 \times 0.07 \times \{[0.01 \times (0.5 + 0.001)] + [0.001 \times (0.01 + 0.5)]\} \times 2.7E{-}05 = 0.005 \times 0.07 \times 0.006 \times 2.7E{-}05 = (<1E{-}8) \quad \text{(Eq. E-28)}$$

E6.5.3.4.4.3 HFE Group #5 Scenario 3(c) for 060-OpCTMImpact1-HFI-COD

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

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

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

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

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

Using the NARA HEP equation yields the following:

$$\text{Operator puts CTM in maintenance mode} = 0.0001 \times [(9-1) \times 0.3 + 1] = 0.0004 \qquad \text{(Eq. E-29)}$$

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

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

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

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

Applying these factors yields the following:

Operator terminates lift prior to automatic stop = 0.003

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

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

Operator fails to close port slide gate = 0.01

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

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

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

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

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

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

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

CTM Slide Gate Interlock Fails

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

This is a mechanical failure of the interlock. This event is quantified in Section 6.5.3.4.1.

CTM slide gate interlock fails = 2.7E−5

HEP Calculation for Scenario 3(c)—The events in the HEP model for Scenario 3(c) are presented in Table E6.5-14.

Table E6.5-14. HEP Model for HFE Group #5 Scenario 3(c) for 060-OpCTMImpact1-HFI-COD

Designator	Description	Probability
A	Operator puts CTM in maintenance mode	0.0004
B	Operator terminates lift prior to automatic stop	0.003
C	Operator fails to close port slide gate	0.01
D	Operator fails to notice that port slide gate does not fully close	0.001
E1	Operator fails to close CTM slide gate (independent)	0.01
E2	Operator fails to close CTM slide gate (given failure to close the port slide gate)	0.5
F1	Operator fails to notice CTM slide gate does not fully close (independent)	0.001
F2	Operator fails to notice CTM slide gate does not fully close (given failure notice that port slide gate did not fully close)	0.5
G	CTM slide gate interlock fails	2.7E−05

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

Source: Original

The Boolean expression for this scenario follows:

$$A \times B \times \{[C \times (E2 + F1)] + [D \times (E1 + F2)]\} \times G = 0.0004 \times 0.003 \times \{[0.01 \times (0.5 + 0.001)] + [0.001 \times (0.01 + 0.5)]\} \times 2.7E{-}05 = 0.0004 \times 0.003 \times .006 \times 2.7E{-}05 = 7E{-}09 \times 2.7E{-}05 = (<1E{-}08) \quad \text{(Eq. E-30)}$$

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

$$1E{-}5 \times 2.7E{-}5 = (<1E{-}08) \quad \text{(Eq. E-31)}$$

E6.5.3.4.4.4 HFE Group #5 Scenario 3(d) for 060-OpCTMImpact1-HFI-COD

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

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

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

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

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

Operator leaves CTM in maintenance mode = 0.0007

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

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

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

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

Applying these factors yields the following:

Operator terminates lift prior to automatic stop = 0.003

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

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

Operator fails to close port slide gate = 0.01

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

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

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

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

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

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

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

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

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

CTM Slide Gate Interlock Fails

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

This is a mechanical failure of the interlock. This event is quantified in Section 6.5.3.4.1.

CTM slide gate interlock fails = 2.7E−5

HEP Calculation for Scenario 3(d)—The events in the HEP model for Scenario 3(d) are presented in Table E6.5-15.

Table E6.5-15. HEP Model for HFE Group #5 Scenario 3(d) for 060-OpCTMImpact1-HFI-COD

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

Table E6.5-15. HEP Model for Scenario 3(d) (Continued)

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

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

Source: Original

The Boolean expression for this scenario follows:

$$A \times B \times \{[C \times (E2 + F1)] + [D \times (E1 + F2)]\} \times G =$$
$$0.0007 \times 0.003 \times \{[0.01 \times (0.5 + 0.001)] + [0.001 \times (0.01 + 0.5)]\} \times 2.7E{-}05 =$$
$$0.0004 \times 0.003 \times 0.006 \times 2.7E{-}05 = 7E{-}09 \times 2.7E{-}05 = (<1E{-}08) \quad \text{(Eq. E-32)}$$

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

$$1E{-}5 \times 2.7E{-}5 = (<1E{-}08) \quad \text{(Eq. E-33)}$$

E6.5.3.4.4.5 HEP for HFE 060-OpCTMImpact1-HFI-COD

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

$$\text{060-OpCTMImpact1-HFI-COD} = \text{HFE 3(a)} + \text{HFE 3(b)} + \text{HFE 3(c)} +$$
$$\text{HFE 3(d)} = (<1E{-}8) + (<1E{-}8) + (<1E{-}8) + (<1E{-}08) = 4E{-}8 \quad \text{(Eq. E-34)}$$

NOTE: For lifting objects (transportation cask, aging overpack, and waste package lids), the only failure mode that is applicable is 3(d); therefore, 4E−8 conservatively models movement with the lid below the floor.

E6.5.3.4.5 Quantification of HFE Scenarios for 060-OPCTMDirExp1-HFI-NOD: Operator Causes Direct Exposure during CTM Activities (Second Floor)

E6.5.3.4.5.1 HFE Group #5 Scenario 4(a) for 060-OPCTMDirExp1-HFI-NOD

1. Worker violates administrative control by entering the Canister Transfer Room during canister transfer.

2. Operator fails to close port gate before raising shield skirt.

Worker Violates Administrative Control by Entering the Canister Transfer Room during Canister Transfer—If a worker enters the Canister Transfer Room during canister transfer operations, there is a potential for direct exposure. There are several administrative controls restricting personnel from entering the Canister Transfer Room during canister transfer. These controls include the following:

- Personnel are only allowed in the Canister Transfer Room during prescheduled times.

- All personnel must check in with the control room (where the CTM is controlled) before entering the Canister Transfer Room.

If these controls are violated and a person enters the Canister Transfer Room when transfer operations are occurring, that person increases the potential to be exposed.

Any worker that wishes to enter the Canister Transfer Room needs to get permission to do so from a supervisor. If a worker violates this requirement, there is nothing that stops the worker from entering the room. However, this administrative control is fundamental to the operation of the facility and applies to entry to all important (i.e., radiation-controlled) areas of the facility. This is best represented by NARA GTT A5, adjusted by the following EPCs:

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

- EPC 7: No obvious means of reversing an unintended action. The GTT HEP is based on there being time to correct potential errors. This does not exist for this task. The maximum effect of the EPC is 9, which applies when there is no means of recovering from an unintended action once executed. Given that the error is not correctable, the APOA is set at 1.0.

This assessment does not give credit for the worker believing that there is a need to enter the Canister Transfer Room in the first place.

Applying the NARA HEP equation yields the following:

$$\text{Worker violates administrative control by entering the Canister Transfer Room during canister transfer} = 0.0001 \times [(9-1) \times 1.0 + 1] = 0.0009 \qquad \text{(Eq. E-35)}$$

Operator Fails to Close Port Gate before Lifting Shield Skirt—Just entering the Canister Transfer Room during canister transfer cannot result in an exposure since the entire operation is shielded. Therefore, to result in an exposure, the shielding must be compromised. After the canister is placed in a receptacle (e.g., waste package, aging overpack, staging rack), the CTM operator is supposed to close the port gate and then raise the shield skirt and move the CTM. If the operator fails to close the port gate before the shield skirt is raised and before the CTM is moved, then the crew members on the floor of the Canister Transfer Room would get a direct exposure. This is a skill-based action that is performed as part of every CTM movement over a port gate. This action is completely independent of the worker entering the room.

This is a task execution error with no feedback and its consequences are immediate (i.e., no potential for recovery). This most closely corresponds to the task execution error CREAM CFF E5, adjusted for the following CPCs with values not equal to 1.0.

- CFF E5: Missed action. The baseline HEP is 0.03.

- CPC "Working Conditions": The working conditions for the operator are in a control room with a favorable environment. The CPC for advantageous working conditions for an execution task is 0.8.

- CPC "Availability of Procedures": With regard to the notification step, the procedures and checklist clearly list that this task needs to be performed. The CPC for appropriate availability of procedures for an execution task is 0.8.

- CPC "Available Time": There is more than enough time to successfully perform this task. The CPC for adequate available time for an execution task is 0.5.

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

Applying these factors yields the following:

Operator fails to close port gate before lifting
shield skirt = 0.03 × 0.8 × 0.8 × 0.5 × 0.8 = 0.008

HEP Calculation for Scenario 4(a)—The events in the HEP model for Scenario 4(a) are presented in Table E6.5-16.

Table E6.5-16. HEP Model for HFE Group #5 Scenario 4(a) for 060-OPCTMDirExp1-HFI-NOD

Designator	Description	Probability
A	Worker violates administrative control by entering the Canister Transfer Room during canister transfer	0.0009
B	Operator fails to close port gate before lifting shield skirt	0.008

NOTE: HEP = human error probability.

Source: Original

The Boolean expression for this scenario follows:

$$A \times B = 0.0009 \times 0.008 = 8E{-}06 \qquad \text{(Eq. E-36)}$$

E6.5.3.4.5.2 HEP for HFE 060-OpCTMDirExp1-HFI-NOD

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

$$\text{060-OpCTMDirExp1-HFI-NOD} = \text{HEP 4(a)} = 8E{-}6 \qquad \text{(Eq. E-37)}$$

E6.5.3.4.6 Quantification of HFE Scenarios for 060-OPStageRack1-HFI-NOD: Operator Causes Direct Exposure during Canister Staging

E6.5.3.4.6.1 HFE Group #5 Scenario 5(a) for 060-OPStageRack1-HFI-NOD

1. Operator fails to close staging rack port gate before raising shield skirt.

2. Supervisor fails to check that the port gate is closed at the end of canister transfer operations.

Operator Fails to Close Staging Rack Port Gate—If the CTM operator fails to close the staging rack port gate in the staging area after placing a canister in the staging rack, then during the course of normal operations, a worker entering the Canister Transfer Room after the canister transfer operations have ended would be exposed. After the canister is placed in the staging rack, the CTM operator is supposed to close the port gate, raised the shield skirt, and moved the CTM. The operator can fail to close the port gate and not notice that the port gate has remained open. This is a skill-based action that is performed as part of every CTM movement over a port gate. There is more than enough time to successfully perform this task.

This is a task execution error with no feedback, and its consequences are immediate (i.e., no potential for recovery). This most closely corresponds to the task execution error CREAM CFF E5, adjusted for the following CPCs with values not equal to 1.0:

- CFF E5: Missed action. The baseline HEP is 0.03.

- CPC "Working Conditions": The working conditions for the operator are in a control room with a favorable environment. The CPC for advantageous working conditions for an execution task is 0.8.

- CPC "Availability of Procedures": With regard to the notification step, the procedures and checklist clearly list that this task needs to be performed. The CPC for appropriate availability of procedures for an execution task is 0.8.

- CPC "Available Time": There is more than enough time to successfully perform this task. The CPC for adequate available time for an execution task is 0.5.

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

Applying these factors yields the following:

$$\text{Operator fails to close staging rack port gate after canister transfer} = 0.03 \times 0.8 \times 0.8 \times 0.5 \times 0.8 = 0.008$$

Supervisor Fails to Check Port Gates—Once the canisters are in their proper receptacle (i.e., waste package, aging overpack, or staging rack) and the loaded WPTT/site transporter has moved to the Waste Package Positioning Room/Cask Preparation Area, the supervisor must complete an end-of-operations checklist. Before the canister transfer activities can be considered complete, the supervisor must verify per the checklist that all the port gates, particularly the staging rack port gates, are closed. The supervisor is likely only to check the port gates that were involved in the transfer(s) involved in that shift (e.g., if canisters were only moved to a staging rack, then the supervisor would only be inclined to check that staging rack). The check is done remotely via camera; however, the port gates are clearly visible. It is expected that, if the supervisor performs the check, the supervisor would notice that the port gate was open because the supervisor would be looking specifically for that. The failure of concern, then, is the omission of this check. Because this is a procedural control and is emphasized in training, this is not classified as a simple EOO. The most appropriate failure mode was considered to be a NARA GTT B3, failure to "set system status as part of routine operations using strict administratively controlled procedures." The example given for this GTT was "a main control room operator does not adhere to administrative controls (including daily checks) and fails to maintain specified reserve feed water stocks." While the supervisor is not actually setting a system as part of this check, this failure mode was considered most applicable because the context of the error and type of error was the most similar to the unsafe action being quantified. The baseline HEP for this failure is 0.0007, adjusted for the following EPCs:

- EPC 14: A conflict between immediate and long-term objectives. There is more than enough time to successfully perform this task; however, the most likely context for this particular error is if the supervisor feels rushed (e.g., it is the end of the shift and the supervisor is impatient to get home). The full affect of this EPC is ×2.5. The full affect of this EPC was considered applicable, and was assigned an APOA of 1.

- EPC 18: Low workforce morale or adverse organizational environment. This EPC was considered relevant because there maybe some complacency on the part of the supervisor, who trusts the CTM operator and may be less likely to take the check seriously. The full affect of this EPC is ×2. The example given for the full affect is "members of the workforce perceive no value in the tasks they undertake or the values of the organization…." The full affect can be reduced if "personnel have some sense of their value in the context of organization and in the tasks they are undertaking." While complacency may be a factor, the supervisor understands the consequences associated with a failure to close the port gates in the staging rack, and so the APOA was assessed to be 0.5.

Applying these factors yields the following:

$$\text{Supervisor fails to check port gates} = 0.0007 \times [(2.5-1) \times 1 + 1] \times [(2-1) \times 0.5 + 1] = 0.003 \qquad \text{(Eq. E-38)}$$

HEP Calculation for Scenario 5(a)—The events in the HEP model for Scenario 5(a) are presented in Table E6.5-17.

Table E6.5-17. HEP Model for HFE Group #5 Scenario 5(a) for 060-OPStageRack1-HFI-NOD

Designator	Description	Probability
A	Operator fails to close staging rack port gate after canister transfer	0.008
B	Supervisor fails to check port gates	0.003

NOTE: HEP = human error probability.

Source: Original

The Boolean expression for this scenario follows:

$$A \times B = 0.008 \times 0.003 = 3E{-}05 \qquad \text{(Eq. E-39)}$$

E6.5.3.4.6.2 HEP for HFE 060-OPStageRack1-HFI-NOD

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

$$\text{060-OpCTMDirExp1-HFI-NOD} = \text{HEP } 5(a) = 3E{-}5 \qquad \text{(Eq. E-40)}$$

E6.5.4 Results of Detailed HRA for HFE Group #5

The final HEPs for the HFEs that required detailed analysis in HFE Group #5 are presented in Table E6.5-18 (with the original preliminary value shown in parentheses).

Table E6.5-18. Summary of HFE Detailed Analysis for HFE Group #5

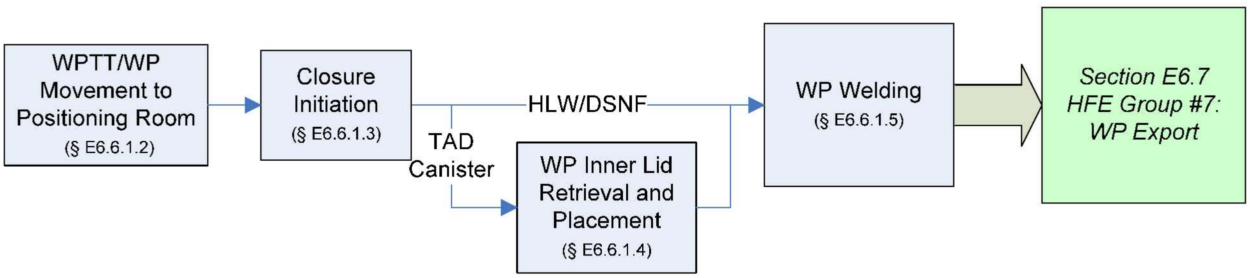
HFE	Description	Final Probability
060-OpCTMdrop001-HFI-COD	Operator causes drop of object onto canister during CTM operations	4E−7 (2E−03)
060-OpCTMdrop002-HFI-COD	Operator causes drop of canister during CTM operations (low level drop)	5E−7 (2E−03)
	Applied to removing a DPC from a TC	5E−7 (2E−03)
	Applied to removing any other canister from a TC or any canister from an AO	5E−7 (2E−03)
060-OpCTMImpact1-HFI-COD	Operator moves the CTM while canister or object is below or between levels	4E−8 (1E−03)
060-OpCTMDirExp1-HFI-NOD	Direct exposure during CTM activities (Second Floor)	8E−6 (1E−4)
060-OPStageRack1-HFI-NOD	Direct exposure during canister staging	3E−5 (1E−3)

NOTE: AO = aging overpack; CTM = canister transfer machine; DPC = dual-purpose canister; HFE = human failure event; TC = transportation cask.

Source: Original

E6.6 ANALYSIS OF HUMAN FAILURE EVENT GROUP #6: WASTE PACKAGE ASSEMBLY AND CLOSURE

HFE group #6 corresponds to the operations and initiating events associated with the ESD and HAZOP evaluation nodes listed in Table E6.0-1, covering waste package assembly and closure. The operations covered in this HFE group are shown in Figure E6.6-1. Closure activities begin with the canister in the waste package, aligned with the waste package port with the port closed. The WPTT moves the loaded waste package from underneath the Canister Transfer Room into position underneath the Waste Package Closure Room where the waste package is closed in preparation for export to the drifts. Closure activities include installing an inner lid (TAD canister only), spread ring, and outer lid, inerting the package, and sealing (welding and polishing) the package. This operation ends with the waste package ready for emplacement, but still in a vertical position in the Waste Package Closure Room.



NOTE: § = Section; DSNF = Department of Energy spent nuclear fuel; HFE = human failure event; HLW = high-level radioactive waste; TAD = transportation, aging, and disposal; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure E6.6-1. Activities Associated with HFE Group #6

E6.6.1 Group #6 Base Case Scenario

E6.6.1.1 Initial Conditions and Design Considerations Affecting the Analysis

The following conditions and design considerations were considered in evaluating HFE group #6 activities:

1. The waste package is secured to the WPTT and is positioned in the Waste Package Positioning Room under the Waste Package Closure Room.

2. The waste package has both the inner lid and spread ring already in place.

3. The waste package port slide gate is closed. There is an interlock between the port slide gates and the Waste Package Positioning Room shield doors. The port slide gate cannot be open while the shield doors to the Waste Package Positioning Room are also open.

4. All operations involving waste package assembly and closure are performed remotely. Operators have an adequate view of all operations via camera.

The following personnel are involved in this set of operations:

- RHS operator
- Arm operators (two)
- WPTT operator
- Quality control
- Level 2 and 3 NDE personnel
- Supervisor.

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

E6.6.1.2 WPTT Movement with Loaded Waste Package under the Waste Package Closure Room

The operator remotely controls the WPTT with a loaded waste package and moves it underneath the Waste Package Closure Room. The WPTT rides on rails, travels at one speed, and has preprogrammed paths to follow. The operator can only start the WPTT movement or make it stop. There is no shield door to traverse in this transfer across the Waste Package Positioning Room.

E6.6.1.3 Closure Process Initiation (Loaded Waste Package with TAD Canister /HLW/SNF)

The operator uses the camera and the bumpy bar code reader to read the bar code on the waste package to ensure it is the correct waste package. At this time, the operator puts the waste package serial number into the tracking chart. This step is verified by quality control.

E6.6.1.4 Waste Package Inner Lid Retrieval and Placement on Waste Package (Waste Package with TAD Canister Only)

The waste package inner lid (which includes the spread ring) is placed on the waste package in the Waste Package Closure Room for waste packages containing shielded waste forms (i.e., TAD canisters). The RHS operator moves the remote handling crane to the waste package inner lid staging area, lifts the inner lid, moves it to the waste package, lowers the inner lid onto the waste package and disengages the grapple.

E6.6.1.5 Waste Package Welding

E6.6.1.5.1 Spread Ring Expansion for Seal Weld

Once the spread ring position is verified, the operator uses the RHS and camera to engage the spread ring expander tool. The RHS operator uses the expander tool to expand the spread ring.

E6.6.1.5.2 Spread Ring Welding to Inner Vessel and Inner Lid; NDE of Weld

The welding team is comprised of two arm operators, an RHS operator, a quality control person, and level 2 and 3 NDE personnel. Each arm operator is responsible for welding half the circumference of the spread ring. The RHS operator is in charge of changing the end effectors as needed for the process. The processes include normal welding, grinding out the weld, and dressing the weld. The arm operators use the robotic arm to do the actual welding, and quality control supervises, visually inspects, and verifies the weld. For this weld, there is a constant stainless steel weld wire spool feed. Level 2 and 3 NDE personnel must sign off this step.

E6.6.1.5.3 Waste Package Inerting and Leak Test at Spread Ring and Purge Port Plug

All operations in this step are performed remotely. The RHS operator remotely retrieves the purge port tool and places it on top of the purge port. Once properly positioned, the RHS operator initiates the port tool and allows the helium to flow until sufficient time has passed and the pressure gage gives the proper reading. The RHS operator then sends the signals for the port tool to stop helium flow, closes the cap and performs leak detection, and then checks the indicators to ensure there are no leaks before continuing. Quality control verifies this step.

E6.6.1.5.4 Purge Port Cap Retrieval and Placement

The RHS operator retrieves the purge port cap from its staging area, scans it with the bumpy bar code reader, documents the serial number, and places it onto the purge port. This is verified by quality control.

E6.6.1.5.5 Purge Port Cap Welding and NDE of Weld

The RHS operator installs the end effector on the robotic arm. The weld material is the same stainless steel used to weld the spread ring. The arm operator welds the cap in place while quality control visually inspects the process. Once welded, the RHS operator switches out the end effector for a dressing end effector, and the arm operator dresses the weld while quality control visually inspects. Level 2 and 3 NDE personnel must sign off this step.

E6.6.1.5.6 Outer Lid Retrieval and Placement on the Waste Package from the Waste Package Closure Room

The RHS operator uses the camera and bumpy bar code reader to read the bar code on the waste package outer lid. At this time, the operator puts the waste package serial number into the tracking chart. This step is verified by quality control. Once the outer lid is documented, the operator retrieves the lid, engages the lid grapple, moves the lid to the proper position and then disengages the grapple.

E6.6.1.5.7 Outer Lid Welding to Outer Barrier and NDE of Weld

In preparation for this step, the RHS operator switches out the stainless steel weld feed spool for Alloy 22. This step is nearly identical to welding the inner lid (Section E6.6.1.5.2). The difference is that the end effector used has an ultrasonic testing/eddy current testing (UT/ET) attachment that follows and tests the weld. The weld and UT/ET testing is verified by level 2 and 3 NDE personnel.

E6.6.1.5.8 Stress Mitigation and NDE on Outer Lid

The RHS operator places the stress mitigation tool on the outer lid, and the operator and quality control visually inspect the polish using a camera. Once the stress mitigation tool is done, the RHS operator removes the tool and places a UT/ET end effector on the robotic arm. The arm operator commences testing. The sealed waste package is verified again by level 2 and 3 NDE personnel.

E6.6.2 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 waste package assembly and closure are summarized in Table E6.6-1. 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.

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Table E6.6-1. HFE Group #6 Descriptions and Preliminary Analysis

HFE ID	HFE Brief Description	ESD	Preliminary Value	Justification
060-OpWPCollide1-HFI-NOD	*Operator Causes Low-Speed Collision of WPTT during Transfer to Closure Area*: As the WPTT is moved from the WP Loading Room to the WP Closure Room, the operator can cause the WPTT to collide into an SSC. The WPTT speed is physically limited by motor design, so all collisions of the WPTT are low-speed.	10	3E−03	The WPTT is on rails, but an operator can cause a collision of the WPTT with an object in its path or into an SSC. The WPTT speed is physically limited by motor design, so all collisions of the WPTT are low-speed collisions. This failure is nearly identical to collision of the railcar while entering the facility (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), and was assigned the same probability. This is a conservative preliminary value because the path the WPTT travels is expected to have fewer obstructions (doors, potential objects in the path) to collide into. The preliminary value was chosen based on the determination that this failure is "highly unlikely" (one in a thousand or 0.001) and was adjusted because there are several ways for a collision to occur (×3).
060-OpTiltDown01-HFI-NOD	*Operator Initiates Premature Tilt-Down during Transfer to Closure Area*: The operator can inadvertently initiate tilt-down of the WP during transfer to the WP Closure Room. If the WP is near a facility structure then this could result in a collision of the WP.	10	1.0	The operator can cause the WPTT to prematurely tilt down. The WPTT operator is in the process of driving the WPTT to the Waste Package Positioning Room. Tilt-down only occurs during waste package loadout in the Waste Package Loadout Room, and the controller for the WPTT tilt-down is distinct from other WPTT controls. In order to accomplish this failure, several interlocks must also fail. These interlocks, including an interlock taking power away from the WPTT when the port gate is open and interlock between the tilt-down mechanism and the docking station, have no bypass. To be conservative, unsafe actions that require an equipment failure to cause an initiating event are generally assigned an HEP of 1.0.
WPTT Derailment	*Operator Causes Derailment of WPTT*: The WPTT travels on rail from the WP Loading Room to the WP Positioning Room. During this transfer the operator can cause the WPTT to derail by running over a large object left on the rail or through other such mechanisms.	10	N/A[a]	In this step, the WPTT moves on rails from outside the Waste Package Loadout Room to the closing position in the Waste Package Positioning Room below the Waste Package Closure Room. During this travel, there is a probability that the WPTT can derail, leading to a tipover of the WPTT. This HFE was not explicitly quantified because the probability of derailment due to human failure is incorporated in the historical data used to provide a general failure probability for derailment. Documentation for this failure can be found in Attachment C.
060-OPWPInnerLid-HFI-NOD	*Operator Fails to Install WP Inner Lid (HLW/SNF Only)*: If the CTM operators fail to install the WP inner lid (Section E6.5.1.4) and a person violates the procedural controls and enters the WP closure area when the WPTT is transferred into the room, that person gets a direct exposure. This failure only applies to waste packages with HLW/SNF; TAD canisters are shielded on top, and do not expose personnel to radiation if the waste package inner lid is not in place.	19	1E−04	The CTM operator fails to install the WP inner lid during CTM operations (Section E6.5, HFE Group #5); however, the actual direct exposure does not occur unless there is an additional unsafe action during closure operations performed in this section. If the CTM operator fails to install the waste package inner lid during CTM operations (Section E6.5.1.4) and a worker enters the Waste Package Closure Room against procedural controls during waste package assembly and closure operations, then that worker gets a direct exposure. The CTM operator would have to omit a major step in CTM operations to fail to install the waste package inner lid. Once the CTM operations are over, the waste package is moved into the Waste Package Positioning Room for waste package closure. If there is a worker in the Waste Package Closure Room, they are exposed. There are no interlocks to prevent this error, however, there is a procedural control associated with the radiation protection program that restricts access to the Waste Package Closure Room while a cask is in the Positioning Room. The closure operation begins with verification and documentation of the inner lid serial number. If the inner lid is missing, it is most likely to be noticed during this procedure. However, if this procedure is omitted, the waste package proceeds to welding. A team of at least four people weld the inner lid to the waste package and the weld is then verified and signed off by quality control after a UT/ET inspection of the weld. The UT/ET weld inspection is an integral part of the welding process and cannot be omitted. During this closure process, the missing inner lid can be detected. This HFE was considered extremely unlikely, requiring two independent human failures (including failing to abide by a serious procedural control) and was accordingly assigned a preliminary value of 0.0001.
Improper WP Closure	*Operator Damages Canister during Welding*: The WP inner and outer lids are welded closed as part of WP closure activities. This is a remote operation with a high level of automation; however, it may be possible that the welder can improperly weld the canister such that the canister becomes damaged. Note: Improper welding may also have postclosure implications. However, HFEs which have no safety consequences over the preclosure period, but may have consequences postclosure that are out of the scope of this analysis and are addressed in the postclosure safety assessment.	11	N/A	The analysts could not identify any human actions which would contribute to canister damage during welding. Latent conditions due to bad welds may have consequences postclosure, but these conditions are out of the scope of this analysis and are addressed in the postclosure safety assessment.

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Table E6.6-1. HFE Group #6 Descriptions and Preliminary Analysis (Continued)

HFE ID	HFE Brief Description	ESD	Preliminary Value	Justification
Drop of Object	*Operator Drops Object on Canister with RHS*: The WP inner and outer lids are welded closed as part of WP closure activities. The RHS is used to move objects over the canister, including the outer lid, as part of this task. The operator could drop an object onto the canister during these lifts.	11	N/A[a]	In this activity the operator uses the RHS to move several objects over the waste package and canister. The outer lid is moved over the waste package and, for TAD canisters, the inner lid is also moved over the waste package. Other objects, such as spools of welding material, may also be moved over the waste package during this operation; however, the inner and outer lids are the only objects that are heavy enough to potentially damage the waste package or canister. These HFEs were not explicitly quantified because the probability of a crane drop due to human failure is incorporated in the historical data used to provide general failure probabilities for drops involving various crane and rigging types. Documentation for this failure can be found in Attachment C.
WPTT uncontrolled tilt-down	Operator causes uncontrolled tilt-down of WPTT	10	N/A	No human actions were identified that would contribute to an uncontrolled tilt-down.

NOTE: [a] HRA preliminary value replaced by use of historic data (Attachment C)
CTM = canister transfer machine; CRCF = Canister Receipt and Closure Facility; ESD = event sequence diagram; HFE = human failure event; N/A = not applicable; RHS = remote handling system; SSC = structure, system, or component; TAD = transportation, aging, and disposal; TEV = transport and emplacement vehicle; UT/ET = ultrasonic testing/eddy current testing; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

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E6.6.3 Detailed Analysis

After the preliminary screening analysis and initial quantification are completed, those HFEs that appear in dominant cut sets for event sequences that do not comply with the 10 CFR 63.111 performance objectives are subjected to a detailed analysis. The overall framework for the HRA is based upon the process guidance provided in ATHEANA (Ref. E8.1.22). Consistent with that framework, the following four steps from the methodology described in Section E3.2 provide the structure for the detailed analysis portion of the HRA:

Step 5: Identify Potential Vulnerabilities

Prior to defining specific scenarios that can lead to the HFEs of interest (Step 6), information is collected to define the context in which the failures are most likely to occur. In particular, analysts search for potential vulnerabilities in the operators' knowledge and information base for the initiating event or base case scenario(s) under study that might result in HFEs or unsafe actions. This information collection step discussed in Section E6.6.3.2.

Step 6: Search for HFE Scenarios (Scenarios of Concern)

An HFE scenario is a specific progression of actions with a specific context that leads to the failure of concern; each HFE is made up of one or more HFE scenarios. In this step, documented in Sections E6.6.3.3 and E6.6.3.4, the analyst identifies deviations from the base case scenario that are likely to result in risk-significant unsafe action(s). These unsafe actions make up an HFE scenario. In serious accidents, these HFE scenarios are usually combinations of various types of unexpected conditions.

Step 7: Quantify Probabilities of HFEs

Detailed HRA quantification methods are selected as appropriate for the characteristics of each HFE and are applied as explained in Section E6.6.3.4. Four quantification methods are utilized in this quantification:

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

There is no implication of preference in the order of listing these methods. They are jointly referred to as the "preferred methods" and are applied either individually or in combination as best suited for the unsafe action quantified. The ATHEANA (Ref. E8.1.22) expert judgment method (as opposed to the overall ATHEANA (Ref. E8.1.22) methodology that forms the framework and steps for the performance of this HRA) is used when the other methods are deemed to be inappropriate to the unsafe action, as is often the case for cognitive EOCs.

Appendix E.IV of this analysis explains why these specific methods were selected for quantification and gives some background on when a given method is applicable based on the focus and characteristic of the method.

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

Step 8: Incorporate HFEs into the PCSA

After HFEs are identified, defined, and quantified, they must be incorporated into the PCSA. The summary table of HFEs by group that lists the final HEP by basic event name provides the link between the HRA and the rest of the PCSA. This table can be found in Section E6.6.4.

E6.6.3.1 HFEs Requiring Detailed Analysis

The detailed analysis methodology, Sections E3.2.5 through E3.2.9, states that HFEs of concern are identified for detailed quantification through the preliminary analysis (Section E3.2.4). An initial quantification of the CRCF PCSA model determined that there is one HFE in this group whose preliminary value was too high to demonstrate compliance with the performance objectives stated in 10 CFR 63.111. This HFE is presented in Table E6.6-2.

Table E6.6-2. Group #6 HFE Requiring Detailed Analysis

HFE	Description	Preliminary value
060-OpWPInnerLid-HFI-NOD	Operator causes direct exposure due to failure to properly install WP inner shield lid	1E−04

Source: Original

E6.6.3.2 Assessment of Potential Vulnerabilities (Step 5)

For those HFEs requiring a detailed analysis, the first step in the approach to conducting a detailed quantification is to identify and characterize the factors that could create potential vulnerabilities in the crew's ability to respond to the scenarios of interest and might result in the HFEs or unsafe actions. In this sense, the "vulnerabilities" are the context and factors that influence human performance and constitute the characteristics, conditions, rules and tendencies that pertain to all the scenarios analyzed in detail.

These vulnerabilities are identified through activities including but not limited to, the following:

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

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

3. Insights gained during the performance of the other PCSA tasks (e.g., initiating events analysis, systems analysis, and event sequence analysis).

The vulnerabilities discussed in this section pertain only to those aspects of the closure operation that relate to potential human failure scenarios relevant to the HFE listed above. Other vulnerabilities exist that would be relevant to other potential HFEs that can occur during the closure operation, but these have no bearing on this analysis. In addition, the potential vulnerabilities presented below are those that relate to the actions relevant to the above HFE and that pertain to those parts of the HFE scenarios that occur during this phase of the CRCF process. Note that the occurrence of this HFE begins with unsafe actions during CTM operations (i.e., the placing of the inner lid into the waste package after loading the canister). Therefore, the vulnerabilities associated with that operation also apply. These vulnerabilities are discussed in Section E6.5.3.2.

E6.6.3.2.1 Operating Team Characteristics

WPTT Operator—Located in the Operations Room, the WPTT operator has received training for the WPTT and has observed operations prior to being allowed to operate the WPTT on a dry run. The WPTT operator has signed off to operate the WPTT based on an evaluation of proficiency during a dry run. The WPTT operator has been observed on initial operations before being signed off for solo operation. A single operator is assigned to the WPTT operation.

Supervisor—The supervisor is located in the Operations Room. The supervisor watches over operations, and verifies the hand over from the CTM operator to the WPTT operator. The supervisor also grants or denies permission for personnel to enter the Waste Package Closure Room.

E6.6.3.2.2 Operation and Design Characteristics

The door to the Waste Package Closure Room is unshielded and unlocked. Radiation control signs and flashing lights (non-ITS equipment) are provided outside the door during waste package closure.

A checklist that must be filled out before the waste package is transferred to the Waste Package Closure Room to ensure the correct canisters are in a waste package and, as appropriate, ensure that the inner lid is installed on the waste package.

Personnel may be located in the Waste Package Closure Room before the WPTT is moved to the Waste Package Positioning Room.

E6.6.3.2.3 Formal Rules and Procedures

Procedural Controls—Procedural controls ensure that the operators and maintenance personnel do not enter the Waste Package Closure Room except during scheduled times. A personnel accountability system is associated with entering and exiting the Waste Package Closure Room. Personnel are required to check in with the supervisor and tag in and tag out before entering or after leaving the Waste Package Closure Room.

E6.6.3.2.4 Operator Tendencies and Informal Rules

Consequences of Failure—The operations are performed remotely. No personnel are in the vicinity of the operation, and so the threat of physical injury is absent. The WPTT operator expects that failures are mitigated by design features without serious consequences, which promotes complacency in the operations.

E6.6.3.2.5 Operator Expectations

Anticipatory Actions—The operator expects that no one attempts to enter the Waste Package Closure Room without a compelling reason.

E6.6.3.3 HFE Scenarios and Expected Human Failures (Step 6)

Given that the vulnerabilities that provide the operational environment and features that could influence human performance have been specified, then the HFE scenarios within this environment are identified. An HFE scenario is a specific progression of actions during normal operations (with a specific context) that lead to the failure of concern; each HFE is made up of one or more HFE scenarios. In accordance with the methodology, each scenario integrates the unsafe actions with the relevant equipment failures so as to provide the complete context for the understanding and quantification of the HFE.

The HAZOP evaluation is instrumental in initially scoping out the HFE scenarios, but they are then refined through discussions with subject matter experts from a wide range of areas, as described in Section E4.2.

Table E6.6-3 summarizes all of the HFE scenarios developed for the HFE in this group.

Table E6.6-3. HFE Scenarios and Expected Human Failures for HFE Group #6

HFE	HFE Scenarios
060-OpWPInnerLid-HFI-NOD *Operator Fails to Install WP Inner Lid*	HFE Scenario 1(a): (1) Operator fails to install the WP inner shield lid, (2) Worker violates administrative control by entering the WP Closure Room prior to the start of welding activities.

NOTE: HFE = human failure event; WP = waste package.

Source: Original

The Boolean logic of this HFE scenario is expressed with an implicit AND connecting the subsequent unsafe actions and OR notation wherever two unsafe action paths are possible, as shown in Table E6.6-3.

The HFE scenarios summarized in Table E6.6-3 are discussed and quantified in detail below.

E6.6.3.4 Quantitative Analysis (Step 7)

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

This section provides a description of the quantitative analysis performed, and is structured hierarchically by each HFE category (identified by a basic event name), the HFE scenario, and then the unsafe actions under each scenario, as previously documented in Table E6.6-3.

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

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

E6.6.3.4.1 Common Values Used in the HFE Detailed Quantification

There is only one HFE scenario associated with this HFE.

E6.6.3.4.2 Quantification of HFE Scenario for 060-OPWPInnerLid-HFI-NOD: Operator Causes Direct Exposure Due to Failure to Properly Install Waste Package Inner Shield Lid

E6.6.3.4.2.1 HFE Group #6 Scenario 1(a) for 060-OPWPInnerLid-HFI-NOD

1. Operator fails to install the waste package inner shield lid
2. Worker violates administrative control by entering the Waste Package Closure Room prior to the start of welding activities.

Operator Fails to Install the Waste Package Inner Shield Lid—For waste forms with unshielded canisters (DOE standardized canisters, multicanister overpacks, and HLW), the waste package inner lid is placed on the waste package with the CTM. For these waste forms, after the canister is placed in the waste package, the CTM operator must then retrieve, verify, document and install the waste package inner lid. The CTM operator can fail to perform this set of activities. Although this is an important and major part of CTM activities, it is the last step in CTM operations (Section E6.5). However, not all waste forms require the waste package inner lid to be installed in the CTM room; the inner lid for waste packages containing a TAD canister is installed during waste package closure in the Waste Package Closure Room. The waste package loading process for TAD canisters also differs from other waste forms in that all other waste forms require several canisters to fill a waste package, while TAD canisters only require one. Waste packages with unshielded canisters are also visually different from those with TAD canisters because they have gridded partitions on the interior which can be seen when looking down from the port.

Waste Package inner lids for unshielded canisters are staged in the Canister Transfer Room, while those for shielded canisters (TAD canisters) are staged in the Waste Package Closure Room. The two lids are physically different: the former lids are roughly eight inches thick while the latter is only about two inches thick; they also have different grapple attachments. If the inner lid for the unshielded canister is mistakenly staged in the Waste Package Closure Room, this may contribute to the operator's failure to install the waste package inner lid.

Failure of the operator to install the waste package inner lid is a significant EOO. This can occur if the CTM operator mistakes a waste package containing an unshielded waste form for a waste package containing a TAD canister. However, it is more likely that the CTM operator could confuse the procedures and believe the appropriate action is to put the lid on a waste package containing an unshielded waste form in the Waste Package Closure Room. Also, because there are roughly three times as many waste packages containing TAD canisters than other waste forms and the operator is on autopilot, the operator could believe that the lid will be emplaced in the Waste Package Closure Room (i.e., given that the majority of waste packages are TAD canisters, the operator would have a bias towards the TAD canister procedure). The CTM operator could also entirely forget to install the inner lid because of other factors (i.e., distraction). This is the last CTM operation for the waste package, so it is likely this is close to the end of the CTM operator's shift. This failure mode corresponds to the task execution error NARA CTT A4, adjusted for the following EPCs as follows:

- CTT A4: Judgment needed for the 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.

While there are EPCs that could affect successful completion of the procedure, there are no applicable EPCs that are felt to make it more likely to select the wrong procedure. Failure to successfully follow the wrong procedure could actually have a beneficial effect in terms of correcting the error, but no credit is taken for that.

Operator fails to install the waste package inner shield lid = 0.006

Worker Violates Administrative Control by Entering the Waste Package Closure Room Prior to the Start of Welding Activities—Failing to install the waste package inner lid by itself does not cause a direct exposure because, in the Canister Transfer Room the port gate and shielded floor protects personnel. However, once the waste package is moved to the Waste Package Closure Room, there is a potential for direct exposure. There are several administrative controls (associated with the radiation protection program) restricting personnel from entering the Waste Package Closure Room during waste package closure. These controls include:

- Personnel are only allowed in the Waste Package Closure Room during prescheduled times
- All personnel must check in with the CRCF Control Room (where the WPTT is controlled) before entering the Waste Package Closure Room.

If these controls are violated and a person enters the Waste Package Closure Room when the waste package inner lid is missing, then that person is exposed. This unsafe action is entirely independent from the failure to install the waste package inner lid.

There is a small window of opportunity for this failure because in the Waste Package Closure Room the waste package inner lid serial number is verified and documented, and if the error is not discovered then, once the welding crew tries to weld the inner lid they discover it is missing.

Any worker that wishes to enter the Waste Package Closure Room needs to get permission to do so from a supervisor. If the worker violates this requirement there is nothing to prevent the worker from entering the room. However, this administrative control is fundamental to the operation of the facility and applies to entry to all important areas of the facility. This is best represented by NARA GTT A5 and is adjusted by the following EPCs:

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

- EPC 7: No obvious means of reversing an unintended action. The GTT HEP is based on their being time to correct potential errors. This does not exist for this task. The maximum effect of the EPC is 9, which applies when there is no means of recovering from an unintended action once executed. Given that the error is not correctable, the APOA is set at 1.0.

This assessment does not give credit to the worker for believing that there is a legitimate need to enter the Waste Package Closure Room in the first place. The analysts could not find a compelling context where this would be the case.

Applying the NARA HEP equation yields the following:

Worker violates administrative control by entering the
Waste Package Closure Room prior to the start of welding activities

$$= 0.0001 \times [(9-1) \times 1.0 + 1] = 0.0009 \quad \text{(Eq. E-41)}$$

HEP Calculation for Scenario 1(a)—The events in the HEP model for scenario 1(a) are presented in Table E6.6-4.

Table E6.6-4. HEP Model for HFE Group #6 Scenario 1(a) for 060-OPWPInnerLid-HFI-NOD

Designator	Description	Probability
A	Operator fails to install the WP inner shield lid	0.006
B	Worker violates administrative control by entering the WP Closure Room prior to the start of welding activities	0.0009

NOTE: WP = waste package.

Source: Original

The Boolean expression for this scenario follows:

$$A \times B = 0.006 \times 0.0009 = 6E{-}06 \quad \text{(Eq. E-42)}$$

E6.6.3.4.2.2 HEP for HFE 060-OpWPInnerLid-HFI-NOD

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

$$\text{060-OpWPInnerLid-HFI-NOD} = \text{HEP 1(a)} = 6E{-}06 \quad \text{(Eq. E-43)}$$

E6.6.4 Results of Detailed HRA for HFE Group #6

The final HEPs for the HFEs that required detailed analysis in HFE Group #6 are presented in Table E6.6-5 (with the original preliminary value shown in parentheses).

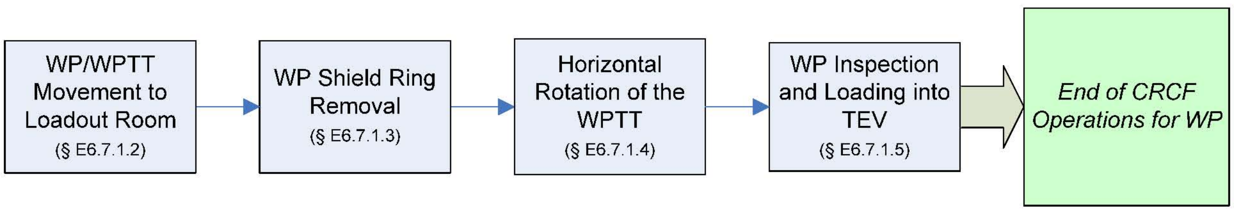
Table E6.6-5. Summary of HFE Detailed Analysis for HFE Group #6

HFE	Description	Final Probability
060-OpWPInnerLid-HFI-NOD	Direct exposure due to improper installation of inner lid	6E−6 (1E−4)

Source: Original

E6.7 ANALYSIS OF HUMAN FAILURE EVENT GROUP #7: WASTE PACKAGE EXPORT

HFE group #7 corresponds to the operations and initiating events associated with the ESD and HAZOP evaluation nodes listed in Table E6.0-1, covering waste package export. The operations covered in this HFE group are shown in Figure E6.7-1. The activities covered in HFE group #7 begin with the sealed waste package ready for emplacement, sitting vertically in the WPTT below the Waste Package Closure Room. The WPTT is moved to the Waste Package Loadout Room, where the waste package shield ring is removed, the WPTT enclosure is rotated to a horizontal position, and the waste package is transferred to the TEV. The operation ends when the TEV is loaded and ready for export.



NOTE: § = section; CRCF = Canister Receipt and Closure Facility; TEV = transport and emplacement vehicle; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure E6.7-1. Activities Associated with HFE Group #7

E6.7.1 Group #7 Base Case Scenario

E6.7.1.1 Initial Conditions and Design Considerations Affecting the Analysis

The following conditions and design considerations were considered in evaluating HFE group #7 activities:

1. The waste package is secured to the WPTT and positioned under the Waste Package Closure Room.

2. The waste package is sealed, inspected, and has a shield ring resting on top.

3. The TEV is staged in the Waste Package Loadout Room ready to be loaded. The shield door is open and the bottom plate is lowered.

4. There is an interlock between the shield door and the personnel access doors. If there is a loaded waste package in the Waste Package Closure Room (load cell), the shield door can not open and the WPTT cannot move into the Waste Package Loadout Room until the personnel access doors are closed and locked.

The following personnel are involved in this set of operations:

- WPTT operator
- Crane operator
- Signaling crew member
- Verification crew member
- Radiation protection worker
- Supervisor
- TEV operator.

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

E6.7.1.2 Loaded Sealed Waste Package Movement to Waste Package Loadout Room and WPTT Docking Station Engagement

This operation is performed remotely. The operator opens the Waste Package Closure Room shield door and moves the WPTT (on rail) to the docking station in the Waste Package Loadout Room. Once the WPTT has cleared the Waste Package Closure Room shield door, an operator closes it. When in the proper position by the docking station, the WPTT engages the docking station by moving an arm down. Engagement is automatic. The operator checks the indicator to ensure proper engagement before continuing.

E6.7.1.3 Waste Package Shield Ring Removal and Shield Ring Movement to Waste Package Shield Ring Stand

At this point, the operator removes the waste package shield ring from the WPTT. This operation may be performed remotely or locally. In this analysis, a local operation is described since it is believed to have the greater potential for error.

The operator installs a lifting device (sling or hooks which connect to eye holes) on the waste package shield ring. Once the fixture is secure, the operator moves several yards away from the WPTT and signals the crane operator to lift the ring and place it on the stand. Once the shield ring is on the stand, all crew members must leave the area and close the shield door. A predesignated person, such as the radiation protection worker, is responsible for ensuring via checklist that all personnel have left the Waste Package Loadout Room and relays that information to the WPTT operator in the control room.

E6.7.1.4 Horizontal Rotation of the WPTT

This step is performed remotely. The WPTT operator confirms that the Waste Package Loadout Room is empty and signals the transfer trolley machine to down end the waste package.

E6.7.1.5 Waste Package Inspection and Loading into TEV

The WPTT operator signals the transfer carriage to move the waste package under the TEV. As the waste package is moving under the TEV, the WPTT and TEV operators visually inspect the waste package for damage. Once the waste package is under the TEV, the TEV operator signals the TEV to pick up the waste package, lift the bottom shield plate, and close the shield door. The TEV operator and WPTT operator are located in separate rooms; the TEV operator is in the Central Control Center and the WPTT operator is in the CRCF Control Room.

This is the end of CRCF operations for canisters exported in a waste package.

E6.7.2 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 waste package export are summarized in Table E6.7-1. 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 see.

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Table E6.7-1. HFE Group #7 Descriptions and Preliminary Analysis

HFE ID	HFE Brief Description	ESD	Preliminary Value	Justification
060-OpWPCollide1-HFI-NOD	*Operator Causes Low-Speed Collision of WPTT during Transfer to Loadout Room*: As the WPTT is moved from the WP Positioning Room to the WP Loadout Room, the operator can cause the WPTT to collide into an SSC. Due to the WPTT motor design all collisions of the WPTT are low-speed.	13	3E−03	The WPTT is on rails, but an operator can cause a collision of the WPTT with an object in its path or with an SSC. The WPTT speed is limited by motor design; therefore, all collisions of the WPTT are low-speed collisions. This failure is nearly identical to collision of the railcar while entering the facility (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), and was assigned the same probability. This is a conservative preliminary value because the path the WPTT travels is expected to have less obstructions (doors, potential objects in the path) to collide into. This is the same failure as collision of the WPTT during transfer to the Waste Package Closure Area (060-OpWPCollide1-HFI-NOD; Section E6.6, HFE Group #6: Waste Package Assembly and Closure).
060-OpTiltDown01-HFI-NOD	*Operator Initiates Premature Tilt Down during Transfer to WP Loadout Room*: The operator can inadvertently initiate a tilt-down of the WP during transfer to the WP Loadout Room. If the WP is near a facility structure then this could result in a collision of the WP.	13	1.0	The operator can cause the WPTT to prematurely tilt down. The WPTT operator is in the process of driving the WPTT to the Waste Package Loadout Room. Tilt-down only occurs during waste package loadout in the Waste Package Loadout Room, and the controller for the WPTT tilt-down is distinct from other WPTT controls. In order to accomplish this failure, several interlocks must also fail. These interlocks, including an interlock taking power away from the WPTT when the port gate is open and an interlock between the tilt-down mechanism and the docking station, have no bypass. To be conservative, unsafe actions that require an equipment failure to cause an initiating event are assigned an HEP of 1.0.
WPTT Derailment	*Operator Causes Derailment of WPTT*: The WPTT travels on rail from the WP Positioning Room to the WP Loadout Room. During this transfer the operator can cause the WPTT to derail by running over a large object left on the rail or through other such mechanisms.	13	N/A[a]	In this step, the WPTT moves on rail from the Waste Package Positioning Room to the Waste Package Loadout Room. During this travel, there is a probability that the WPTT can derail, leading to a tipover of the WPTT. This HFE was not explicitly quantified because the probability of derailment due to human failure is incorporated in the historical data used to provide a general failure probability for derailment. Documentation for this failure can be found in Attachment C.
060-OpSDClose001-HFI-NOD	*Operator Closes Shield Door on Conveyance*: The WPTT passes through shield doors as it enters the WP Loadout Room. During this transfer, the operator can close the shield door on the WPTT.	7	1.0	The WPTT passes through shield doors as it enters the Waste Package Loadout Room. During this transfer, the operator can cause the WPTT to collide into the shield door or can close the shield door on the WPTT. See Section E6.0.2.3.3 for a justification of these preliminary values.
TEV_Collision	*Operator Drives TEV into WP*: The TEV is pre-staged in the WP Loadout Room with power off, ready to receive a WP. Because the TEV is not moved in this operation, this failure was omitted from analysis.	15	N/A	The TEV is pre-staged in the Waste Package Loadout Room with power off, ready to receive a waste package. Because the TEV is not moved in this operation, this failure was omitted from analysis.
060-OpTEVDrClosd-HFI-NOD	*Operator begins WP Extraction before TEV Doors Open*: If the operator extracts the WP before opening the TEV shield doors, then the WP runs into the TEV.	15	1E−03	The TEV is pre-staged and TEV operations in this respect are very standard, so it is unlikely that the TEV operator can not open the TEV shield door and extend the bed plate (0.01). The shield doors and bedplate are very visible, and there is adequate time between WPTT tilt-down and TEV loading for the operators to notice the TEV has not been properly staged before tilt-down (fail to notice, 0.1). Therefore, the preliminary value for waste package impact due to extraction before TEV doors are open is 0.001.
060-OpCraneIntfr-HFI-NOD	*Operator Causes Crane to Interfere with TEV or WPTT*: If the operator fails to properly stow the crane rigging, then the WPTT can impact the crane hook while tilting down.	15	1E−04	This operation was given the same preliminary value as the cask tipover during upending and removal HFE (060-OpTipover001-HFI-NOD; Section E6.2, HFE Group #2: Cask Upending and Removal from Conveyance) because it is a similar operation (movement with crane using same type of rigging and attachments) and has similar failure modes (i.e., failure to properly stow crane rigging).
060-OpWPTiltUp01-HFI-NOD	*Operator Causes Premature Tilt-up of WPTT*: If the operator signals the WPTT to tilt up while the WP is being extracted, this results in a drop of the WP.	15	1.0	While moving a waste package into the TEV, the operator can inadvertently cause the WPTT to tilt up, resulting in a drop of the waste package. In order to accomplish this, there are interlock(s) that must also fail. To be conservative, unsafe actions that require an equipment failure to cause an initiating event are assigned an HEP of 1.0.
Drop of Object on WP	*Operator Drops Heavy Object on WP*: During WP Export the WP Shield Ring is removed. It is possible that the shield ring can be dropped onto the WP during this operation.	15	N/A	In this step the operator moves the waste package shield ring over the waste package; the operator can potentially drop the shield ring onto the waste package. This HFE was not explicitly quantified because the probability of a crane drop due to human failure is incorporated in the historical data used to provide general failure probabilities for drops involving various crane and rigging types. Documentation for this failure can be found in Attachment C.

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Table E6.7-1. HFE Group #7 Descriptions and Preliminary Analysis (Continued)

HFE ID	HFE Brief Description	ESD	Preliminary Value	Justification
060-OpDirExpose3-HFI-NOD	*Operator Opens Facility Door during TEV Loading*: There is a gap between the tilted down WPTT and the TEV. The operator gets a direct exposure by opening the facility door while the WP is pulled into the TEV.	19	1E−03	In the process of TEV loading, the waste package is purposefully exposed to the Waste Package Loadout Room. Because of this "shine by design" mode of TEV loading, there are many safeguards to prevent personnel from being in the Waste Package Loadout Room during TEV loading. There are two general ways for a person to be in the Waste Package Loadout Room during this operation: an operator is left in the Waste Package Loadout Room when the operation begins or an operator enters the room after operations begin. There are procedural controls associated with the radiation protection program which limit who and when people can be in the Waste Package Loadout Room. There are also at least two separate checks of the room before operations begin: one locally and one from the control room via camera. Finally, there are radiation lights and alarms (non-ITS) which activate when the operations begin. If a person is left in the Waste Package Loadout Room, they have several minutes to exit the room through clearly marked exits. For an operator to enter the room after operations begin, the door must be unlocked. There is an interlock which ensures the shield doors are locked before the WPTT enters the Waste Package Loadout Room. For the shield doors to be unlocked, the interlock would have to fail, or a worker must ask the control room supervisor for permission to enter. If the supervisor chooses to grant permission, then the following actions must be taken to allow someone in the room: stop operations, move the waste package to a safe and shielded state, and then unlock the shield door. If the supervisor fails to stop operations before letting the worker in, or if the operations are prematurely restarted before the worker leaves, then the worker gets a direct exposure. This failure was assessed to be "highly unlikely" and assigned a preliminary value of 0.001.
060-OpShieldRing-HFI-NOD	*Operator Fails to Install WP Shield Ring in WPTT*: If a WP shield ring is not preinstalled in the WPTT before the canister is placed inside the WP during CTM activities, then when operators approach the WP to remove the shield ring in the WP Loadout Room, they get a direct exposure.	19	1E−04	The waste package shield ring is installed as part of the staging activities before CRCF operations for waste package loading begin. Shield ring installation is checked off by the staging crew and is also checked off by the operations crew directly before operations begin as part of the prejob plan. If the shield ring is not installed, the CTM operator has the chance to notice when emplacing the canister inside the waste package (camera view looking down on missing shield ring). If the canister is emplaced in the waste package, then, when operators approach the waste package to remove the shield ring in the Loadout Room, they get a direct exposure. This failure received a preliminary value of 0.01 for failure of the staging crew to install the shield ring and 0.01 for failure of the CTM operator to notice before a direct exposure occurs, resulting in a total preliminary value of 0.0001.
060-OpFailRstInt-HFI-NOM	*Operator Fails to Restore Interlock after Maintenance*: There is an interlock which prevents the WP port gate from opening if a WP containing a shield ring is not below the port. This interlock may be bypassed during normal maintenance. If the bypass is not restored, this could contribute to the HFE above (060-OpShieldRing-HFI-NOD).	18	1E−02	There is an interlock which prevents the port gate from opening if a waste package containing a waste package shield ring is not below the port. This interlock may be bypassed during normal maintenance. If the bypass is not restored by the maintenance crew member and not discovered by the prejob check, this could contribute to the HFE above (060-OpShieldRing-HFI-NOD). This failure was assigned a preliminary value of 0.01, which corresponds to the generic preliminary value for the pre-initiator "failure to properly restore an operating system to service when the degraded state is not easily detectable."
WPTT uncontrolled tilt-down	Operator causes uncontrolled tilt-down of WPTT	15	N/A	No human actions were identified that would contribute to an uncontrolled tilt-down.

NOTE: [a] HRA value replaced by use of historic data (Attachment C).
CRCF = Canister Receipt and Closure Facility; CTM = canister transfer machine; ESD = event sequence diagram; HEP = human error probability; HFE = human failure event;
ITS = important to safety; SNF = spent nuclear fuel; SSC = structure, system, or component; TEV transport and emplacement vehicle; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

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E6.7.3 Detailed Analysis

After the preliminary screening analysis and initial quantification are completed, those HFEs that appear in dominant cut sets for event sequences that do not comply with the 10 CFR 63.111 performance objectives are subjected to a detailed analysis. The overall framework for the HRA is based upon the process guidance provided in ATHEANA (Ref. E8.1.22). Consistent with that framework, the following four steps from the methodology described in Section E3.2 provide the structure for the detailed analysis portion of the HRA:

Step 5: Identify Potential Vulnerabilities

Prior to defining specific scenarios that can lead to the HFEs of interest (Step 6), information is collected to define the context in which the failures are most likely to occur. In particular, analysts search for potential vulnerabilities in the operators' knowledge and information base for the initiating event or base case scenario(s) under study that might result in HFEs or unsafe actions. This information collection step discussed in Section E6.7.3.2.

Step 6: Search for HFE Scenarios (Scenarios of Concern)

An HFE scenario is a specific progression of actions with a specific context that leads to the failure of concern; each HFE is made up of one or more HFE scenarios. In this step, documented in Sections E6.7.3.3 and E6.7.3.4, the analyst identifies deviations from the base case scenario that are likely to result in risk-significant unsafe action(s). These unsafe actions make up an HFE scenario. In serious accidents, these HFE scenarios are usually combinations of various types of unexpected conditions.

Step 7: Quantify Probabilities of HFEs

Detailed HRA quantification methods are selected as appropriate for the characteristics of each HFE and are applied as explained in Section E6.7.3.4. Four quantification methods are utilized in this quantification:

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

There is no implication of preference in the order of listing these methods. They are jointly referred to as the "preferred methods" and are applied either individually or in combination as best suited for the unsafe action quantified. The ATHEANA (Ref. E8.1.22) expert judgment method (as opposed to the overall ATHEANA (Ref. E8.1.22) methodology that forms the framework and steps for the performance of this HRA) is used when the other methods are deemed to be inappropriate to the unsafe action, as is often the case for cognitive EOCs.

Appendix E.IV of this analysis explains why these specific methods were selected for quantification and gives some background on when a given method is applicable based on the focus and characteristic of the method.

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

Step 8: Incorporate HFEs into the PCSA

After HFEs are identified, defined, and quantified, they must be incorporated into the PCSA. The summary table of HFEs by group that lists the final HEP by basic event name provides the link between the HRA and the rest of the PCSA. This table can be found in Section E6.7.4.

E6.7.3.1 HFEs Requiring Detailed Analysis

The detailed analysis methodology, Sections E3.2.5 through E3.2.9, states that HFEs of concern are identified for detailed quantification through the preliminary analysis (Section E3.2.4). An initial quantification of the CRCF PCSA model determined that there was one HFE in this group whose preliminary value was too high to demonstrate compliance with the performance objectives stated in 10 CFR 63.111. This HFE is presented in Table E6.7-2.

Table E6.7-2. Group #7 HFE Requiring Detailed Analysis

HFE	Description	Preliminary Value
060-OpDirExpose3-HFI-NOD	Operator causes Direct Exposure while loading TEV	1E−03

NOTE: HFE = human error probability; TEV transport and emplacement vehicle.

Source: Original

E6.7.3.2 Assessment of Potential Vulnerabilities (Step 5)

For those HFEs requiring detailed analysis, the first step in the ATHEANA approach to detailed quantification is to identify and characterize factors that could create potential vulnerabilities in the crew's ability to respond to the scenarios of interest and might result in HFEs or unsafe actions. In this sense, the "vulnerabilities" are the context and factors that influence human performance and constitute the characteristics, conditions, rules, and tendencies that pertain to all the scenarios analyzed in detail.

These vulnerabilities are identified through activities including but not limited to the following:

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

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

3. Insights gained during the performance of the other PCSA tasks (e.g., initiating events analysis, systems analysis, and event sequence analysis).

E6.7.3.2.1 Operating Team Characteristics

WPTT operator—Located in the Operations Room, the WPTT operator has received training for the WPTT and observed operations prior to being allowed to operate the WPTT on a dry run. The WPTT operator has been signed off to operate the WPTT based on an evaluation of proficiency during a dry run. The WPTT operator has been observed on initial operations before being signed off for solo operation. A single operator is assigned to the WPTT operation.

Waste package handling crane operator—Located in the Operations Room for this set of operations, the waste package handling crane operator has received training for crane operations and has observed operations prior to being allowed to operate the crane on a dry run. The waste package handling crane operator has been signed off to operate crane based on an evaluation of proficiency in dry run. The waste package handling crane operator has been observed on initial operations before being signed off for solo operation. A single operator is assigned the waste package handling crane operation.

Radiation protection worker—The radiation worker is a fully certified health physics technician, whose job is to monitor radiation during cask-related activities. The radiation protection worker is responsible for stopping operations if high radiation levels are detected.

Supervisor—The supervisor is in the CRCF Control Room during TEV loading. The supervisor is in charge of verifying proper operations and is also the only one who can grant other personnel access to the Waste Package Loadout Room (via pass code and key) from the CRCF Control Room.

E6.7.3.2.2 Operation and Design Characteristics

There are no humans in the Waste Package Loadout Room during this operation; all operators are located remotely in the CRCF Control Room. Crew members only enter this room for waste package preparation, which happens before the waste package is loaded.

All doors from the Waste Package Loadout Room can be opened from the inside in case of an emergency.

To open the facility shield door to the Waste Package Loadout Room, two people are required: one person has to unlock the shield door locally, and the other (a supervisor) has to unlock the door from the CRCF Control Room.

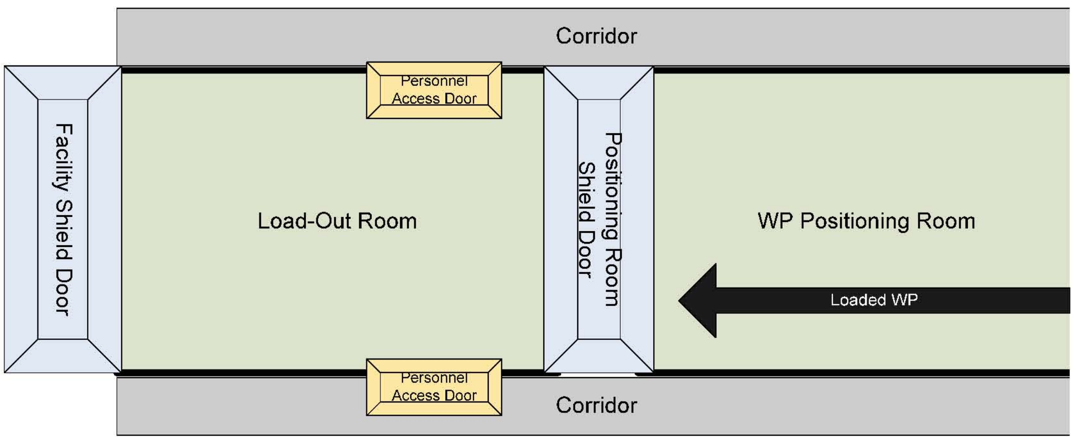
The personnel access door can only be opened from the CRCF Control Room and requires two separate actions (i.e., entering a pass code and then inserting a key). Only a supervisor is able to perform this action. However, the personnel access door is unlocked during waste package preparation, and must be relocked before TEV loading begins.

Radiation control signs and flashing lights are provided outside the door during TEV loading. These are non-ITS equipment.

After the personnel have removed the waste package shield ring and left the Waste Package Loadout Room, the radiation protection worker or other predesignated person ensures the Waste Package Loadout Room is vacant and signals the WPTT operator that it is safe to begin tilt-down.

A public address announcement is made inside the area to alert workers to clear the area before the WPTT is tilted. Intercom communications and television monitoring between workers and the CRCF Control Room ensure that the operator knows if exit is delayed.

Interlocks—The Waste Package Positioning Room has a load cell that can differentiate between an empty waste package and a loaded waste package. If there is a loaded waste package in the Waste Package Positioning Room, the Waste Package Positioning Room shield door cannot open to allow the WPTT to move to the Waste Package Loadout Room for export unless the facility shield door and the personnel shield doors are locked. Figure E6.7-2 is an illustration of the location of the various shield doors; this illustration is conceptual, and does not provide a precise representation of the actual configuration.



NOTE: WP = waste package.

Source: Original

Figure E6.7-2. Waste Package Positioning Room and Waste Package Loadout Room Conceptual Configuration

E6.7.3.2.3 Formal Rules and Procedures

Procedural controls—Procedural controls associated with the radiation protection program ensure that the operators and maintenance personnel do not enter the Waste Package Loadout Room except during scheduled times. A personnel accountability system is associated with entering and exiting the Waste Package Loadout Room. Personnel are required to check in with the supervisor and tag in and out before entering or after leaving the Waste Package Loadout Room.

E6.7.3.2.4 Operator Tendencies and Informal Rules

Consequences of Failure—The operations are performed remotely. No personnel are in the vicinity of the operation, and so the threat of physical injury is absent. The WPTT operator expects that failures are mitigated by design features without serious consequences, which promotes complacency in the operations.

Anticipatory Actions—The loadout process is remote, has a high degree of automation, and problems of any kind are not expected. There is a tendency for the WPTT operator to focus on future tasks while waste package is being loaded into the TEV.

Requests to enter Waste Package Loadout Room—The supervisor is present in the CRCF Control Room and aware of the stage of TEV loading. Serious consequences are associated with personnel being present in the Waste Package Loadout Room while a TEV is being loaded. Therefore, the supervisor would be very cautious not to admit anyone into the Waste Package Loadout Room during this time. If access to the room is necessary, the supervisor either stops operations and tilts up the WPTT or makes sure the TEV is fully loaded with shield doors closed before admitting a worker into the room.

E6.7.3.2.5 Operator Expectations

Anticipatory Actions—No one attempts to enter the Waste Package Loadout Room without a compelling reason.

E6.7.3.3 HFE Scenarios and Expected Human Failures (Step 6)

Given that the vulnerabilities that provide the operational environment and features that could influence human performance have been specified, then the HFE scenarios within this environment are identified. An HFE scenario is a specific progression of actions during normal operations (with a specific context) leading to the failure of concern; each HFE is made up of one or more HFE scenarios. In accordance with the methodology, each scenario integrates the unsafe actions with the relevant equipment failures so as to provide the complete context for the understanding and quantification of the HFE.

The HAZOP is instrumental in initially scoping out the HFE scenarios, but they are then refined through discussions with subject matter experts from a wide range of areas, as described in Section E4.2.

Table E6.7-3 summarizes all of the HFE scenarios developed for each HFE.

Table E6.7-3. HFE Scenarios and Expected Human Failures for Group #7

HFE	HFE Scenarios
060-OpDirExpose3-HFI-NOD *Operator causes Direct Exposure while loading TEV*	HFE Scenario 1(a): (1) A crew member remains in the Waste Package Loadout Room after evacuation ordered OR the WPTT operator fails to order an evacuation; (2) radiation protection worker fails to check if room is empty or radiation protection worker fails to recognize that someone is still in room; (3) crew member fails to notice that load-out is occurring OR Crew member fails to exit the room in time to avoid exposure. HFE Scenario 1(b): (1) Crew member requests reentry into enter the Waste Package Loadout Room; (2) supervisor agrees to allow access. HFE Scenario 1(c): (1) Personnel access shield door left open, (2) interlock OR Load Cell fails and WPTT enters the Waste Package Loadout Room.

NOTE: HFE = human failure events; WPTT = waste package transfer trolley.

Source: Original

Since there is one HFE identified for detailed analysis in this group, the scenarios are organized under this HFE category, with the scenarios numbered as 1(a), 1(b), and 1(c). Each HFE scenario is in turn characterized by several unsafe actions, numbered sequentially as (1), (2), (3), etc. The Boolean logic of the HFE scenarios is expressed with an implicit AND connecting the subsequent unsafe actions and OR notation wherever two unsafe action paths are possible, as shown in Table E6.7-3.

The HFE scenarios summarized in Table E6.7-3 are discussed and quantified in detail below.

E6.7.3.4 Quantitative Analysis (Step 7)

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

This section provides a description of the quantitative analysis performed, structured hierarchically by each HFE category (identified by a basic event name), the HFE scenario, and the unsafe actions under each scenario, as previously documented in Table E6.7-3

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

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

E6.7.3.4.1 Common Values Used in the HFE Detailed Quantification

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

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

Interlock fails to perform function = 2.7E−05

E6.7.3.4.2 Quantification of HFE Scenarios for 060-OpDirExpose3-HFI-NOD: Operator Causes Direct Exposure during TEV Loading

E6.7.3.4.2.1 HFE Group #7 Scenario 1(a) for 060-OpDirExpose3-HFI-NOD

1. A crew member remains on the second floor of the Waste Package Loadout Room after evacuation ordered OR the WPTT operator fails to order an evacuation.

2. Radiation protection worker fails to check if the room is empty OR fails to recognize that someone is still in the room.

3. Crew member fails to notice that loadout is occurring OR a crew member fails to exit the room in time to avoid exposure.

A Crew Member Remains on the Second Floor of the Waste Package Loadout Room after an Evacuation Is Ordered—Prior to moving a loaded waste package to the Waste Package Loadout Room there may be maintenance or (empty) waste package preparation activities going on in the Waste Package Loadout Room. Once the WPTT is ready to be moved to the Waste Package Loadout Room, the WPTT operator makes an announcement for all personnel to leave the Waste Package Loadout Room.

Even if the WPTT operator notifies workers to leave the Waste Package Loadout Room, it is possible that they won't leave. The action of leaving itself is quite simple, but the communication of the request could be missed by virtue of the person being engrossed in the task. This can be represented by NARA GTT D1, adjusted for the following EPCs:

- GTT D1: Verbal communication of safety-critical data. The baseline HEP is 0.006.

- EPC 4: Low signal-to-noise ratio. This usually applies to a proliferation of information, but can be applied to masking by any distracting mechanism. The full effect is ×10, which applies to significant levels of distraction. In this case, the level of distraction is small as there is not a significant amount of machine noise to mask the public announcement. The APOA is judged to be minimal, and thus is set to 0.1.

Using the HEP equation yields the following:

Crew member remains on the second floor of the Waste Package Loadout Room after evacuation ordered = $0.006 \times [(10\text{-}1) \times 0.1 + 1] = 0.01$ (Eq. E-44)

WPTT Operator Fails to Order Evacuation—The WPTT operator is required to announce that all personnel are to leave the Waste Package Loadout Room prior to initiating movement of the WPTT into the room. This action is part of the process procedure. The WPTT operator is required to make the announcement whether or not the operator believes anyone is in the room, so this can be represented by CREAM (Ref. E8.1.18) execution CFF E5, adjusted for the following CPCs with value not equal to 1.0:

- CFF E5: Action missed, not performed (omission). The baseline HEP is 0.03.
- CPC "Working Conditions": The working conditions for the operator are in the CRCF Control Room with a favorable environment. The CPC for advantageous working conditions for an execution task is 0.8.
- CPC "Availability of Procedures": With regard to the notification step, the procedures and checklist clearly list that this task needs to be performed. The CPC for appropriate availability of procedures for an execution task is 0.8.
- CPC "Available Time": There is more than enough time to successfully perform this task. The CPC for adequate available time for an execution task is 0.5.
- CPC "Adequacy of Training/Preparation": This is a routine task that is clearly trained and emphasized in training. Because it is routine, there is a high level of experience. The CPC for adequate training and high experience for an execution task is 0.8.

Applying these factors yields the following:

WPTT operator fails to order evacuation =

$0.03 \times 0.8 \times 0.8 \times 0.5 \times 0.8 = 0.008$ (Eq. E-45)

Radiation Protection Worker Fails to Check if Room Is Empty—This is an EOO by the radiation protection worker, (or another predesignated person) who fails to personally ensure that the Waste Package Loadout Room has been cleared of personnel. This is considered to be represented by CREAM (Ref. E8.1.18) execution CFF E5, adjusted for the following CPCs:

- CFF E5: Action missed, not performed (omission). The baseline HEP is 0.03.
- CPC "Working Conditions": The working conditions are in the Waste Package Loadout Room with less favorable environment than the control room due to controlled access. The CPC for incompatible working conditions for an execution task is 2.0.

- CPC "Availability of Procedures": With regard to the notification step, the procedures and checklist clearly list that this task needs to be performed. The CPC for appropriate availability of procedures for an execution task is 0.8.

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

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

Applying these factors yields the following:

$$\text{Radiation protection worker fails to check if room is empty} = 0.03 \times 2.0 \times 0.8 \times 1.0 \times 0.8 = 0.04 \quad \text{(Eq. E-46)}$$

Radiation Protection Worker Fails to Recognize that Someone Is Still in the Room—An EOC is considered to occur due to a lack of attention or perhaps a distraction that causes the Radiation protection worker to fail to perform the check properly. It is considered to be covered by HEART (Ref. E8.1.28) generic task (D) modified by the following EPC:

- GT (D): Fairly simple task performed rapidly or given scant attention with a baseline HEP of 0.09.

- EPC 17: Inadequate checking (HEART EPC 17). Little or no independent checking. The full effect is ×3. In this case, since the radiation protection worker is completely unsupervised, the APOA is judged to be complete and is set at 1.0.

$$\text{Radiation protection worker fails to recognize that someone is still in the room} = 0.09 \times [(3\text{-}1) \times 1.0 + 1]) = 0.27 \quad \text{(Eq. E-47)}$$

Crew Member Fails to Notice that Loadout Is Occurring—While the WPTT operator does a remote check of the Waste Package Loadout Room, credit is not given for this check. It is up to the crew member, then, to notice that the WPTT is tilting down and to exit the room. The WPTT is large, and its movement is obvious. The crew member has just sufficient time to exit the room if the WPTT tilt-down is immediately noticed (within the first 30 seconds). The response is simple and no significant diagnosis is required. This error most closely corresponds to the CREAM (Ref. E8.1.18)observation error O3, observation not made.

- CFF O3: Observation not made (omission). The baseline HEP is 0.001.

- CPC "Working Conditions": The working conditions are in the Waste Package Loadout Room with a less favorable environment than the CRCF Control Room due to controlled access. The CPC for incompatible working conditions for an observation task is 2.0.