INTENTIONALLY LEFT BLANK

Table E6.3-1. HFE Group #3 Descriptions and Preliminary Analysis

HFE ID	HFE Brief Description	ESD	Preliminary Value	Justification
200-OpCaskDrop01-HFI-NOD	*Operator Drops Cask during Preparation Activities*: The cask is not lifted in this step, and no plausible scenarios that would lead to a cask drop could be identified.	3	N/A	The cask is not lifted in this step, and the 200-ton crane is not used in this operation. For TAD canisters, there is no possible configuration that can result in a cask drop. For DPCs, a cask drop would require the following human failures to occur during the same set of activities: during lid removal, the crew must fail to remove some fraction of the lid bolts (EOO), the crew must fail to properly use a checklist to verify bolt removal, and the crane operator must use the wrong crane (EOC) to remove the partially attached lid. In addition to the human failures, the bolts would have to hold the weight of the cask long enough to lift the cask. The crane operator and at least two other crew members would be standing on the platform in direct view of the cask during lid removal, and they would also all have to fail to notice that the entire cask is being lifted before the bolts break. This failure was therefore omitted from analysis.
Crane Drop	*Operator Drops Object on Cask during Preparation Activities*: Preparation of a cask entails moving several heavy objects over the cask using the cask handling crane auxiliary hook. These objects include the lid lift fixture and, for DPCs, the cask lid and canister lift fixture. During these lifts, the operator can drop the object onto the cask or canister by improperly connecting the object to the crane, two-blocking the object, or other such failures.	3	N/A[a]	In this step the operator uses the cask handling crane auxiliary hook to move objects over the cask. There are three heavy-object lifts (i.e., the lid lift fixture, the cask lid, and the canister lift fixture) using the auxiliary hook. The lid lift and canister lift fixtures are moved with a grapple or hook, the cask lid is moved with a sling, and the canister lift fixture and cask lid lifts are only applicable to the preparation of DPCs. Each of these lifts can potentially result in a drop. 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/rigging types. Documentation for this failure can be found in Attachment C.
200-OpCTCollide1-HFI-NOD	*Operator Causes Low Speed Collision of Auxiliary Vehicle with CTT*: During cask preparation, the CTT is loaded and parked under the preparation platform for a long period of time. During this time, an operator can cause an auxiliary vehicle to collide with the CTT.	3	3E−03	In this step the CTT is loaded and parked under the cask preparation platform. The speed of auxiliary vehicles is slow, the CTT is very visible and procedural controls are expected to limit the number of other vehicles in the Cask Preparation Room during cask operations. This HEP was assigned the same preliminary probability as railcar collision HFE (*200-OpRCCollide1-HFI-NOD*; Section E6.1, HFE Group #1) because the dominant mechanism of both failures is a collision with an auxiliary vehicle. In this case, the preliminary value is conservative because the CTT is staged under the platform and the railcar collision HFE has additional failure modes associated with movement of the SPM which are not applicable here. 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 (×3) because there are several ways for a collision to occur.
200-OpFLCollide1-HFI-NOD	*Operator Causes High-Speed Collision of Auxiliary Vehicle with CTT*: During cask preparation, the CTT is loaded and parked under the preparation platform for a long period of time. During this time, an operator can cause an auxiliary vehicle to collide with the CTT. If the collision is due to the auxiliary vehicle speed governor malfunctioning, this is a high-speed collision.	3	1.0	The operator can cause either the auxiliary vehicle to over speed, resulting in collision. In order to accomplish this, the speed governor of the vehicle must fail. To be conservative, assigned unsafe actions that require an equipment failure to cause an initiating event are assigned an HEP of 1.0.
200-OpSpurMove01-HFI-NOD	*Operator Causes Spurious Movement of CTT during Preparation Activities*: The CTT is supposed to be deflated, with the control pendant stored during this operation; however, if the CTT is not in the proper configuration for cask preparation, the operator can inadvertently cause the CTT to move. This spurious movement can cause the CTT to collide into the preparation platform.	3	1E−04	In this step the CTT is parked under the preparation platform and the CTT is deflated, with the control pendant stored. For operations in this step there are several crew members on the preparation platform and no operators below the platform. This error was considered to be extremely unlikely (0.0001) because it requires multiple human errors as follows: it would require the CTT to be left inflated, the observers (the crane operator, two crew members or the radiation protection worker) would have to fail to notice or fail to stop operations and deflate the CTT, and an operator would have to access the pendent and signal the CTT to move.
200-OpCTTImpact1-HFI-NOD	*Operator Causes an Impact Between SSC and Loaded CTT due to Crane Operations*: While performing crane operations, the operator can potentially impact the cask if the crane is moved with the hook lowered below the platform.	3	3E−03	In this step the CTT is stationed under the preparation station and the lid lift fixture, lid (DPC only), and canister lift fixture (DPC only) are moved over the cask. For crane operations in this step there are three observers with clear visibility, the operations are simple, the travel distances are short, and the crane speed is slow. There are no interlocks to prevent this error. No part of the cask is above cask preparation platform, and therefore the only way the CTT (containing a cask) can be impacted with the crane is if the crane is moved with the load/hook lower than the platform, and the crane moves into the platform causing the load/hook to swing into the CTT. The crane hook can also be improperly stowed such that the CTT, when moving to the Cask Unloading Room, collides with the crane hook. However, the CTT travels under the platform to the Cask Unloading Room and the last preparation activity for both DPCs and TAD canisters requires the shield plate to be closed. It is therefore unlikely that, if the crane is improperly stored, the hook would be in the path of the CTT. The likelihood of impacting a cask was assessed to be comparable to the crane impact during upending and removal HFE (200-OpTCImpact01-HFI-NOD; Section E6.2, HFE Group #2) and was assigned the same preliminary value. This is considered a conservative assessment because, in comparison with upending and removal, there are fewer crane movements in this operation, and there is a platform around the CTT which makes it harder to impact the CTT. This failure is “highly unlikely” (one in a thousand or 0.001, which also corresponds to the generic failure rate for a simple operation that is performed daily) but is adjusted because there are several ways for an impact to occur (×3).

INTENTIONALLY LEFT BLANK

Table E6.3-1. HFE Group #3 Descriptions and Preliminary Analysis (Continued)

HFE ID	HFE Brief Description	ESD	Preliminary Value	Justification
200-OpTipover002-HFI-NOD	*Operator Causes Cask to Tip Over during Cask Preparation Activities*: The operator can improperly stow the crane rigging and it can catch the CTT or cask. If this happens, movement of the crane or the CTT can cause the cask and CTT to tip over.	3	1E−04	In this step the CTT is stationed under the cask preparation station, the lid lift fixture is attached to the cask lid and the CTT is then moved to the Cask Unloading Room. In order to get a tipover of the cask/CTT, the crane must be attached to the cask or CTT and the crane or CTT must also move. To be conservative, the 20-ton crane is considered to be physically capable of tipping over the cask while it is underneath the platform. At no point in the operations is the crane attached to the cask. For DPC preparation, the crane is attached to the lid, but the lid is unbolted (Section 2.1 provides a discussion of the failure to remove lid bolts). Therefore, the only way for the crane to be attached to the cask is if the crane rigging catches the cask or CTT. This is unlikely because the CTT is protected by the platform and shield plate during this operation. If the rigging is caught, it is unlikely that the crane operator would not notice while trying to move the crane. It is also unlikely that, when the CTT begins movement to the Cask Unloading Room, the CTT operator and observers would not notice that the rigging is attached to the CTT. The dominant contributor is the crane hook catching the cask. While it may be unlikely (0.01) that a stray hook or grapple might be hanging from the crane, it would still need to catch on the cask securely enough to pull it over (0.1), and then the cask tipping would have to go unnoticed by all three observers. This task is done under direct observation, there is platform and shield plate to protect the cask from stray rigging, and a tipover is a slow process; therefore, the value was adjusted by a further 0.1. This operation was given the same preliminary value as the cask tipover during upending and removal HFE (200-OpTipover001-HFI-NOD; Section E6.2, HFE Group #2) because it is a very similar operation (i.e., movement with a crane using the same type of rigging/attachments) and has similar failure modes. The difference between the two scenarios is that there are more crane operations and more failure modes during upending and removal, and so there would be more opportunities for a tipover in that scenario; also, there is no platform/shield plate in upending to protect the cask from stray rigging.
200-OpTipOver3-HFI-NOD	*Operator Causes Tipover of CTT during Movement to the Cask Unloading Room*: The operator can improperly stow the crane rigging, and it can catch the CTT or cask. If this happens while the CTT is moving to the unloading room, it can cause the CTT to tip over.	4	N/A	The CTT, loaded with a cask, undergoes a set of operations that includes activities under the preparation platform and then movement of the CTT away from the platform to the Cask Unloading Room. Tipover of the CTT during this set of activities constitutes one HFE because the most likely scenario is that the crane would be attached during preparation and a tipover would occur during movement of the CTT away from the platform. The event sequences, however, model a tipover during platform activities and a tipover during CTT movement. Because this is only one human failure, the appropriate preliminary value was only modeled in the event sequence associated with platform activities (200-OpTipover002-HFI-NOD, modeled in ESD 3). The HEP for a tipover in the event sequence associated with the subsequent movement of the CTT (200-OpTipOver3-HFI-NOD in ESD 4) was assigned a probability of zero to avoid double counting.
200-OpImpact0000-HFI-NOD	*Operator Causes Impact of Cask during Transfer from Preparation Station to Unloading room*: While moving from the Preparation Station to the Cask Unloading Room, the CTT can impact the crane hook or rigging if it is improperly stowed.	4	N/A	While moving from the preparation station to the Cask Unloading Room, the CTT can impact the crane hook or rigging if it is improperly stowed. The last step in preparation activities for both DPCs and TAD canisters requires the shield plate of the platform to be closed. It is unlikely, then, that the crane rigging can be improperly stowed such that it can impact the site transporter while it is moving out of the Cask Unloading Room; it is more likely that rigging impacts the cask while the crane is actually in use. Therefore, any crane interference with the CTT is already covered by 200-OpCTTImpact1-HFI-NOD and 200-OpTipover002-HFI-NOD.
200-OpCTCollide2-HFI-NOD	*Operator Causes Low Speed Collision of CTT during Transfer from Preparation Station to Cask Unloading Room*: Once the preparation activities are over, an operator inflates the CTT and moves the cask from the Cask Preparation Room to the Cask Unloading Room. The operator can cause the CTT to collide with the preparation platform structure during this transfer. The CTT is designed such that it physically cannot over speed; therefore, all CTT collisions are below the designed speed.	4	1E−03	In this step the CTT moves from the preparation station to the Cask Unloading Room and the doors of the preparation station must be opened to allow the CTT to pass through. There are three observers with clear visibility, the speed of the CTT and other vehicles is low, the CTT is very visible, and there are two guide rails and an end stop to keep the CTT on the safe load path. Procedural controls are expected to limit the number of other vehicles in the Cask Preparation Room during cask operations. The CTT could collide into a conveyance or facility structures (i.e., preparation station platform). This could happen if the guide rails were not installed properly. This operation is simple, straightforward, and is expected to occur very regularly (daily). It was assigned the default probability of an “highly unlikely” occurrence (0.001). It was considered reasonable and consistent that the preliminary value assigned for this HFE be less likely than a railcar collision because of the guide rail, number of observers, and short travel distance.
200-OpSDClose001-HFI-NOD	*Operator Closes Shield Door on Conveyance*: Once the preparation activities are over, an operator inflates the CTT and moves the cask from the Cask Preparation Room to the Cask Unloading Room. There is a shield door between the Cask Preparation Room and the Cask Unloading Room. The operator can impact the cask by inadvertently closing the shield door on the CTT as the CTT passes through the door.	5	1.0	The railcar passes through shield doors as it enters the Cask Preparation Room. During this transfer, the operator can cause the CTT to collide into the shield door or can close the shield door on the CTT. Section E6.0.2.3.3 provides a justification of this preliminary value.

INTENTIONALLY LEFT BLANK

Table E6.3-1. HFE Group #3 Descriptions and Preliminary Analysis (Continued)

HFE ID	HFE Brief Description	ESD	Preliminary Value	Justification
200-OpDPCShield1-HFI-NOW	*Operator Causes Loss of Shielding While Installing DPC Lift Fixture*: In this step, the DPC canister lift fixture is attached to the canister. There are two ways for the crew to get a direct exposure during this activity: an operator can fail to properly close and verify the closure of the shield plate after the cask lid is removed and the crew continues with the installation or an operator can inadvertently open the shield plate while the crew is installing the canister lift fixture.	10	1E−03	In this step, the DPC lift fixture is attached to the canister. If an operator fails to properly close the shield plate after removing the DPC lid, then the crew can be directly exposed to the shine from the DPC while installing the canister lift fixture. Likewise, if an operator inadvertently opens the shield plate while the crew is installing the canister lift fixture, then the crew can be exposed. In this case, the crew is on top of the shield plate and notices if the shield plate moves. The crew is highly trained and, although they only perform DPC preparation activities weekly, they are accustomed to operating the shield plate during preparation of other transportation casks. In addition to the crew members, there is also a radiation worker present who is monitoring activities. This error was assessed to be highly unlikely and given a preliminary value of 0.001.
200-Liddisplace1-HFI-NOD	*Operator Inadvertently Displaces Lid*: The operator can improperly store the crane rigging such that it catches the lid lift fixture and pulls off the cask lid during cask preparation, resulting in a direct exposure.	10	N/A	In this step the lid is unbolted and the lid lift fixture is attached. Due to design changes to the preparation platform, improperly stowed rigging during this operation can not catch the lid lift fixture. These design changes include raising the platform and adding a shield plate so the cask is recessed underneath the platform.
Gas Sampling	*Operator Improperly Performs Gas Sampling*: Gas Sampling may be performed to determine if an incoming canister has been damaged by the transportation process. If the gas sampling process is incorrectly performed and a damaged canister goes undetected, a radiation release occurs by continuing with normal operations.	N/A	N/A	If the gas sampling process is incorrectly performed and a damaged canister goes undetected, a radiation release occurs by continuing with normal operations. Assessing accident scenarios with pre-damaged canisters is beyond the scope of this analysis.

NOTE: [a]HRA preliminary value replaced by use of historic data (Attachment C).
CTT = cask transfer trolley; DPC = dual-purpose canister; EOC = error of commission; EOO = error of omission; ESD = event sequence diagram; HEP = human error probability; HFE = human failure event; ID = identification; N/A = not applicable; SPM = site prime mover; SSC = structure, system, or component.

Source: Original

INTENTIONALLY LEFT BLANK

E6.3.3 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 E6.3.3.2.

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 E6.3.3.3 and E6.3.3.4, 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 E6.3.3.4. Four quantification methods are utilized in this quantification:

- CREAM (Cognitive Reliability and Error Analysis Method, CREAM (Ref. E8.1.18 DIRS 181532))
- HEART ("HEART – A Proposed Method for Assessing and Reducing Human Error" (Ref. E8.1.28 DIRS 184001))/NARA (*A User Manual for the Nuclear Action Reliability Assessment (NARA) Human Error Quantification Technique* (Ref. E8.1.11 DIRS 184080))
- THERP (Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications Final Report, NUREG/CR-1278 (Ref. E8.1.26 DIRS 139383))
- ATHEANA expert judgment (Technical Basis and Implementation Guidelines for a Technique for Human Event Analysis (ATHEANA). NUREG-1624 (Ref. E8.1.22 DIRS 157661)).

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 E6.3.4.

E6.3.3.1 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 RF 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 E6.3-2.

Table E6.3-2. Group #3 HFE Requiring Detailed Analysis

HFE	Description	Preliminary Value
200-OpDPCShield1-HFI-NOW	Operator fails to properly shield DPC while installing canister lift fixture, leading to direct exposure	1E−03

NOTE: DPC = dual-purpose canister; HFE = human failure event.

Source: Original

E6.3.3.2 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).

The vulnerabilities discussed in this section pertain only to those aspects of the preparation 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 preparation operation, but these have no bearing on this analysis.

E6.3.3.2.1 Operating Team Characteristics

Crew members—There are several crew members involved in the installation of the canister lift fixture. One predesignated crew member operates the platform shield plate. This crew member, referred to here as the shield plate operator, is trained as to when the shield plate must be opened or closed. When the operations require the shield plate to be moved, the crew member informs the other crew members on the platform that the shield plate is going to be moved. The other crew members confirm that the shield plate is in the proper position before continuing on to the next step of the operation. All crew members are expected to have the proper training commensurate with nuclear industry standards. This training is followed by a period of observation until the operator is proficient.

Radiation protection worker—The radiation protection worker is a fully certified health physics technician, whose job is to monitor radiation from the cask during movement. The radiation protection worker is responsible for stopping operations if high radiation levels are detected or if there is a situation that would lead to direct exposure.

E6.3.3.2.2 Operation and Design Characteristics

Preparation operations are slow and tedious, and they promote complacency.

The position of the shield plate is very visible. The shield plate is opened to place the canister lift fixture on the DPC, and it is then closed to bolt the fixture. The shield plate remains closed while the DPC is transferred to the Cask Unloading Room.

Shield plate operations—The shield plate has two modes: a normal travel mode (forward and reverse) and a jog mode (forward and reverse). The jog mode only allows the plate to move very slowly and in small increments. The shield plate operator uses the travel mode to move the shield plate completely over the cask port until it reaches the end stop. The jog function is then used for fine control of the shield plate to line up the shield plate with the bolt holes in the canister lift fixture. To open the shield plate, the shield plate operator again uses the normal travel mode until it reaches the end stop at the other end of the platform. Before opening or closing the shield plate, the shield plate operator ensures that the path of the shield plate is clear of personnel.

E6.3.3.2.3 Formal Rules and Procedures

Procedures—Formal procedures exist for these operations; however, there are no written, formal procedures that the crew has in front of them during these operations. Operators are trained in the operations, and their proficiency is attested to by the training staff. They perform the operations as a skill.

E6.3.3.2.4 Operator Tendencies and Informal Rules

Observation and communication—The shield plate crew member communicates the actions to other crew members throughout this operation. The entire crew should be aware of the procedure and order of operations.

E6.3.3.2.5 Operator Expectations

Anticipatory actions—The preparation process is simple but time consuming. There can be a tendency for the crew to focus on future tasks while preparing the DPC.

Consequences of Failure—The cask is not lifted in this step, and a shield plate is over the cask, so the threat of radiation release or physical injury is very low in this procedure. The crew expects failures to be relatively inconsequential, which promotes complacency in the operations.

E6.3.3.3 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 E6.3-3 summarizes all of the HFE scenarios developed for the HFE in this group.

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

HFE	HFE Scenarios
200-OpDPCShield1-HFI-COW *Operator fails to properly shield DPC while installing canister lift fixture, leading to direct exposure*	HFE Scenario 1(a): (1) Shield plate crew member does not place shield plate entirely over the cask; (2) crew fails to notice improper shield plate closure before approaching the shield plate. HFE Scenario 1(b): (1) Shield plate crew member opens shield plate while crew bolts canister lift fixture; (2) crew fails to notice shield plate movement in time OR shield plate crew member fails to respond to warnings from crew.

NOTE: HFE = human failure event.

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) and 1(b).

Each HFE scenario is in turn characterized by several unsafe actions, numbered sequentially as (1) and (2). 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 E6.3-3.

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

E6.3.3.4 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 then the unsafe actions under each scenario, as previously documented in Table E6.3-3.

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.

E6.3.3.4.1 Common Values Used in the HFE Detailed Quantification

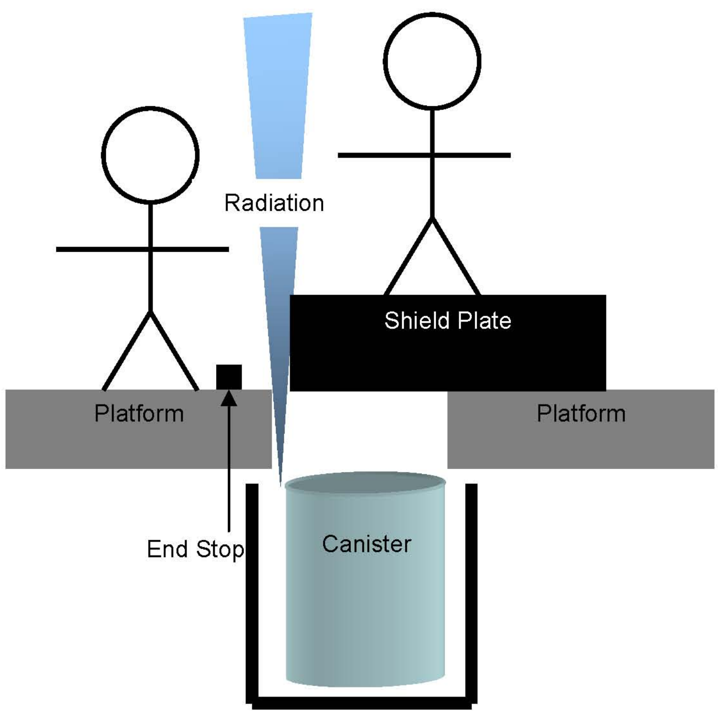
There are some mechanical failures that combine with unsafe actions to form HFEs. In general, these mechanical failures are independent of the specific HFE scenario, and so they can be quantified independently. These values are presented in this section.

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−06

E6.3.3.4.2 Quantification of HFE Scenarios for 200-OpDPCShield1-HFI-NOW: Operator Fails to Properly Shield DPC while Installing Canister Lift Fixture, Leading to Direct Exposure

Figure E6.3-2 is an illustration of this failure scenario; this figure is not to scale. The DPC itself is shielded on top. The radiation of concern in this scenario is streaming from the small portion of the annulus which is not covered by the preparation platform. Because the shield plate is so visible and because the crew cannot access the canister to bolt the canister lift fixture to the DPC without the shield plate, the only scenarios considered in this analysis are those in which the shield plate is partially open; failure to close the shield plate entirely has been omitted from analysis.



Source: Original

Figure E6.3-2. 200-OpDPCShield1-HFI-NOW Operator Failure Scenario

E6.3.3.4.2.1 HFE Group #3 Scenario 1(a) for 200-OpDPCShield1-HFI-NOW

1. Shield plate crew member fails to cover cask entirely with shield plate
2. Crew fails to notice improper shield plate closure before approaching the shield plate.

Shield Plate Crew Member Fails to Cover Cask Entirely with Shield Plate—After the canister lift fixture is placed on the DPC, the shield plate operator ensures that the platform area around the shield plate path is clear, announces that the shield plate is closing, and holds down the forward control of the shield plate until it hits the end stop. At that point, the shield plate operator stops moving the shield plate and informs the crew that they can begin their bolting procedure. This process may have some degree of automation; however, to be conservative, this process is analyzed as if it is entirely manual. This is a simple manual action that the operator performs on a regular basis based on training.

The shield plate operator action of closing the shield plate until it hits the end stop is a simple manual action that the operator performs several times a day based on training. Operation of the shield plate is always the same. The end stop provides an indication, or feedback, that the shield plate has been appropriately moved. This error most closely corresponds to the task execution error NARA (Ref. E8.1.11) generic task type (GTT) A1, and it is adjusted by the following EPCs:

- 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.

- EPC 13: Operator underload/boredom. The full effect EPC would be ×3, which applies to a routine task of low importance, carried out by a single individual for several hours. The assessed proportion of effect (APOE) anchor for 0.1 is for low difficulty, low importance, single individual, for less than one hour. This assessment appears reasonable for this task since the closure operation takes place in just minutes, so the APOE is set at 0.1.

Shield plate crew member fails to cover cask entirely with shield plate $= 0.005 \times [(3-1) \times 0.1 + 1] = 0.006$

Crew Fails to Notice Improper Shield Plate Closure before Approaching the Shield Plate—If the crew fails to notice that the shield plate is not entirely closed before they approach the shield plate to begin bolting operations, they can potentially get a direct exposure while getting onto the platform. The bolting crew has to get onto the shield plate in order to bolt the canister lift fixture. Part of their training is to visually confirm the shield plate position before approaching the plate. The shield plate, platform opening, and end stop are all easily visible from the preparation platform. This error most closely corresponds to the observation error CREAM (Ref. E8.1.18) cognitive function failure (CFF) O3, adjusted by the following CPCs with values not equal to 1.0.

- CFF O3: Observation not made. The baseline HEP is 0.003.
- CPC "Working Conditions": The crew is physically present with a good view of the area, which qualifies as advantageous. The CPC for advantageous working conditions for an observation task is 0.8.
- 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:

Crew fails to notice improper shield plate closure before approaching the shield plate = $0.003 \times 0.8 \times 0.8 = 0.002$

This is the HEP if the action is completely independent on the part of the crew. However, there is a dependency between the shield plate operator's failure to close the shield plate properly and the crew's failure to notice based on a certain level of trust between the unbolting crew and their crewmate working the shield plate. In normal, low-consequence circumstances, this dependency might be considered "medium" or "high"; however, in this scenario, the crew is directly at risk if the shield plate operator fails, and thus more likely to actually perform the check. Therefore, this dependency was assessed to be "low." From THERP (Ref. E8.1.26, Table 20-21, item (a)(2)), the revised probability of this unsafe action follows:

Crew fails to notice improper shield plate closure before approaching the shield plate = 0.05

HEP Calculation for Scenario 1(a)—The events in the HEP model for Scenario 1(a) are presented in Table E6.3-4.

Table E6.3-4. HEP Model for HFE Group #3 Scenario 1(a) for 200-OpDPCShield1-HFI-NOW

Designator	Description	Probability
A	Shield plate operator fails to cover cask entirely with shield plate	0.006
B	Crew fails to notice improper shield plate closure before approaching the shield plate	0.05

Source: Original

The Boolean expression for this scenario follows:

$$A \times B = 0.006 \times 0.05 = 0.0003 \quad \text{(Eq. E-1)}$$

E6.3.3.4.2.2 HFE Group #3 Scenario 1(b) for 200-OpDPCShield1-HFI-NOW

1. Shield plate crew member opens the shield plate while the crew bolts the canister lift fixture.
2. The crew fails to notice the shield plate movement in time OR the shield plate crew member fails to respond to warnings from the crew.

Shield Plate Crew Member Opens Shield Plate while Crew Bolts Canister Lift Fixture—While it is likely that the entire crew involved in cask preparation is trained in proper shield plate operations, during normal cask preparation operations, the only crew member authorized to open the shield plate is the predesignated shield plate operator. The shield plate operator is trained to ensure that the shield plate and shield plate path are cleared of personnel before moving the shield plate. Also, there is a direct view of the entire shield plate path from the shield plate control location.

The shield plate is not supposed to be moved again during cask preparation activities once the canister lift fixture has been placed on the DPC. The only operations that occur after the canister lift fixture is emplaced and the shield plate is closed are bolting of the fixture and then movement of the CTT to the Cask Unloading Room. Neither of these actions requires actions that can be confused with the actions that correspond to operating the shield plate; bolting requires tools, and CTT movement is not done from the platform.

Once the canister lift fixture is placed on the DPC and the shield plate is closed, the shield plate is not supposed to be opened for the remainder of the operations. Therefore, this error is an EOC. The crew who are on the shield plate bolting the canister lift fixture would immediately notice that the shield plate was moving and would signal the person committing this error to stop. THERP (Ref. E8.1.26, Table 20-12) describes several EOCs. None of these errors, however, appropriately describes this error. EOCs described in THERP (Ref. E8.1.26) primarily refer to actions where the operator intends to perform an action (e.g., flip a switch or turn a knob) but performs a different action (e.g., flips the wrong switch or turns the knob the wrong way). In this case, none of crew members would be performing an action similar to opening the shield plate during this step. They would only be installing bolts in the canister lift fixture. The most appropriate error that corresponds with this HFE was determined to be the task execution error NARA (Ref. E8.1.11) GTT A5, adjusted by the following EPCs:

- NARA GTT A5: Task execution. Completely familiar, well-designed, highly practiced routine task performed to highest possible standards by highly motivated, highly trained and experienced person, totally aware of implications of failure, with time to correct potential errors. The baseline HEP is 0.0001. While this error is not a task execution error (because there is no task being performed) this error was considered the most appropriate because it describes the operations the best. This value is considered to be conservative when applied to this failure because there is no task being performed in this step.

- EPC 13: Operator underload/boredom. The full effect EPC would be ×3, which applies to a routine task of low importance, carried out by a single individual for several hours. This EPC is applicable in its full effect because the whole set of cask preparation activities is slow and tedious, and the operator could get bored and distracted and believe it is time to open the shield before the workers are completely clear. This is the only relevant EPC, and the APOE is set at 1.0.

Using the NARA (Ref. E8.1.11) HEP equation yields the following:

Shield plate crew member opens shield plate while crew bolts canister lift fixture

$$= 0.0001 \times [(3-1) \times 1.0 + 1]) = 0.0003 \qquad \text{(Eq. E-2)}$$

Crew Fails to Notice Shield Plate Movement in Time—During this portion of the operation, there are several people on the shield plate bolting the fixture with long reach tools that go through the shield plate. If the shield plate is inadvertently opened, these crew members would notice and provide immediate feedback to the person operating the plate. The crew would have roughly 30 seconds to notice and try to warn the shield plate operator. If they failed to notice the movement or did not realize what it meant, they would be exposed.

The crew works on the platform and stands on the shield plate or very close to it. Their reaction to it is a very simple response to a very obvious indicator; in this case the indicator is movement of the shield plate. This would be very obvious to the workers present, and they would have on the order of 30 seconds to react. While the NARA task execution error GTT C1 is primarily applicable to response to indicators in a control room, it is seen as the most applicable failure mode to this scenario because the basic action is, again, a very simple response to a very obvious indicator. Specifically, the portions of the description of GTT C1 related to "simple diagnosis required" and "response must be direct execution of simple actions" were considered applicable to this action. The other human failure quantification option for this action might be CREAM generic failure type I3 for "delayed interpretation"; however, the CREAM CPCs did not allow the influence of unfamiliarity to be fully addressed. Therefore, it is considered that NARA GTT C1 captures both the observation and interpretation characteristics of the action, adjusted by the following EPCs:

- GTT C1: Simple response to a range of alarms or indications providing clear indication of situation (simple diagnosis required). The baseline HEP is 0.0004.

- EPC 2: Unfamiliarity (a potentially important situation that occurs infrequently or is novel). The full effect EPC would be ×20, which applies to a rare event not covered in training, but procedures exist. The APOE anchor for 0.5 is for a rare event covered once per year in training. The APOE anchor for 0.1 is for a rare event covered in regular training. Other considerations for a reduction from full effect is something rarely practiced but easy to carry out and for which the crew has some familiarity. This is covered in regular health physics training and in health physics procedures. Proper health physics practices and the importance of shielding is emphasized in the training. It appears reasonable for this task that the APOE be set at 0.1.

- EPC 3: Time pressure. The full effect would be ×11, which applies if, in order to complete the required task, the operator would have to complete each task step correctly and as quickly as possible. The anchor example for the full effect of this EPC being applied (APOE of 1.0) is "just enough time to complete the task when working as quickly as possible," while an APOE of 0.5 is anchored with "operator must work at a fast pace with reduced time for checking." It was considered that the time would not be a full effect but more than half effect and was therefore assessed at an APOE of 0.7.

Using the NARA (Ref. E8.1.11) HEP equation yields the following:

$$\text{Crew fails to notice shield plate movement in time} \\ = 0.0004 \times [(20-1) \times 0.1 + 1] \times [(11-1) \times 0.7 + 1] = 0.01 \qquad \text{(Eq. E-3)}$$

Shield Plate Crew Member Fails to Respond to Warnings from Crew—If the crew realized what was happening, they would need to get the attention of the operator in some manner. Their only means of communication is verbal, without the aid of any communication devices. They would need to be heard over the noise of the machinery in the preparation area. The plate control is in direct view of the shield plate, and the operator has roughly 30 to 60 seconds to stop moving the shield plate before a potential direct exposure can occur. If the operator fails to do so, the workers would not have sufficient time to avoid exposure.

The shield plate crew member is on the floor near the platform and is unlikely to be looking up at the workers on the platform, in particular because at this point the shield plate crew member is in the process of opening the shield plate and expects that no one is on the platform. There is machinery noise from the platform and other things in the preparation area like the CTT. The other members of the crew are trying to communicate the error to the shield plate crew member verbally. The action itself (stopping the shield plate) is very simple, and there is plenty of time to execute it once the need is recognized. This error most closely corresponds to the communication error NARA (Ref. E8.1.11) GTT D1, adjusted by 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 pertains to competing data or signals that obscure the most important ones, but it can also mean masking of the important information by other types of distractions. In this case, the masking effect is the abundance of machine noise and the distance between the crew on the platform and the crew member on the floor. The full effect EPC would be ×10, which applies to a required signal being highly masked (such as when there is a proliferation of other signals). Given the level of noise that is expected and the difficulty in communicating above it, it appears reasonable for this task that the APOE be set at 1.0.

Using the NARA (Ref. E8.1.11) HEP equation yields the following:

$$\text{Shield plate crew member fails to respond to warnings} \\ \text{from crew} = 0.006 \times [(10-1) \times 1.0 + 1]) = 0.06 \qquad \text{(Eq. E-4)}$$

Calculation for Scenario 1(b)—The events in the HEP model for Scenario 1(b) are presented in Table E6.3-5.

Table E6.3-5. HEP Model for HFE Group #3 Scenario 1(b) for 200-OpDPCShield1-HFI-NOW

Designator	Description	Probability
A	Shield plate crew member opens shield plate while crew bolts canister lift fixture	0.0003
B	Crew fails to notice shield plate movement in time	0.01
C	Shield plate crew member fails to respond to warnings from crew	0.06

NOTE: HEP = human error probability; HFE = human failure event.

Source: Original

The Boolean expression for this scenario follows:

$$A \times (B + C) = 0.0003 \times (0.01 + 0.06) = 2E{-}5 \qquad \text{(Eq. E-5)}$$

E6.3.3.4.2.3 HEP for HFE 200-OpDPCShield1-HFI-NOW

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

$$\text{HFE 200-OpDPCShield1-HFI-NOW} = \text{HEP 1(a)} + \text{HEP 1(b)}$$
$$= 0.0003 + 2E{-}5 = 0.00032 \sim 0.0004 \qquad \text{(Eq. E-6)}$$

E6.3.4 Results of Detailed HRA for HFE Group #3

The final HEPs for the HFEs that required detailed analysis in HFE Group #3 are presented in Table E6.3-6 (with the original preliminary value shown in parentheses).

Table E6.3-6. Summary of HFE Detailed Analysis for HFE Group #3

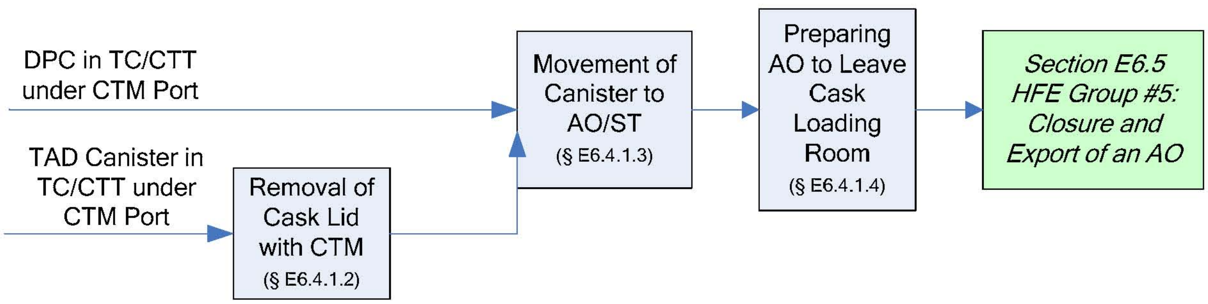
HFE	Description	Final Probability
200-OpDPCShield1-HFI-NOW	Operator fails to properly shield DPC while installing canister lift fixture, leading to direct exposure	4E−04 (1E−3)

NOTE: DPC = dual-purpose canister; HFE = human failure event.

Source: Original

E6.4 ANALYSIS OF HUMAN FAILURE EVENT GROUP #4: TRANSFER OF A CANISTER INTO AN AGING OVERPACK WITH THE CANISTER TRANSFER MACHINE

HFE group #4 corresponds to the operations and initiating events associated with the ESD and HAZOP evaluation nodes listed in Table E6.0-1, covering the transfer of a canister into an aging overpack with a CTM. The operations covered in this HFE group are shown in Figure E6.4-1. The activities covered in HFE group #4 begin with a canister in position aligned with a port, ready to be lifted with the CTM. The canister could be in a transportation cask that has a lid (i.e., a TAD canister) or one that has its lid removed (i.e., a DPC). The operation continues through the tasks of opening the port gate above the canister, removing the canister with the CTM, moving the CTM to the receiving port gate, and placing the canister in an aging overpack. This operation ends when the canister has been placed in the aging overpack, the aging overpack lid has been emplaced, the CTM has been withdrawn, and the port gate has been closed.



NOTE: § = section; AO = aging overpack; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; HFE = human failure event; ST = site transporter; TAD = transportation, aging, and disposal; TC = transportation cask.

Source: Original

Figure E6.4-1. Activities Associated with HFE Group #4

E6.4.1 Group #4 Base Case Scenario

E6.4.1.1 Initial Conditions and Design Considerations Affecting the Analysis

The following conditions and design considerations were considered in evaluating HFE group #4 activities:

1. The transportation cask is secure in the CTT. For TAD canisters, the lid is sitting on the transportation cask, unbolted. The transportation cask has a lid lift fixture attached. For a DPC, the cask lid is removed, and a canister lid lift fixture is attached to the DPC.

2. The aging overpack is stationed under the aging overpack port, secured, with the lid removed.

3. CTM operations are performed remotely from a control room unless otherwise specified.

4. The CTM has the following safety features and hardwired interlocks:

   A. Vertical movement and upper limit—The CTM is raised and lowered with the use of an ASD. The ASD has at least three settings: one for lift of canisters, one for lift of objects that do not fit inside the bell (e.g., cask lid), and a maintenance mode. The operator selects the setting and uses the controller to raise the hoist until it automatically stops at the selected setting height.

      1) For the canister mode, the ASD automatically stops once the canister clears the bottom of the bell. There is also an optical sensor at the bottom of the bell that, once cleared, stops the hoist and erases the lift command (i.e., can only lower the hoist).

      2) For the object mode, the ASD automatically stops the hoist once it clears the port gate. The operator can potentially restart the lift operation and further lift the object.

      3) The maintenance mode is fully manual; the ASD does not stop the lift. The optical sensor interlock itself is not to be bypassed; rather, the bell is uncoupled from the trolley, effectively bypassing this interlock. Once the bell and trolley are coupled, the sensor bypass is in effect.

      Above the ASD stop point is an upper limit switch that, when reached, stops the hoist from lifting. This first limit switch (final hoist lower limit) effectively erases the lift command. The hoist still has power, but the operator can only lower the hoist. Roughly a foot above that limit switch is another limit switch (i.e., the final hoist upper limit) that, when reached, cuts off the power to the CTM hoist.

   B. Horizontal movement/port alignment—There is a visually based system which aligns the CTM with the canister such that the grapple can properly engage the canister. The form of this system may use a scheme as simple as laser/target alignment or a more complex system including image recognition software coupled with PLCs. Likewise, horizontal movement and final alignment of the CTM with the cask/aging overpack ports is potentially a highly automated process. However, to be conservative, the horizontal movement process analyzed here considers a manual process, generically relying on a visual alignment system and camera for alignment confirmation.

C. There is an interlock between the shield skirt and the port gate that requires the shield skirt to be lowered in order for the port gate to open. If the automated system is used, the CTM alignment is based on a coordinate system, and the CTM would not be able to move at all if the port gate is open. However, for manual alignment, to get exact alignment, the CTM needs a "jog" feature that allows the CTM to move in small increments while the shield skirt is lowered. There is also a maintenance bypass for this interlock.

D. There is an interlock between the CTM bridge/trolley travel and shield skirt position. Neither the CTM bridge nor the trolley can travel while the skirt is lowered.

E. There is an interlock between the slide gate and shield skirt; the shield skirt cannot be raised unless the slide gate is closed. This interlock can be bypassed for maintenance.

F. There are interlocks preventing improper hoist movement. The hoist cannot move unless the shield skirt is lowered. This interlock is based on hoist movement, not position, so movement with the hoist too low is not precluded.

G. There are speed limiters designed into the motors.

H. There are end-of-travel interlocks on the trolley and bridge.

I. There are anticollision interlocks on the CTMs.

J. There is a weight interlock that cuts off power to the hoist when the crane capacity is exceeded.

K. There is an interlock that prevents CTM canister grapple (primary grapple) operation if the grapple is not properly connected to the hoist.

L. There is an interlock between the grapple engagement/position (fully engaged or fully disengaged) and hoist movement. The secondary grapple has the same interlock that is enabled when the power is connected to the grapple.

M. The CTM is mechanically or electrically prevented from inadvertent canister disengagement.

N. The following grapples are associated with these CTM activities:

1) Lid grapple (for transportation cask/aging overpack lid).

2) DPC/TAD canister grapple—The same grapple is used for a TAD canister and a DPC.

3) It is expected that if the wrong grapple is used, the grapple designs preclude partial/full engagement (i.e., the wrong grapple would be too big, too small, or otherwise mechanically incompatible with the fixture).

O. It is expected that if the wrong grapple is used, the grapple designs preclude partial or full engagement (i.e., the wrong grapple would be too big, too small, or otherwise mechanically incompatible with the fixture).

P. Grapple installation—When the design is finalized, one option under consideration is that an automatic system would be used to remove and attach the grapples. It is expected that such a system would be more reliable than a local manual process. This analysis retains the local manual process so that compliance can be demonstrated without the automatic system.

5. The shield doors to the unloading and loading rooms are closed. There is an interlock between the port slide gates and the shield doors; the port slide gate cannot be open while the shield doors are also open.

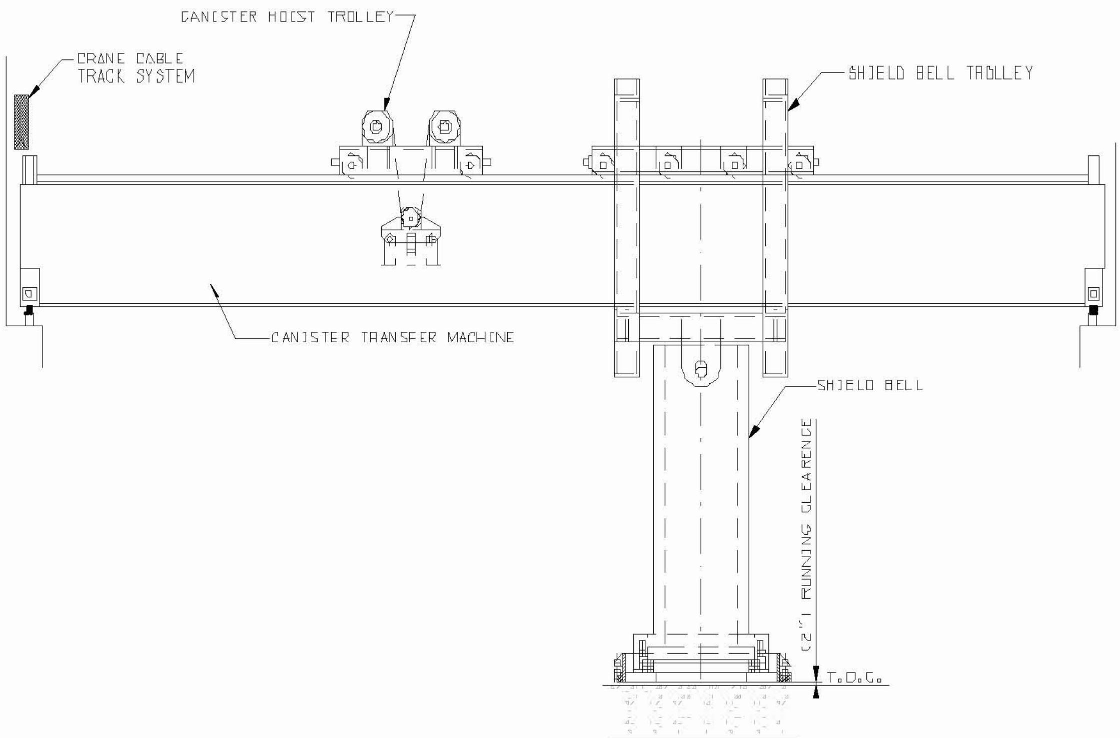
6. There are interlocks between the port slide gate and the aging overpack/site transporter. The gate cannot open unless the aging overpack is under the port.

The following personnel are involved in this set of operations:

- CTM operator
- Crew members (two people)
- Supervisor.

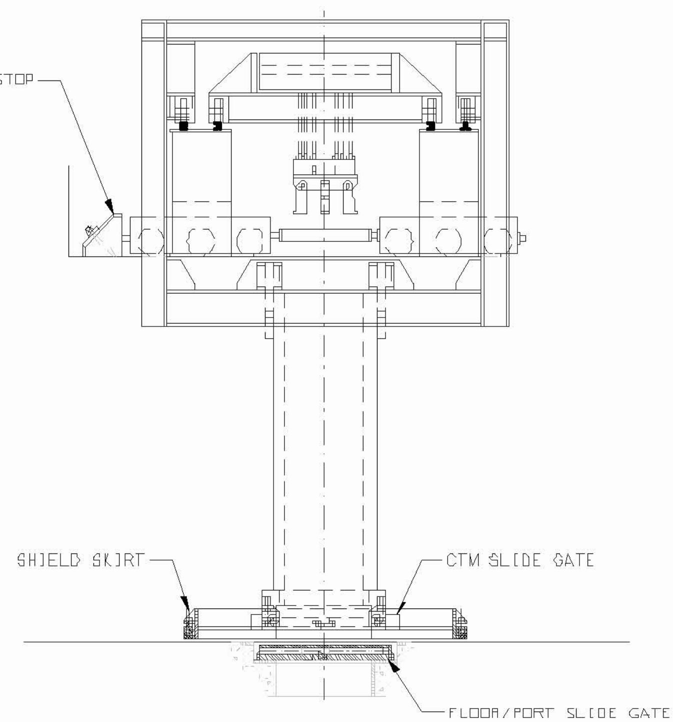
Section E5.1.2 provides a more detailed description of the duties performed by each of these personnel.

Figure E6.4-2 and Figure E6.4-3 are simple diagrams illustrating the CTM.



Source: Modified from Ref. E8.1.6

Figure E6.4-2. Canister Transfer Machine—Side View



Source: Modified from Ref. E8.1.6

Figure E6.4-3. Canister Transfer Machine—End View

E6.4.1.2 Removal of Transportation Cask Lid with CTM (if Required)

Install Proper Grapple—The CTM operator moves the CTM to the CTM maintenance area (Canister Transfer Room floor), where a crew member manually takes off and stores the grapple attached to the CTM (i.e., canister grapple) and replaces it with the lid grapple. The CTM operator also ensures that the ASD is set to the appropriate setting to lift the canister.

Moving CTM to Cask Port—The CTM operator uses a visual alignment system and a camera to position the CTM, with the lid grapple, over the cask port. There is a position indicator, along with a camera view, so the operator knows when the CTM is in position.

Opening CTM Slide Gate and Port Slide Gate—The CTM operator remotely lowers the skirt shield, opens the CTM slide gate, and opens the cask port slide gate once the CTM is in place.

Lifting Transportation Cask Lid into CTM and Slide Gate Closure—The operator first sets the ASD to lid lift mode and then lowers and engages the lid grapple; the grapple does not lower unless the slide gate is open and skirt is lowered. Grapple engagement is manual, and it is verified visually via camera and via an indicator. Once the grapple is engaged and verified, the operator then lifts the cask lid just past the CTM slide gate. At this point the operator closes the port and CTM slide gates.

Moving CTM to Transportation Cask Lid Station and Lowering Lid to Lid Station—The CTM operator lifts the CTM skirt and moves the CTM with lid to the lid station. Once at the lid station, the operator lowers the lid, disengages the grapple, lifts the grapple, resets the ASD to canister lift setting, closes the slide gate, and lifts the skirt. A camera is used to ensure that the lid is staged in the proper location.

E6.4.1.3 Moving Canister to Aging Overpack

Proper Grapple Installation—Once the lid is removed (as needed), the CTM operator moves the CTM to the CTM maintenance area (Canister Transfer Room floor), where a crew member manually takes off and stores the grapple attached to the CTM and replaces it with the canister grapple. The CTM operator also ensures that the ASD is set to the appropriate setting to lift the canister.

Moving CTM to Cask Port—The CTM operator uses a visual alignment system and camera to position the CTM, with lid grapple, over the cask port. There is a position indicator, along with a camera view, so the operator knows when the CTM is in position. Once in position, the CTM operator then lowers the shield skirt.

Opening CTM Slide Gate and Port Slide Gate—Once the CTM is in position over the cask port, with the shield skirt lowered, the CTM operator remotely opens the CTM slide gate and the cask port slide gate.

Lifting Canister into CTM—The CTM operator again looks at the relative canister and hoist position and adjusts the alignment if necessary to ensure that the CTM is over the canister. This final adjustment is done with the alignment system, in conjunction with a camera view. Once the CTM is appropriately aligned to the canister, the operator lowers the canister grapple and engages the grapple. Grapple engagement is manual, and is verified visually via camera and an indicator. The operator then lifts the canister by holding down a controller (i.e., joystick) until the ASD automatically stops the lift.

Closing CTM Slide Gate and Port Slide Gate—Once the canister is raised inside the bell, the operator closes the CTM slide gate, closes the port slide gate, and lifts the CTM skirt in preparation for movement.

Moving CTM to Aging Overpack Port—The CTM operator moves the CTM from the cask port into position over the aging overpack port using a visual alignment system in conjunction with a camera view to ensure alignment with the port. Once positioned, the operator lowers the skirt of the CTM.

Opening CTM Slide Gate and Port Slide Gate—The CTM operator then opens the CTM slide gate and the aging overpack port slide gate.

Lowering Canister—Once the port gate is open, the operator verifies alignment using a visual alignment system in conjunction with a camera view; if not properly aligned, the CTM operator makes fine adjustments of the CTM position until alignment is verified. The operator then lowers the canister into the aging overpack port, disengages the grapple, verifies disengagement (via camera and indicator), and then retracts the grapple.

Closing CTM Slide Gate and Port Slide Gate—Once the grapple is raised, the operator closes the CTM slide gate, closes the aging overpack port slide gate, and lifts the CTM skirt in preparation for movement.

E6.4.1.4 Preparing Aging Overpack to Leave Cask Loading Room

Grapple Exchange—The CTM operator moves the CTM to the CTM maintenance area, where a crew member removes the canister grapple and attaches the lid grapple. The operator then closes the slide gate and lifts the skirt. The CTM operator also sets the ASD to the proper setting for moving the aging overpack lid.

Install Aging Overpack Spacer (if required)—Once the skirt is lifted, the CTM operator retrieves the aging overpack spacer, moves the CTM to the aging overpack, lowers the shield skirt, opens the port and CTM slide gates, and lowers the hoist. Once the spacer is in place, the CTM operator disengages the grapple, retracts the hoist, closes the port and CTM slide gates, and lifts the shield skirt for movement.

Moving CTM to Aging Overpack Lid Station and Retrieving Lid—Once the skirt is lifted, the operator moves the CTM and positions it over the aging overpack lid station. The operator then lowers the grapple, engages the grapple, verifies the engagement (via camera and indicator), and lifts the aging overpack lid.

Moving CTM to Cask Port—The CTM operator positions the CTM, with lid, over the aging overpack cask port and lowers the skirt. The operator uses a visual alignment system in conjunction with a camera view to ensure alignment with the port.

Opening Cask Port Slide Gate and Placing Lid on Aging Overpack—Once the skirt is lowered, the operator remotely opens the cask port slide gate, confirms alignment (via the visual alignment system and camera), and lowers the lid into position. The CTM operator then disengages the grapple, verifies that the grapple is disengaged (via indicator and camera), and retracts the grapple.

Closing Cask Port Slide Gate—Once the grapple is retracted, the operator remotely closes the cask port slide gate.

E6.4.2 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 the base case scenario are summarized in Table E6.4-1. The analysis presented here includes the assignment of preliminary HEPs in accordance with the methodology described in Section E3.2 and Appendix E.III of this analysis; Section E4.2 provides details on the use of expert judgment in this preliminary analysis.

Table E6.4-1. HFE Group #4 Descriptions and Preliminary Analysis

HFE ID	HFE Brief Description	ESD	Preliminary Value	Justification
200-OpCTMdrop001-HFI-COD	*Operator Drops Object onto Canister during CTM Operations*: Some variations of CTM activities require heavy objects to be moved over the canister: some TC lids are removed, a spacer may be installed, and all AO lids are installed. It is possible that these objects can be dropped onto the canister while being lifted with the CTM.	6	2E−03	In this step, the operator can potentially drop the cask lid, aging overpack lid, or spacer on the canister. The spacer is not heavy enough to damage the canister There are several ways for this failure to occur, including: • Operator fails to fully engage/disengage the grapple before lifting hoist (partial engagement of grapple). There is an indicator and camera view by which the operator is required to verify engagement. There is also an interlock that does not allow the hoist to move unless the grapple is fully engaged or fully disengaged. This interlock does not have a bypass. • Operator fails to properly connect the grapple to the CTM when switching grapples. • Operator lifts the lid with the CTT significantly misaligned with the cask port. This can cause part of the lid to be caught under the second floor; if the CTM keeps pulling, the cable can snap and the lid can drop. There are several electromechanical safeguards preventing this, including load cell interlock, motor temperature interlock, and the cable design. (A similar failure can occur if the CTM is moved with an object below the floor; however, this event is treated separately in 200-OpCTMImpact1-HFI-COD.) • The only object that is lifted over a canister is the lid. The bell is flared at the bottom to accommodate the cask lid; if the operator puts the ASD in maintenance mode or sets it in canister mode, the lid can be lifted until it hits the inside of the bell. If the operator continues trying to lift, the cable can snap, causing the lid to drop onto the canister. There are several electromechanical safeguards preventing this, including load cell interlock, motor temperature interlock, and the cable design. Interlocks that prevent or mitigate these unsafe actions are considered as an integral part of this HFE and are not explicitly modeled in the fault tree in connection with this failure. The preliminary value was chosen based on the determination that this failure is "highly unlikely" (0.001) and was adjusted because there are several ways for a drop to occur and, because the operation is performed remotely, this is a somewhat complex process (×2) as opposed to an extremely complex process (which would be ×3). This HFE was assessed to be less likely than a cask impact or a RC collision, and, indeed, the preliminary value reflects this.
200-OpCTMdrop002-HFI-COD	*Operator Drops Canister during CTM Operations*: All variations of CTM activities require the canister to be lifted and transferred to an AO. During this lift, the operator can drop the canister (e.g., by improper grapple engagement).	6	2E−03	Moving a canister with the CTM is very similar to moving an object (200-OpCTMdrop001-HFI-COD) with the CTM during cask transfer, and it has the same failure modes. The only difference between moving a canister and moving an object (specifically, the lid) is that a canister drop due to lifting too high into the bell (two-blocking is considered separately) does not result in a drop. Therefore, it was considered conservative to assign the same preliminary value to this HFE.
200-OpCTMDrInt01-HFI-COD	*Operator Lifts Canister too High with CTM*: It is possible that, while lifting the canister, the operator can cause a two-block by lifting the object to high.	6	1.0	When lifting the canister, the operator can lift it too high, resulting in a two-block event and drop of the canister. In order to accomplish this, the interlocks (i.e., optical sensor) and other anti-two-block equipment (e.g., limit switches) must also fail. To be conservative, unsafe actions that require an equipment failure to cause an initiating event have generally been assigned an HEP of 1.0.
200-OpNoUnBolt00-HFI-NOD	*Operator Fails to remove Lid Bolts, Resulting in Impact, Drop, or Tip Over [TAD]*: If the operators fail to remove all or some of the lid bolts from the cask, when they attempt to remove the cask lid with the CTM, the load may be significantly heavier than the CTM is rated for, and the result could be a drop of the cask.	6	1E−03	If the lid bolts were not all removed during preparation activities and the CTM operator does not notice, one of two things may happen: the operator may attempt to lift the cask and the bolts may break, or the CTM operator may attempt to lift the cask and the bolts may hold. If the bolts hold, the load cell stops the CTM from lifting before the cask can be lifted. This failure was not assigned a 1.0 like other failures, which are ANDed with mechanical failures because the load cell is never bypassed and the HFE requires several independent human failures. For this failure to occur, the preparation crew must fail to remove all the bolts and must fail to verify on the checklist that all the bolts have been removed. Independently, the CTM operator would also have to fail to notice that the entire cask is lifting as the lid is lifted into the CTM. This failure was assessed to be "highly unlikely" (0.001) because it involves two human failures by different teams and significant inattention to the operation. This operation is performed daily and also corresponds closely to the generic human-induced initiator, "failure to properly conduct an operation performed on a daily basis," which also has a default probability of 0.001.
200-OpNoUnBoltDP-HFI-NOD	*Operator Fails to remove Lid Bolts, Resulting in Impact, Drop or Tipover [DPCs]*	6	N/A	There is no lid on casks containing a DPC; therefore, this failure mode was omitted from analysis.

INTENTIONALLY LEFT BLANK

Table E6.4-1. HFE Group #4 Descriptions and Preliminary Analysis (Continued)

HFE ID	HFE Brief Description	ESD	Preliminary Value	Justification
200-OpCTMImpact1-HFI-COD	*Operator Moves the CTM while Canister or Object is below or between Levels*: If the operator moves the trolley before the canister has cleared the port gate, then the canister can impact the floor if the canister is between levels. If the canister or the lid is completely below the floor, this failure can result in the cable snapping and the canister or object dropping.	6	1E−03	The operator can inappropriately move the CTM while the canister or lid is below the port gate or while the canister is between levels. If this inadvertent movement occurs while the canister is between levels, it can result in an impact and shear force to the canister. If the movement occurs while the canister is below the port gate, then the cable can snap, resulting in a drop. In order to accomplish this inadvertent movement, the operator would have to fail to follow proper lifting procedure and operate the ASD in manual or lid lift mode. If the lift is performed in manual mode, then the operator can fail to lift the canister or object high enough to clear the floor before starting horizontal movement. If it is in lid lift mode, it would automatically stop too soon, but the operator would have to fail to notice that the canister is not high enough when closing the port and CTM slide gates on the canister. For a canister, the operator would also have to fail to rely on the optical sensor and must also fail to close the slide gate to accomplish this HFE. There are interlocks, such as the load cell interlock, that prevent the CTM from exerting enough force to snap the cable and drop the canister or object. There is also an interlock that prevents horizontal motion if the CTM slide gate is not closed, but this interlock can be bypassed during normal maintenance. Due to the complicated nature of this failure, the interlock was not separately modeled for this HFE; rather, it was included in the preliminary value. This failure was considered highly unlikely and accordingly assigned a preliminary value of 0.001.
200-OpClCTMGate1-HFI-NOD	*Operator Inappropriately Closes Slide or Port Gate during Vertical Canister Movement and Continues Lifting*: If the operator signals the CTM slide gate or port gate to close while the canister is being raised, it can result in a canister impact if the door closes on the canister, or it can result in a canister drop if the door closes on the host, severing the cables. The NSDB requires the gate motors to be sized such that they cannot damage the canisters; the gate cannot sever the cables either. This failure can, however, result in a drop if the operator closes the slide gate on the cables and continues hoisting such that the canister is stuck and the cable snaps.	6	1E−03	In this operation, the CTM operator is lifting and lowering the canister. The slide gate cannot damage the canister or sever the hoist cables, so the failure required here is for the operator to prematurely close the slide gate and keep hoisting such that the canister catches on the slide gate and the hoist cable snaps. There are two slide gates for each motion: the CTM slide gate and the cask/aging overpack port slide gate. The operator performs CTM operations daily and has a camera view of the operations. There is no interlock to prevent this unsafe action, but if the canister is lifted per the procedure, the operator uses the ASD and does not close the gate until the ASD has stopped. It is unlikely the operator would try to close the slide gate while lifting the canister; the most likely scenario is for the operator to fail to lift the canister high enough, close the slide gate as if to move the CTM, and then notice that the canister is too low and try to lift the canister without first opening the slide gate. In order for the operator to fail to lift the canister high enough, the ASD has to have a mechanical failure or the ASD has to be in the wrong mode. The manual mode is only accessible by entering a password. Because lifting is a slow procedure, it is unlikely that the operator would put the ASD in manual mode, even if it is possible; if the operator does so, it is unlikely that the operator would stop the canister too soon because, independent of the ASD, the optical sensor in the bell stops the canister once it has cleared the bell. The more likely case is that the operator fails to restore the ASD to canister lift mode after moving the lid. For all waste forms except the DPC, the lid is removed in the previous step. If the operator does fail to change ASD mode, the operator must also fail to visually verify the height of the canister before closing the slide gate. In either case, if the operator does stop the canister too soon and closes the slide gate, the operator still has to forget to reopen the slide gate before resuming the lift in an attempt to correct the error. This failure was assessed to be "highly unlikely" (0.001) because it involves several unlikely failures and significant inattention to the operation. This operation is performed daily and also corresponds closely to the generic human-induced initiator "failure to properly conduct an operation performed on a daily basis," which also has a default probability of 0.001. There is a load cell interlock that prevents a drop. This interlock is never bypassed, even in maintenance; therefore, it was considered appropriate to apply a more realistic preliminary value (i.e., not 1.0) to this HFE.
200-OpCTMImpact2-HFI-COD	*Operator Causes Canister Impact with Lid during CTM Operations (TAD Canister)*: The cask lid, when removed by the CTM, is staged such that the canister must travel over it to move from the Cask Unloading Room to the Loading Room or the staging area. If the lid is improperly stowed, the CTM can collide with the lid. This failure mode is not applicable to DPCs because the cask lid is removed in the Cask Preparation Room.	6	N/A	The lid staging area is in the pathway of the CTM; if the lid is improperly stored, the CTM, carrying a canister, can potentially impact the lid. This failure was omitted from analysis because, if the lid was stored such that it was an obstruction to the CTM, the CTM would run into the lid as it returns to the cask from lid staging. At that point, the error would have to be corrected before operations were continued.
200-OpCTMImpact5-HFI-COD	*Operator Causes Canister Impact with SSC during CTM Operations (All)*: If the CTM is moved too far while transferring a canister, it can collide into an end stop and impact the inside of the CTM bell or hit an SSC.	6	1.0	In this step, the operator can potentially impact the canister in several ways: • CTM bridge impacts end stops while moving canister. • CTM trolley impacts end stops while moving canister. In order to accomplish either of these, however, additional equipment failures must also occur. To be conservative, unsafe actions that require an equipment failure to cause an initiating event have generally been assigned an HEP of 1.0.

INTENTIONALLY LEFT BLANK

Table E6.4-1. HFE Group #4 Descriptions and Preliminary Analysis (Continued)

HFE ID	HFE Brief Description	ESD	Preliminary Value	Justification
200-OpDirExpose1-HFI-NOD	*Operator Causes Direct Exposure During CTM Activities (First Floor, All CTM Movements)*: If a crew member inadvertently opens the shield door and enters the Cask Unloading Room while the canister is being lifted out of the cask, that crew member would get a direct exposure.	11	1E−01	Direct exposure during CTM activities can happen if a crew member inadvertently opens the shield door to the transfer room while the canister is being lifted. In order to accomplish this, an interlock must also fail. The shield door interlock cannot be easily bypassed and is not bypassed during normal operations or normal maintenance. As was previously discussed, the HRA team has generally assigned unsafe actions that are combined with interlocks an HEP of 1.0. As was also discussed, if this very conservative approach did not demonstrate compliance with the performance objectives of 10 CFR Part 63.111 (Ref. E8.2.1) then the HRA team would consider whether a lower preliminary value were justified. That is the case here. In further considering this event, it would be very difficult to make it happen. An extraordinary bypass of the interlock would be required or a random failure of the interlock. Then, a worker would have to violate all administrative controls and training and attempt to enter the room without appropriate clearance from the control room (according to the radiation protection program). Therefore, the HRA team feels justified in assigning a lower preliminary value of 0.1 to the unsafe action (still believed to be quite conservative), which in combination with the interlock failure value results in an overall value of 3E−6/demand for an exposure.
200-OPCTMDirExp1-HFI-NOD	*Operator Causes Direct Exposure during CTM Activities (Second Floor, All CTM Movements)*: If the CTM operator fails to close the port gate before lifting the shield skirt after placing a canister in a the aging overpack and a worker violates the procedural control by entering the Cask Transfer Room during canister transfer activities, that worker would be exposed.	11	1E−04	Closure of the port gate is a simple action that is performed multiple times a day. This action is performed every time the CTM is moved without deviation, and the operator is trained on the consequences associated with this failure. In addition to these failures, a completely independent failure, involving violation of a strict procedural control by inappropriately entering a radiation controlled area, by a person of a separate "team" must also occur. This HFE was considered extremely unlikely and assigned a preliminary value of 0.0001.
200-OpDirExpose2-HFI-NOD	*Operator Causes Direct Exposure During CTM Activities (Movement into AO)*: If the AO is not pre-staged in the Cask Unloading Room, the operator can lower the canister to the floor of the Cask Unloading Room and then place the AO lid directly on the canister. The next step in operations is movement of the AO to the Cask Preparation Room. In this step, the ST operator opens the shield door and enters the Cask Unloading Room as part of normal operations and is exposed. There is an interlock that prevents the port gate from opening if a receptacle (AO or cask) is not below the port.	11	1E−4	Operators can also cause direct exposure during CTM operations by failing to stage an aging overpack in the Loading Room, and then placing the canister on the floor of the Loading Room and opening the shield door. Placing the aging overpack beneath the cask port is part of the staging activities before RF operations for aging overpack loading. Aging overpack staging is checked off by the staging crew and also by the operations crew directly before operations begin as part of the prejob plan. If the aging overpack is not staged, the CTM operator has the chance to notice when emplacing the canister inside the aging overpack (camera view looking down on aging overpack). If the canister is emplaced on the floor, then the operator has an additional chance to notice the aging overpack is missing when trying to put the aging overpack lid on the aging overpack with the CTM. These unsafe actions are independent because they are temporally separated and are performed by different crews. This failure received a preliminary value of 0.01 for failure to pre-stage the aging overpack and 0.01 for failure to notice before a direct exposure occurs, resulting in a total preliminary value of 0.0001.
200-OpFailRstInt-HFI-NOM	*Operator Fails to Restore Interlock after Maintenance*: There are several interlocks that may be bypassed during normal maintenance. Failure to restore the interlock that prevents the port gate from opening before a receptacle is placed underneath the port is explicitly modeled. If the bypass is not restored, this could result in a direct exposure due to HFE 200-OpDirExpose2-HFI-NOD.	11	1E−02	If the maintenance bypass for the interlock that prevents the cask port gate from opening before an aging overpack or transportation cask is placed underneath the port is not restored, it could result in a direct exposure due to HFE 200-OpDirExpose2-HFI-NOD. This interlock would be bypassed during CTM maintenance. This failure would require the crew member to fail to reset the bypass and the crew member to fail to properly perform the prejob check of the CTM equipment. These failures were 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."
200-OpFailSG-HFI-NOD	*Operator Fails to Close the CTM Slide Gate before Moving the CTM with the Canister inside the Bell*: If the canister is inside the CTM with the shield skirt raised and slide gate open, then personnel on the Transfer Room floor may get a direct exposure. This configuration is achieved if the operator fails to close the CTM slide gate and the raises the shield skirt to move the canister to a new receptacle and a person violates the procedural control by entering the Transfer Room. There is an interlock that prevents the shield skirt from rising if the slide gate is open.	11	1E−03	Direct exposure during CTM activities can happen if there is a canister in the bell and the CTM slide gate is open while the shield skirt is raised. The most likely way to get this configuration is for the operator to forget to close the slide gate and then raise the shield skirt to move the CTM as per normal operations. There is an interlock that prevents this error and cannot be bypassed. Furthermore, for a direct exposure to occur, a person would have to violate a procedural control associated with the radiation protection program by entering the Transfer Room during canister transfer. This operation is performed multiple times a day and, for every CTM lift, the operator closes the slide gate before lifting the shield skirt. This operation is performed by a highly trained operator and also corresponds closely to the generic human-induced initiator "failure to properly conduct an operation performed on a daily basis," which also has a default probability of 0.001. No adverse PSFs were identified in this operation that would merit adjusting this preliminary value.

INTENTIONALLY LEFT BLANK

Table E6.4-1. HFE Group #4 Descriptions and Preliminary Analysis (Continued)

HFE ID	HFE Brief Description	ESD	Preliminary Value	Justification
200-OpNoUnplugST-HFI-NOD	*Operator Causes Spurious Movement of the ST while Canister is Being Loaded*: When the ST is moved to the Loading Room and positioned under the cask port, the operator is supposed to lower and turn off the ST. If crew fails to disconnect the ST from the power source, the ST can get a spurious signal during canister lifting that would cause a collision of the ST into the canister.	6	1E−03	While in the Loading Room, the site transporter is off with the load lowered. The site transporter is controlled locally (i.e., via pendent), and there are no operators in the Loading Room during CTM operations; however, before CTM operations begin an operator must be present to align the site transporter to the port. In order to cause a spurious movement of the site transporter, the operators must fail to disconnect the site transporter from the power source, and the controller must send a spurious signal to the site transporter. The connection point for the site transporter is outside of the Loading Room, in the Lid Bolting Room. In order for this failure to occur, when exiting the Loading Room and closing the shield door, the personnel would have to fail to notice the cord going in through the shield door. If the shield door does not sever the power cord, then there is an interlock that prevents this error: the interlock prevents the port gate from opening (and thus CTM activities commencing) if the shield door is not completely closed. The shield door cannot be easily bypassed and is never bypassed during normal operations or normal maintenance. This failure was assessed to be "highly unlikely" (0.001) because it involves several unlikely failures and significant inattention to the operation. This operation is performed daily and also corresponds closely to the generic human-induced initiator "failure to properly conduct an operation performed on a daily basis," which also has a default probability of 0.001.
200-OpNoDiscoAir-HFI-NOD	*Operator Causes Spurious Movement of CTT while Canister is Being Unloaded*: When the CTT is moved to the Cask Unloading Room and positioned under the cask port, the operator is supposed to disconnect the air supply from the CTT. If the crew fails to do so, the CTT can get a spurious signal during canister lifting that would cause a collision of the CTT into the canister.	6	1E−03	While in the transfer room, the CTT is parked with the air supply disconnected. The CTT is controlled locally (i.e., via pendent), and there are no operators in the transfer room during CTM operations. In order to cause a spurious movement of the CTT, the operators must fail to disconnect the CTT from the air source, and the controller must send a spurious signal to the CTT. The connection point for the CTT is outside of the Cask Unloading Room, in the Cask Preparation Room. In order for this failure to occur, when exiting the unloading room and closing the shield door, the personnel would have to fail to notice the hose going in through the shield door. If the shield door does not sever the air hose, then there is an interlock that would prevent this error: the interlock prevents the port gate from opening (and thus CTM activities commencing) if the shield door is not completely closed. The shield door cannot be easily bypassed and is never bypassed during normal operations or normal maintenance. This failure was assessed to be "highly unlikely" (0.001) because it involves several unlikely failures and significant inattention to the operation. This operation is performed daily and also corresponds closely to the generic human-induced initiator "failure to properly conduct an operation performed on a daily basis," which also has a default probability of 0.001.
Spurious movement of CTT or ST during CTM activities	*Operator Causes Spurious Movement of CTT or ST while Canister is Being Loaded or Unloaded*	6	N/A	The CTT is locally controlled and sitting in the unloading room deflated. The ST is locally controlled and sitting in the Loading Room disconnected from a power source. There are no personnel in either room during this operation, and there is an interlock on the shield door that prevents access to both rooms while the canister is being removed from the cask. This failure was omitted from analysis because it involves several mechanical and human failures, including violation of the procedural control that restricts access to the loading/unloading rooms. Furthermore, if a person enters the loading or unloading room during canister transfer, that person would receive a direct exposure; this failure is captured in 51A-OpDirExpose1-HFI-NOD.

NOTE: AO = aging overpack; ASD = adjustable speed drive; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; ESD = event sequence diagram; HEP = human error probability; HFE = human failure event; HRA = human reliability analysis; ID = identification; N/A = not applicable; NSDB = nuclear safety design basis; PSF = performance shaping factor; RC = railcar; RF = Receipt Facility; SSC = structure, system, or component; ST = site transporter; TAD = transportation, aging, and disposal (canister); TC = transportation cask.

Source: Original

INTENTIONALLY LEFT BLANK

E6.4.3 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 is discussed in Section E6.4.3.2.

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 E6.4.3.3 and E6.4.3.4, 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 E6.4.3.4. Four quantification methods are utilized in this quantification:

- CREAM (Cognitive Reliability and Error Analysis Method, CREAM (Ref. E8.1.18 DIRS 181532))

- HEART ("HEART – A Proposed Method for Assessing and Reducing Human Error." (Ref. E8.1.28 DIRS 184001))/ NARA (*A User Manual for the Nuclear Action Reliability Assessment (NARA) Human Error Quantification Technique* (Ref. E8.1.11 DIRS 184080))

- THERP (Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications Final Report, NUREG/CR-1278 (Ref. E8.1.26 DIRS 139383))

- ATHEANA expert judgment (Technical Basis and Implementation Guidelines for a Technique for Human Event Analysis (ATHEANA), NUREG-1624 (Ref. E8.1.22 DIRS 157661)).

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 E6.4.4.

E6.4.3.1 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 RF PCSA model determined that there were four HFEs in this group whose preliminary values were too high to demonstrate compliance with the performance objectives stated in 10 CFR 63.111. These HFEs are presented in Table E6.4-2.

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

HFE	Description	Preliminary Value
200-OpCTMdrop001-HFI-COD	Operator causes drop of object onto canister during CTM operations.	2E−03
200-OpCTMdrop002-HFI-COD	Operator causes drop of canister during CTM operations (low level drop).	2E−03
200-OpCTMImpact1-HFI-COD	Operator moves the CTM while canister or object is below or between levels.	1E−03
200-OPCTMDirExp1-HFI-NOD	Operator causes direct exposure due to CTM activities (second floor).	1E−04

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

Source: Original

E6.4.3.2 Assessment of Potential Vulnerabilities (Step 5)

For those HFEs requiring detailed analysis, the first step in the 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 event analysis, systems analysis, or event sequence analysis).

The vulnerabilities discussed in this section pertain only to those aspects of the preparation operation that relate to potential human failure scenarios relevant to the previously listed HFEs. Other vulnerabilities exist that would be relevant to other potential HFEs that can occur during the preparation operation, but these have no bearing on this analysis.

E6.4.3.2.1 Operating Team Characteristics

The operating team consists of the following personnel:

- **CTM operator**—The CTM operator is located in the RF Control Room. The CTM operator receives standard training for crane operations and observes operations prior to being allowed to operate the CTM on a dry run. After training, the CTM operator is signed off to operate the CTM based on an evaluation of proficiency in a dry run. The CTM operator is observed on initial operations until signed off for solo operation. A single operator is assigned to the CTM operation.

- **Crew members (two)**—Maintenance crew members are trained in tasks required for preparing the CTM for canister transfer, including affixing the appropriate grapple for the canister. Training consists of observation and "hands-on" instruction for the CTM preparation process. The CTM is prepared by a team of two workers.

- **Supervisor**—The supervisor, or some other personnel with comparable training and certification, is in the RF control room watching CTM operations. This person is in charge of completing an end-of-operations checklist and independently verifying that the Canister Transfer Room is in a safe configuration after canister transfer activities have been completed.

E6.4.3.2.2 Operation and Design Characteristics

Control Panel—The panel consists of a joystick controller for two-dimensional movements of the bridge and trolley. Speed in both directions is fully variable within unit capabilities, based on the extent of joystick deflection. Buttons for the up–down movement of the hoist are spring returned and must be held in for hoist movement. The height of the hoist yoke is displayed digitally on the panel. There is a joystick for fine motion alignment of the grapple (e.g., it can move the hoist within the bell). A flat screen display shows view from the camera mounted on the boom above the yoke. A control interface for the ASD is incorporated into the panel.

ASD—The ASD is equipped with a semiautomated system for lifts. The ASD has two normal modes and one maintenance (i.e., manual) mode. Normal modes have two settings: canister lift and lid lift. In the canister lift mode, the operator sets the mode and pushes/holds the lift button; the ASD lifts to the proper height and stops. The maintenance mode allows for full manual operation. The maintenance mode can be engaged only by entering a password.

Interlocks/Alarms—Only hardwired (non-PLC) interlocks are considered.

Hoist Operational Upper Limit—A light curtain located just above (~2 in.) the CTM slide gate. The interlock removes the power from the hoist lift circuit if nothing is sensed within the bell at this height (i.e., when the hoist cables, load cell, grapple, and any load have cleared this height). Indicators on the control panel (red/green lights) indicate whether the limit is cleared or blocked. The upper limit can be bypassed.

Grapple Engagement/Disengagement Interlock—The grapple interlock provides indication to the operator that the grapple is either fully engaged with the load or fully disengaged. Red and green lights indicate position. When both lights are on, this indicates that the grapple is between positions, and the interlock prevents hoist movement under this condition.

Grapple Interlock—The grapple interlock also prevents hoist movement if the secondary grapple is not properly attached to the primary grapple on the hoist. There is an interlock that prevents operation of the CTM canister grapple (primary grapple) if it is not properly attached to the hoist.

Load Cell Overlimit—The load cell overlimit stops hoist movement when excessive force is applied to the hoist. This could shut down the hoist if the lid is pulled up against the bottom of the bell, but it would not provide any protection against two-blocking because it is located below the lower block (i.e., between the block and the grapple).

Inadvertent Grapple Disengagement—The grapples are mechanically designed such that they cannot disengage while under a load, thus precluding inadvertent grapple disengagement. However, to be conservative, this is modeled as an electric interlock.

Shield Skirt/Slide Gate Interlock—Prevents the shield skirt from lifting if the CTM slide gate is not closed. The failure mode of failing to reset the bypass for this interlock has not been modeled because there is no bypass for this interlock.

E6.4.3.2.3 Operational Conditions

There is no direct view of the CTM operation by any individual. Visual cues are hampered because all observations are made through cameras and observed on screens. The precise locations of the cameras have not been specified in the design, but the intent is to provide cameras that can view the grapple and canister (and move with the hoist) on the hoist trolley (that can see into the bell) and at other locations that can provide views of the outside of the bell and the Canister Transfer Room.

Control panel indications provide positive indications that the grapple has been deployed in the locked position (a red light) or the unlocked position (a green light), but the ability to provide a direct (as opposed to indirect or inferred) confirmation of full engagement in the lift fixture is not proven.

The total operation of the CTM for a canister takes about two hours. The operator has a number of specific tasks to perform during that time, so the overall process can be considered reasonably active. However, the lifting task (relevant to drops) is one of the longest periods of inactivity for the operator (i.e., 10 minutes, of which only the last 30 seconds or so can be considered potentially active). The potential for the onset of boredom, complacency, or distraction is higher than normal during this task.

E6.4.3.2.4 Formal Rules and Procedures

Procedural Controls—Procedural controls ensure that the operators and maintenance personnel do not enter the Canister Transfer Room during CTM activities. Procedural controls also include a checklist that must be filled out at the end of transfer activities to ensure that all the port slide gates are closed.

E6.4.3.2.5 Operator Tendencies and Informal Rules

Dependency on Hoist Interlocks and Alarms—The CTM operator should actively observe and confirm proper operation of the CTM and not depend on either alarms to be informed that limits are being reached or interlocks to stop or prevent improper motion. However, there can be a tendency for the operator to count on these devices to prevent human failure, in particular because the visual information received from the cameras is distorted.

Dependency on Grapple Engagement/Disengagement Indicator—In a similar fashion, the operator should confirm positive engagement of the grapple through the camera, but the lack of clarity expected in the camera view can create a tendency to depend solely on the indicator.

E6.4.3.2.6 Operator Expectations

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

Anticipatory Actions—The lifting process is simple, the goal is clear, and problems are not expected. There is a tendency for the CTM operator to focus on future tasks while the hoist is in motion rather than concentrate on the ongoing task. The operator expects that no one attempts to enter the Canister Transfer Room during CTM activities.

Expectation of Grappling Success—The grapple is a simple device. The operator can expect that once the grapple is actuated, it properly engages or disengages. The operator does not expect a failure or expect the engagement indicator to show a failure. The operator also cannot expect that the grapple is not properly attached to the hoist (i.e., the operator can expect and trust that the crew members have properly prepared the CTM).

E6.4.3.3 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 to provide the complete context for 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 E6.4-3 summarizes all of the HFE scenarios developed for the HFEs in this group.

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

HFE	HFE Scenarios
200-OpCTMdrop001-HFI-COD *Operator causes drop of object onto canister during CTM operations*	HFE Scenario 1(a): (1) A crew member improperly installs the grapple, (2) the preoperational check fails to note the improper installation, (3) the primary grapple interlock gives a false positive signal, (4) the operator fails to notice the bad connection between the hoist and the grapple through the camera, and (5) the grapple/lid drops from the hoist and strikes the canister. HFE Scenario 1(b): (1) The operator fails to fully engage the grapple, (2) the grapple engagement interlock gives a false positive signal, (3) the operator fails to notice that the grapple is not fully engaged through the camera, and (4) the lid drops from the grapple and strikes the canister. HFE Scenario 1(c)[a]: (1) The operator leaves the ASD in maintenance mode OR the operator places the ASD in canister mode OR the ASD height control fails, (2) the operator fails to notice that the lift is taking too long OR the operator "locks" the lift button into position, (3) the load cell overload interlock fails, and (4) mechanical failure of the hoist under overload causes the lid to drop. HFE Scenario 1(d)[a]: (1) The CTT is not sufficiently centered under the port, (2) the operator fails to notice that the CTT is not sufficiently centered, (3) the operator fails to notice the lid tilt and continues the lift OR the operator "locks" the lift button into position, (4) the lid catches and jams in port, (5) the load cell overload interlock fails, and (6) mechanical failure of the hoist under overload causes the lid to drop. HFE Scenario 1(e): (1) The operator activates the grapple disengagement switch prematurely, (2) the load cell disengagement interlock fails, and (3) the lid drops from the grapple and strikes the canister.
200-OpCTMdrop002-HFI-COD *Operator causes drop of canister during CTM operations (low-level drop)*	HFE Scenario 2(a): (1) A crew member improperly installs the grapple, (2) a primary grapple interlock gives a false positive signal, (3) the operator fails to notice the bad connection between the hoist and the grapple through the camera, and (4) the grapple/canister drops from the hoist. HFE Scenario 2(b): (1) The operator fails to fully engage the grapple, (2) the grapple engagement interlock gives a false positive signal, (3) the operator fails to notice that the grapple is not fully engaged through camera, and (4) the canister drops from the grapple. HFE Scenario 2(c)[b]: (1) The CTT is not sufficiently centered under the port, (2) the operator fails to notice that the CTT is not sufficiently centered, (3) the operator fails to notice that the DPC contacting the ceiling and continues the lift OR the operator "locks" the lift button into position, (4) the load cell overload interlock fails, and (5) mechanical failure of the hoist under overload causes the DPC to drop.

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

HFE	HFE Scenarios
200-OpCTMImpact1-HFI-COD *Operator moves the CTM while canister or object is below or between levels*	HFE Scenario 3(a): (1) The operator leaves the CTM in the lid lift mode (TAD canister); (2) the operator fails to notice that the lift stops too soon, (3) the operator fails to close the port slide gate OR fails to notice that it does not fully close, (4) the operator fails to close the CTM slide gate OR fails to notice that it does not fully close, and (5) the CTM slide gate interlock fails. HFE Scenario 3(b): (1) The operator puts the CTM in the lid lift mode (for DPCs), (2) the operator fails to notice that the lift stops too soon, (3) the operator fails to close the port slide gate OR fails to notice that it does not fully close, (4) the operator fails to close the CTM slide gate OR fails to notice that it does not fully close, and (5) the CTM slide gate interlock fails. HFE Scenario 3(c): (1) The operator puts the CTM in the maintenance mode (for non-DPCs), (2) the operator terminates the lift prior to the automatic stop, (3) the operator fails to close the port slide gate OR fails to notice that it does not fully close, and (4) the operator fails to close the CTM slide gate OR fails to notice that it does not fully close, and (5) the CTM slide gate interlock fails. HFE Scenario 3(d)[c]: (1) The operator leaves the CTM in the maintenance mode (for DPCs), (2) the operator terminates the lift prior to the automatic stop, (3) the operator fails to close the port slide gate OR fails to notice that it does not fully close, and (4) the operator fails to close the CTM slide gate OR fails to notice that it does not fully close, and (5) the CTM slide gate interlock fails.
200-OPCTMDirExp1-HFI-NOD	HFE Scenario 4(a): (1) A worker violates administrative control by entering the Canister Transfer Room during canister transfer, and (2) the operator fails to close port gate before raising the shield skirt.

NOTE: [a] Scenarios 1(c) and 1(d) in this event do not apply to DPCs since DPC lids are not removed in the CTM, and these scenarios can only occur when lifting a lid off the cask.
[b] This scenario only applies to DPCs because the transportation cask lid was removed in the preparation area.
[c] Only scenario 3(d) is applicable for lids.
AO = aging overpack; ASD = adjustable speed drive; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; HFE = human failure events; TAD = transportation, aging, and disposal; TC = transportation cask.

Source: Original

Since there are four HFEs identified for detailed analysis in this group, the scenarios are organized under these HFE categories, with the scenarios under the first HFE category numbered as 1(a), 1(b), etc.; those under the second category numbered 2(a), etc.; and similarly those under the third category numbered 3(a), 3(b), etc.

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

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

E6.4.3.4 Quantitative Analysis (Step 7)

Once the HFE scenarios and the unsafe actions within them are scoped out, it is then possible to review them in detail and apply the appropriate quantification methodology in each case that permits an HEP to be calculated for each HFE. Stated another way, each HFE is quantified through the quantification 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 E6.4-3.

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

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

E6.4.3.4.1 Common Values Used in the HFE Detailed Quantification

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

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

Interlock fails to perform function = 2.7E−05

ASD Height Control Fails—This event is an equipment failure and does not have a human component to its failure rate. The demand failure rate for the ASD, from Attachment C, Table C4-1, is approximately 3.4E−05 per demand.

ASD height control fails = 3.4E−5

Load Drops from Hoist—This is the last event in a drop scenario. This event accounts for the safety margin built into the hoist system to accept overload without failure resulting in severed cables, failed clutches, and partially engaged grapples. The various events need to be quantified in relation to each other, using engineering judgment to account for the load being applied to the system versus its capacity to bear the load.

The first drop considered is where a canister (DPC) is being lifted and it catches the ceiling of the Cask Unloading Room. In this case, an overload of the system is created by adding the additional force of the hoist motor straining to lift the unmoving canister (over and above the force created by the canister) to the system. The extent to which this exceeds the ultimate load-bearing capacity of the system is a function of the total force that can be generated by the motor and the amount of time that the motor can exert this force while not turning before the motor overheats. Typical design requirements for NOG-1 cranes (Ref. E8.1.2) provide a significant safety margin against overload failures. The probability of this event is based on analyst judgment in accordance with the PCSA approach to the use analyst judgment for probability estimation. There is limited analysis of this condition. Lacking or inconclusive analysis would argue for assignment of even odds (0.5) for this event. The weight of evidence for the inherent margin in a single-failure proof design could form an argument that the failure is unlikely (0.1). The HRA team is convinced that the best estimate from the available information (given the current state of knowledge) is somewhere in between. The HRA team assigns 0.5 as the 95% confidence level and 0.1 as the 5% confidence level. Using a lognormal distribution, the mean associated with these confidence limits follows:

Mechanical failure of hoist under overload causes DPC drop = 0.25

The other drops are evaluated relative to this. First considered is the similar case where the lid is jammed in the port and the hoist is straining to lift the jammed lid. In this case, the force generated by the hoist is the same, but the weight of the lid is less. The HRA team judges that it is reasonable to reduce the failure probability by a factor of two to account for this difference:

Mechanical failure of hoist under overload causes lid drop = 0.1

Considered next is the condition where the grapple is either not properly connected to the hoist, or the grapple itself is only partially engaged to the canister or lid lift. This failure (i.e., drop of canister or lid from an improperly engaged grapple) is judged to be comparable to mechanical failure of the hoist under overload because in both cases the load-bearing capacity of the system is reduced. Therefore the resulting probability is as follows:

Grapple/canister drops from hoist = 0.25

Canister drops from grapple = 0.25

Regarding the case of a lid, again the force is lower than the canister case and also lower than the jammed lid case, with a similar situation in that the load-bearing capacity of the system is reduced. Using the previously mentioned logic, this would argue for using the 0.1 value. However, in the case of the lid, there is always the possibility that the drop would occur when the lid was not over the canister or would occur in a manner such that the object would not impact the canister (i.e., it would only strike the structure of the transportation cask or aging overpack). In the absence of analysis, the HRA team has applied a 50−50 chance of this occurring, which reduces the probability by a factor of two. Therefore:

Grapple/lid drops from hoist and strikes canister = 0.05

Lid drops from grapple and strikes canister = 0.05

Given the information available about the design, the analyses in existence, and the knowledge of the requirements of NOG-1 (Ref. E8.1.2) and other applicable standards to be applied to the CTM, the HRA team believes this to be both a reasonable assessment and at as fine a level of detail and differentiation as can be justified.

E6.4.3.4.2 Quantification of HFE Scenarios for 200-OpCTMdrop001-HFI-COD: Operator Causes Drop of Object onto Canister during CTM Operations

This event applies to both dropping a transportation cask lid during removal or an aging overpack lid during placement; however, Scenarios 1(c) and 1(d) would not apply during aging overpack lid placement since they can only occur during lifting. Scenarios 1(c) and 1(d) do not apply to DPCs since DPC transportation cask lids are not removed in the CTM.

E6.4.3.4.2.1 HFE Group #4 Scenario 1(a) for 200-OpCTMdrop001-HFI-COD

1. Maintenance crew member improperly installs grapple.
2. Preoperational check fails to note improper installation.
3. Primary interlock gives false positive signal.
4. Operator fails to notice bad connection between hoist and grapple through camera.
5. Grapple/lid drops from hoist and strikes canister.

Crew Member Improperly Installs Grapple—Prior to a lift operation, a crew member prepares the CTM for the operation by installing the appropriate grapple for the type of cask lid to be processed. While it is possible that this operation need not be performed (it may be the attached grapple from previous CTM work is the appropriate grapple), it is uncertain how often this occurs, so this analysis considers that this action needs to be performed each time. To install the grapple, the primary CTM grapple lowers and engages the secondary grapple. If the primary grapple is only partially engaged, then the secondary grapple appears to be secured in place, even though it is not.

The operator aligns the grapple visually using the camera view and then engages the grapple. If it is not aligned properly, the grapple does not fully engage. The crew members locally verify engagement and connect the appropriate wire connections from the secondary grapple to the primary grapple. This is a straightforward matter of task execution. The task is simple and routine and can be represented by NARA GTT A5, adjusted by the following EPCs:

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

- EPC 3: Time pressure. The full effect 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 APOE 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. The crew member probably feels a little more time pressure than that, so the APOE is set at 0.2.

- EPC 8: Poor environment. This EPC is applied not so much because the environment is poor, but rather that it is simply not optimal. The full effect EPC would be ×8, but this applies when working in the plant with suit and breathing apparatus, possible access problems, and for more than 45 minutes so that fatigue sets in. The APOE anchor for 0.1 is for work in the plant with suit and breathing apparatus, but none of the other environmental stressors. In this task no breathing apparatus is required, but the task is somewhat physically demanding. Given the tradeoffs, the APOE is set at 0.1.

- EPC 13: Operator underload/boredom. The full effect EPC would be ×3, which applies to a routine task of low importance, carried out by a single individual for several hours. The APOE 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 APOE is set at 0.1.

Using the NARA HEP equation yields the following:

$$\text{Crew member improperly installs grapple} = 0.0001 \times [(11-1) \times 0.2 + 1] \times [(8-1) \times 0.1 + 1] \times [(3-1) \times 0.1 + 1] = 0.0006 \qquad \text{(Eq. E-7)}$$

Preoperational Check Fails to Notice Improper Installation—There are two crew members responsible for preparing the CTM for each operation. Each crew member has a distinct set of assignments, although they collaborate when needed and are expected to check each other's work. The second crew member checks the first crew member's installation of the grapple, which provides an opportunity for the error to be detected. The second crew member also has a set of activities to perform, and so checking the first crew member is a secondary function. In addition, the existence of the grapple/hoist interlock provides an expectation that any error will be detected.

The second crew member would have helped initially with the connection of the grapple to line it up but would then move on to other things. At best, the second crew member performs a cursory check at the end of the job. Since the crew member was involved in the early stages, there is a bias that the job was done correctly. It is concluded that the level of dependence is high. The baseline HEP for the checking, for checking routine tasks without a checklist, is best determined from THERP (Ref. E8.1.26, Table 20-22, item (2)), which is 0.2. The HEP for high dependence is from THERP (Ref. E8.1.26, Table 20-21, item (4)(e)), which is 0.6.

Preoperational check fails to note improper installation = 0.6

Primary Grapple Interlock Gives False Positive Signal—Before beginning the lifting process, the operator should confirm engagement by checking the primary grapple engagement interlock. The indicator could give a false positive signal. This could result from a failure in the indicator itself or as the result of a partial engagement that generates a positive signal by triggering the sensor even though only partial engagement has occurred. Since the indicator system has not yet been designed, and the specific detection approach has not been defined, this cannot be ruled out.

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

Primary grapple interlock gives false positive signal = 2.7E−5

Operator Fails to Notice Improper Connection between Hoist and Grapple through Camera—When the CTM operator is in the process of lifting the canister, the view through the camera shows the secondary grapple and its connection to the primary grapple. The operator is not focused on that connection but is focused on lining up the secondary grapple with the lifting device. However, as the lift begins, the operator is supposed to watch through the cameras. This gives the operator the opportunity to note that the grapple is not properly connected (e.g., unexpected lid movement to one side or tilting of the grapple). This also gives the operator the opportunity to question the stability of the connection and to lower the lid back down to recheck the connection. However, the operator is not expecting any problems in this simple operation and tends to believe that any perceived problems are illusions caused by the distortions of viewing through a camera.

This action is best represented by the CREAM CFF O3, adjusted by the following CPCs with values not equal to 1.0:

- CFF O3: Observation not made. The baseline HEP is 0.003.

- CPC "Adequacy of Man–Machine Interface": For this particular observation, the use of a camera view (while the only practical means) is somewhere between tolerable and inappropriate. The CPC for an observation task with tolerable man–machine interface is 1.0, and for inappropriate is 5.0. With regard to being able to actually observe the condition of the grapple lock pin, the CPC is set as 4.0.

- CPC "Number of Simultaneous Goals": The operator is primarily focusing on properly aligning the bell and hoist, opening the ports, and grappling the lid. While it could be argued that this is not "more than capacity," it certainly relegates looking at the grapple/hoist connection to a secondary action. It is therefore deemed appropriate to apply the more than capacity CPC, which is 2.0.

- 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.

The resulting value follows:

Operator fails to notice bad connection between hoist and grapple through camera
$= 0.003 \times 4 \times 2 \times 0.8 = 0.02$

Grapple/Lid Drops from Hoist and Strikes Canister—Just because the lift is occurring with an improper grapple installation does not mean that the lid and grapple falls. The safety margin built into these systems means that it is possible that the lift and placement can be completed successfully even with improper installation, especially given that it is sized for a canister, and the lid is much lighter. Additionally, even if the lid and grapple do fall, they could fall early (a weak connection) or later (sufficient connection that they need time and motion to cause them to break loose). These two cases can result in the lid and grapple breaking loose when they are not above the canister. In addition it is not a certainty that the lid and grapple, once dropped, would fall in an orientation that impacts the canister in the transportation cask or aging overpack, even if they are above the canister at the time of the drop (the orientation of the falling lid and grapple may cause them to only impact the transportation cask or aging overpack structure).

This event is quantified in Section E6.4.3.4.1.

Grapple/lid drops from hoist = 0.05

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

Table E6.4-4. HEP Model for HFE Group #4 Scenario 1(a) for 200-OpCTMdrop001-HFI-COD

Designator	Description	Probability
A	Crew member improperly installs grapple	0.0006
B	Pre-operational check fails to note improper installation	0.6
C	Primary grapple interlock gives false positive signal	2.7E−5
D	Operator fails to notice bad connection between hoist and grapple through camera	0.02
E	Grapple/lid drops from hoist and strikes canister	0.05

NOTE: HEP = human error probability.

Source: Original

The Boolean expression for this scenario follows:

$$A \times B \times C \times D \times E = 0.0006 \times 0.6 \times 2.7E{-5} \times 0.02 \times 0.05 = 1E{-11} \qquad \text{(Eq. E-8)}$$

According to NARA (Ref. E8.1.11), the lower limit of credibility for an HFE accomplished by a single operator or team is 1E−5 per demand. Using this truncated value for the set of unsafe actions, the probability of this scenario follows:

$$1E{-5} \times 2.7E{-5} < 1E{-8} \qquad \text{(Eq. E-9)}$$

E6.4.3.4.2.2 HFE Group #4 Scenario 1(b) for 200-OpCTMDrop001-HFI-COD

1. Operator fails to fully engage grapple.
2. Grapple engagement interlock gives false positive signal.
3. Operator fails to notice grapple not fully engaged through camera.
4. Lid drops from grapple and strikes canister.

Operator Fails to Fully Engage Grapple—The operator engages the grapple from the control panel. The grapple can be roughly positioned using the alignment guides for the CTM and the hoist height indicator on the control panel, but final alignment must be done visually using the view from the cameras provided on the grapple. Once the operator believes the grapple is aligned, the operator engages the grapple with the lift fixture and confirms through the camera that the grapple has engaged. If the operator sees that the grapple has not properly engaged (generally by checking the interlock condition if it looks engaged visually), the operator disengages and repositions the grapple and then tries again to engage the grapple.

The operator aligns the grapple visually using the view from the camera and engages the grapple. If it is not aligned properly, it can not fully engage. This unsafe action can be best represented by the task execution error NARA GTT A1, adjusted by the following CPCs:

- NARA GTT A1: Carry out a simple manual task with feedback. Skill-based and therefore not necessarily with procedures. The baseline HEP is 0.005
- EPC 3: Time pressure. The full effect 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 APOE 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. The crew member probably feels a little more time pressure than that, so the APOE is set at 0.2.
- EPC 11: Poor, ambiguous, or ill-matched system feedback. This EPC is applied to account for the need to observe the operation through cameras. The full effect EPC would be ×4. The full effect is applicable when legibility is poor or the label is obscured, or where the layout of controls makes visual access and physical access difficult. The use of the camera view is deemed to represent full effect. The APOE is set at 1.0.
- EPC 13: Operator underload/boredom. The full effect EPC would be ×3, which applies to a routine task of low importance, carried out by a single individual for several hours. The APOE 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 APOE is set at 0.1.

Using the NARA HEP equation yields the following:

$$\text{Operator fails to fully engage grapple} = 0.005 \times [(11-1) \times 0.2 + 1] \times [(4-1) \times 1.0 + 1] \times [(3-1) \times 0.1 + 1] = 0.07 \quad \text{(Eq. E-10)}$$

Grapple Engagement Interlock Gives False Positive Signal—Before beginning the lifting process, the operator should confirm engagement by checking the grapple engagement interlock. The indicator could give a false positive signal. This could result from a failure in the indicator itself or as the result of a partial engagement that generates a positive signal by triggering the sensor, even though only partial engagement has occurred. Since the indicator system has not yet been designed and the specific detection approach has not been defined, this cannot be ruled out.

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

$$\text{Grapple engagement interlock gives false positive signal} = 2.7\text{E}{-5}$$