Design Analysis Cover Sheet

Complete only applicable items.

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1. PURPOSE

The purpose of this analysis is to identify and evaluate expected operational failures in the Waste Handling Surface Facilities and recommend equipment and building configuration design features and specialized recovery equipment to enable efficient and safe recovery. "Failure" for the purpose of this analysis is defined as an expected malfunction of equipment occurring during an operation, which halts the operation, but is recoverable within a limited duration. Accidents and operational failures, which are expected to result in major delays, are not in the scope of this analysis.

The analysis focuses on the Waste Handling Building (WHB) configuration recommended in the *Waste Handling Systems Configuration Analysis* (WHSCA) (Reference 5.1). This configuration uses both wet and dry environments for spent fuel handling and a dry environment only for canistered waste and waste package (WP) handling. The evaluation of the waste handling operation considers the operating equipment failure modes, the waste items being handled, and expected hazards to be encountered during recovery from failure. Operational problems caused by anomalies in arriving waste items are also evaluated in this analysis. The conclusions reached in this analysis recommend procedures and equipment necessary to recover from expected operational failures. Recommendations for operating equipment, cell and building configuration features associated with equipment used for recovery are also presented.

2. QUALITY ASSURANCE

The classification of permanent items described in QAP-2-3, *Classification of Permanent Items*, has not been performed for the Waste Handling Systems and Facilities discussed in this analysis. However, the Waste Handling Systems and Facilities are identified as "Q" in the project *Q-List* (Reference 5.2) by direct inclusion. Therefore, the items addressed in this analysis will be treated as Q items. An activity evaluation has been performed in accordance with QAP-2-0, *Conduct of Activities*, and has determined that the QA program is applicable to this analysis. Therefore, as specified in NLP-3-18, *Documentation of QA Controls on Drawings, Specifications, Design Analyses, and Technical Documents*, this activity is subject to QA controls. Although the activities associated with performing this work are not expected to affect the ability of any Q item to perform its intended safety function, the activities will affect the size, configuration, and cost of the Q items and their ability to meet throughput requirements. These activities are subject to the requirements of the *Quality Assurance Requirements and Description* (Reference 5.3) because they affect items on the *Q-List*.

Although the conclusions of this analysis will define the recommended technology and establish portions of the configuration of the Waste Handling Systems and Facilities, they will not be used directly for procurement, fabrication or construction and are considered preliminary. Therefore, the formal tracking system described in NLP-3-15, *To Be Verified (TBV) and To Be Determined (TBD) Monitoring System*, is not applicable. Any data from this analysis that is used as design input must be treated as unconfirmed (TBV) and tracked per NLP-3-15, prior to inclusion in documents supporting licensing, fabrication, procurement, or construction.

3. METHOD

The method used to perform this analysis is focused around a review of major waste handling operations in the WHB. This review identifies failure modes of handling equipment that are selected to establish a design basis. The selected failure modes are based on readily available nuclear industry technology and experience. Problems caused by as-received anomalies with the various waste items being handled are also considered.

For each failure mode identified in the review an assessment of recovery options is made to determine the safest and most efficient method of recovery. Potential hazards associated with the operating environment of the failure are listed to determine the risks involved in either remote and/or contact recovery from the failure or problem. These hazards are categorized into the following three general areas:

- Radiation exposure risks from unshielded or partially shielded nuclear sources in the dry or wet operating area
- Contamination risks from radioactive airborne particulates in a hot cell or water entrained particulates in a pool environment
- Industrial safety risks associated with the handling, maintenance and recovery of large, heavy items weighing up to 100 tons, particularly in a remote environment.

Based upon the selection of a remote or contact recovery procedure, several recommendations affecting the operating equipment, supporting equipment, and/or building design features are identified. General types of recommendations to enable the recovery from operating equipment failures will include:

- The inclusion of design features in the operating equipment that will permit safe and efficient recovery from expected failure conditions. These may include redundant drives, drive shaft extensions, and the use of captive bolts and other design features to enable remote electro-mechanical manipulators (EMMs) to assist in recovering from failures.
- The inclusion of remote handling equipment, if not already provided for waste handling operations, to support recovery operations. These may include robotic/remote manipulators with electric, pneumatic or mechanical tool adapters.
- The inclusion of building design features to support recovery operations. These may include dedicated maintenance areas in the operating areas, overhead transfer galleries with hatch access to the operating areas, transfer tunnels with hatch access to the operating areas, and robotic vehicle access to the operating areas via airlocks.

Recovery operations in a nuclear facility can be challenging tasks requiring specialized equipment with a high degree of dexterity and flexibility. Personnel operating recovery equipment are often restricted in their viewing and manipulation of the equipment performing the task. The major design

issues in planning these recovery tasks are the selection of the types of equipment to perform the recovery operations and the means of moving the recovery equipment to the problem, or the problem to the recovery equipment.

The alternatives in equipment selection are types of equipment that are proven in both the nuclear and general industries to have the capability to perform the anticipated tasks. These include manipulators adapted with special tools (e.g., impact wrenches) to perform specific recovery tasks and bridge cranes. The use of master-slave manipulators (MSMs) is not currently considered to be a viable alternative for the type of recovery tasks anticipated in the WHB. The MSMs have historically been used for repetitive, dexterous, and direct handling of small items in fixed locations. Industrial robotics have advanced to the degree that they offer significant advantages to the use of MSMs.

4. DESIGN INPUT

4.1 DESIGN PARAMETERS

Not used

4.2 CRITERIA

The following design criteria, which are applicable to this analysis, were developed to respond to requirements found in the *Repository Design Requirements Document* (RDRD) (Reference 5.4).

- 4.2.1 The waste handling recovery operations shall support the ability to limit radiation exposures and releases of radioactive materials (RDRD 3.2.1.2.C, 3.2.2.1.C, 3.2.2.1.D, 3.2.4.5.1.B, 3.2.4.5.2).
- 4.2.2 The WHB design features recommended to support recovery operations, shall provide access for equipment maintenance, repair or replacement and shall accommodate the lifting and movement of equipment during removal and replacement operations (RDRD 3.2.5.2.2.A, 3.2.5.2.2.B, 3.2.5.2.4.B, 3.2.5.2.6).
- 4.2.3 The waste handling recovery operations shall provide systems and equipment that allow the continued management (i.e., handling, transfer, storage and retrieval) of spent nuclear fuel (SNF) and defense high-level waste (DHLW) in a safe manner that optimally protects personnel health and safety, and the environment under normal and anticipated off-normal operating conditions (RDRD 3.2.5.1, 3.7.4.1.A.1).

4.3 ASSUMPTIONS

Potential waste form anomalies are assumed to be as follows: bowed spent fuel assemblies (SFAs); swelled SFAs; leaking SFAs; broken SFAs; damaged SFA fittings (grapple interfaces); damaged DHLW canister pintles and damaged dual-purpose canisters (DPC)/multi-purpose canisters (MPC) lifting fixture provisions. This assumption is based on readily available experience in the nuclear industry and personal experience defining remote equipment requirements.

4.4 CODES AND STANDARDS

4.4.1 Code of Federal Regulations (CFR):

Title 10 Energy, Part 20 - *Standards for Protection Against Radiation*, January 1996.

5. REFERENCES

- 5.1 *Waste Handling Systems Configuration Analysis*. Management and Operating Contractor (M&O) Document Identifier: BCB00000-01717-0200-00001 Rev. 00, January 1997.
- 5.2 *Q-List*. YMP/90-55Q, Rev. 4, February 1997.
- 5.3 *Quality Assurance Requirements and Description (QARD)*, DOE/RW-0333P Rev. 7. U.S. Department of Energy, Office of Civilian Radioactive Waste Management, June 1997.
- 5.4 *Repository Design Requirements Document (RDRD)*. YMP/CM-0023, Rev 0, ICN 1, September 1994.
- 5.5 *Preliminary System Safety Analysis for the Mined GDS Advanced Conceptual Design*, BAB000000-0200-00152, Rev. 00.
- 5.6 *Dual-Purpose SNF Transportation and Storage Systems Interface Information for the ISF*, M&O Document Identifier: CCC000000-01717-0200-00001, Rev. 00, August 1996.

6. USE OF COMPUTER SOFTWARE

Not used

7. DESIGN ANALYSIS

7.1 INTRODUCTION

The Mined Geologic Disposal System (MGDS) WHB will handle a wide range of radioactive waste forms at annual throughput rates unprecedented in the history of the DOE or United States commercial nuclear plants. Successfully achieving the required throughput rates referenced in the WHSCA (Reference 5.1) that ultimately produce WPs ready for underground emplacement will require operations and equipment in the building to have a relatively high availability rate. A major design consideration in achieving this high availability rate for building operations will be the capability to quickly and safely recover from unplanned problems and failures with equipment and waste forms.

The handling, temporary storage, and packaging of waste forms will require numerous operations and equipment items. Each of these operations and the equipment performing these operations are subject to a wide variety of credible, unplanned failure scenarios, based on readily available nuclear industry technology and experience. While not inclusive of all possible failure scenarios, these scenarios will encompass the failures expected in a nuclear material handling facility. Also, hundreds of thousands of spent fuel assemblies, many of them over 20 years old, will be handled and packaged. It is expected that some of these assemblies will have age-related and structural anomalies that will delay their unloading, handling, and packaging. A major challenge in designing the WHB and its equipment is in specifying equipment and facility capabilities that can safely accommodate and recover from these failures and waste form anomalies in a time frame that does not compromise the annual waste receiving and emplacement schedule.

This analysis addresses the above design challenge by the comprehensive review of the types of recovery operations anticipated, the risks involved in performing these recovery tasks, and the recommended design solutions based on the proven technology available and the operating history in successful nuclear facilities. Specifically, this analysis consists of sections which address the following:

- A description of the nuclear and industrial safety risks to be expected in the various operating environments of the WHB.
- A detailed survey, by operational area, of the types of equipment failures expected to occur based on readily available nuclear industry technology and experience and the recommended recovery procedures, support equipment, and hazards associated with each recovery procedure.
- A general summary of the types of anomalies with incoming waste forms expected to occur during their unloading and handling in the WHB.
- A general summary of building configuration features recommended to support recovery operations.

7.2 GENERAL OPERATIONAL RISKS

Operational failures in industrial plants often require the attention of trained personnel with the proper tools and support equipment necessary to recover from the failures and bring the plant back to full production as quickly as possible. In recovering from failures, caution must be exercised to avoid accidents that can damage equipment, result in major production losses, or worse, cause injury to personnel performing the recovery operation.

The recovery from failures in a facility handling radioactive nuclear waste forms presents additional challenges to personnel performing the recovery procedure. In many areas, high radiation fields prevent or greatly restrict the ability of personnel to perform contact recovery procedures. In some low radiation field areas, radioactive contamination, either airborne, in water, or on surfaces, prevents the entry of personnel without anti-contamination suits and either appropriate self-contained breathing apparatus or provisions for conditioned air supply and any necessary cooling to prevent heat stress. These breathing apparatus and anti-contamination suits reduce the efficiency of personnel performing recovery operations due to restricted vision, motion, dexterity, and communication. Without equipment and facility design features that recognize and accommodate these restrictions, the remote recovery of failed equipment can be time consuming, hazardous, and very expensive.

The WHB operations involve the handling, temporary storage, and packaging of waste forms ranging in weight up to 125 tons as identified in the dual-purpose SNF transportation and storage systems interface information for the ISF (Reference 5.6). These waste forms are radioactive and produce radiation fields ranging from a few mR/hr to thousands of R/hr. A large quantity of the waste forms handled are bare spent fuel assemblies that will introduce particulate contamination into the environment in which they are handled and stored. The following paragraphs address the general hazards associated with radiation, contamination, and handling of large, heavy items in the WHB.

7.2.1 Radiation

All waste forms arriving at the repository will generate radiation fields of varying levels dependent on the following factors:

- The activity of the radioactive isotopes that make up the waste form
- The density, geometry, and mass of shielding material, if any, around the waste form
- The distance, either straight-line or reflective, between the waste form source and the receptor.

In performing recovery operations, the expected radiation field will determine whether operator entry into operating areas containing failed equipment is feasible, and if so, the time duration that personnel can safely work in the vicinity of the radiation source

without exceeding NRC radiation worker exposure limits as identified in 10 CFR 20, *Standards For Protection Against Radiation*. Waste forms in the WHB will satisfy one of four shielded conditions:

- Safely shielded in the transportation cask in which the waste form arrived
- Unshielded while being handled or stored in a remote hot cell
- Safely shielded by water in a pool or shield blocks placed over a dry storage area
- Safely shielded by the WP Transporter.

In general, presence of the following waste forms in an unshielded or partially shielded state will preclude operator entry into operating areas for any time period due to high direct or reflected radiation levels:

- Bare SFAs
- SFAs in DPCs
- SFAs in MPCs
- DHLW canisters
- Disposal container (DC)/WP.

A canister surrounding spent fuel or high-level waste provides very little shielding since its primary function is containment. Even the disposal container with its substantial mass and volume surrounding the waste forms does not provide enough shielding to permit operator access.

Transportation casks used for shipping waste forms provide a significant amount of shielding to permit safe transport over highways and rail lines. However, dose levels at the surface of a typical cask will not permit personnel to be in the vicinity of a cask for extended periods of time. In many cases, recovery from a problem during cask preparation operations before the cask lid bolts have been removed, can be accomplished by simply moving the unopened cask back into the Carrier Bay. If the cask lid bolts have been removed, recovery can be performed remotely or by providing some shielding and distance between the cask and personnel performing contact recovery operations.

If the cask lid has been removed and the waste forms are still in the cask at the time of the failure, recovery operations should attempt the replacement of the cask lid. Since indirect radiation streaming and reflection will not permit personnel entry into the operation area, cask lid replacement would have to be performed remotely or a means of placing a temporary shield lid would have to be employed. In the case of a cask containing a DPC, the DPC has a shield plug on top and therefore cask lid replacement operations could be performed by contact.

As stated previously, entry into operating areas containing unshielded spent fuel assemblies and canistered waste forms would not be permitted. Once unloaded from transportation casks, shielding of these waste forms in the WHB operating areas will be provided by one of two means, water pools or concrete and steel structures.

Spent fuel assemblies, either as bare assemblies or in DPCs, will be unloaded and temporarily stored in water pools with sufficient depth to shield operating personnel above the pool. Most failures of equipment operating over these pools can be repaired directly without moving the waste forms, since the pool continues to provide the necessary shielding. Failed equipment in the pool can be withdrawn, decontaminated, and repaired. Infrequently, in order to access and repair failed equipment, waste forms may have to be transferred to another location and the pool drained. On an extremely rare basis, divers may have to enter the pool and repair equipment as long as they maintain a minimum distance from any waste forms remaining in the pool. As determined in the WHSCA, water pools provide greater flexibility for handling repairs and recovery as opposed to hot cells.

The primary means of shielding waste forms (spent fuel and canistered waste) in the dry hot cells are the reinforced concrete shielding walls and structures that form the cell boundaries. While these structures provide sufficient shielding for personnel to safely view and remotely operate equipment, they greatly limit recovery operations when personnel enter a hot cell to repair failed equipment. Thus, recovery operations in these cells containing unshielded waste forms must rely exclusively on remote support equipment to perform the repair and recovery. In some cases waste forms in the cell can either be removed or locally shielded. An example is a dry interim storage pit or rack which can be designed to be totally shielded by the placement of a shielding block. Once all waste forms have been removed or locally shielded and radiation surveys have been performed, personnel can enter the cell although they may require full anti-contamination suits and breathing apparatus due to residual contamination in the cells.

Once waste forms are loaded into a DC the radiation fields are reduced, but dose rates at the DC surface will not permit operator entry into the cell. Therefore, the hot cells containing DC operations (loading, inspection, decontamination, handling, and welding) will require remote recovery procedures for equipment failures. The major challenge in performing recovery operations in these areas is handling the very large weight and physical size of the DC, if necessary, in a remote environment. Should handling devices such as carts and cranes fail while handling a DC, an auxiliary means of handling the full weight of the container may be necessary.

Once loaded into a WP transporter, prior to transfer to the underground, the radiation field around a WP will permit proximity of personnel for short time periods to perform any necessary recovery procedures.

7.2.2 Contamination

The safety hazard associated with contamination, concerns the risk of skin contamination, lung contamination, or ingestion of small radioactive particles that exist on the waste form or result from an unexpected release from a container breach. Spent nuclear fuel assemblies are expected to arrive with a coating of “crud”, basically consisting of radioactive particulates and oxidation deposition on the fuel assembly structure resulting from storage in a pool for many years. Additionally, any failed fuel cladding can also release both particulates and gaseous radioactive products that form contamination sources. Airborne particulates and gaseous radioactive products can also create sizable radiation fields in unwanted areas. These radiation levels may require remote support equipment for repair and recovery as discussed in Section 7.2.1.

Upon unloading of arriving casks in the repository cask unloading pools, these sources of contamination may be released in the pool. While a portion of these radioactive particles will be captured in the pool’s filtration system, it is expected that any item leaving the pool will be exposed to these contamination sources. Thus, the outside surface of the shipping cask will require decontamination, as well as any tools or equipment retrieved from the pool. Transfer of the fuel assemblies from the unloading pool into the dry hot cell used for drying and loading of DCs will also introduce pool contamination sources into the hot cell.

SFAs will be loaded into DCs through a cell port which will be designed to minimize contamination of the outside surface of the DC and the cells through which the DC is transported. The performance of the cell port is important to ensure that recovery operations in those areas with DCs would only be concerned with the radiation sources inside the DC, not contamination.

A number of canistered waste forms will arrive at the WHB which will be loaded directly into DCs without opening the canister. The canister acts as a containment barrier to prevent contamination of the cell. The only exceptions would be the following rare occurrences:

- The exterior surface of the arriving cask or canister was contaminated at the shipping site.
- A shipping or handling accident has caused the canister containment to fail.

7.2.3 General Industrial Hazards

While radiation and contamination exposure of personnel present the greatest nuclear-related risks in performing recovery operations, general non-radioactive industrial hazards need to be recognized in the planning of these recovery operations (Reference 5.5).

One of the major industrial hazards involves recovery of large heavy loads on failed bridge cranes; primarily the incoming transportation casks, canisters, and the outgoing WPs. Handling of loads weighing up to 100 tons involves the risk that loss of control of the load can cause major facility damage, personnel injury, and the possibility of radioactive release from the item being handled. Proper maintenance of handling equipment, particularly crane controls and hoist brakes, minimizes but does not eliminate this risk.

7.3 OPERATIONAL SURVEY

For the purpose of this survey, the WHB configuration recommended in the WHSCA (Reference 5.1) is broken down into the following operational systems (Reference Figure 7.3-1):

1. Carrier/Cask Handling System
2. Assembly Transfer System
3. Canister Transfer System
4. DC Handling System

A review of the WHSCA waste handling operations, associated with each of these operational systems, was performed to identify expected operational and equipment failures. The list of operational and equipment failures is based on readily available nuclear industry data and experience associated with similar systems and equipment.

The results of the review are documented in a series of tables included as Attachments I through V. In addition to the operational equipment and the expected failures associated with each waste handling operation, each table identifies recommended recovery procedures, required recovery equipment/facility features, and operational risks associated with the recovery operations. A general discussion of the review results is provided below (reference Subsections 7.3.1 through 7.3.5).

7.3.1 Carrier/Cask Handling System

7.3.1.1 Operations

High-level waste will be received in the WHB in the form of shipping casks on rail and truck carriers. Cask handling operations in the Carrier Bay will basically consist of engaging the cask trunnions with an overhead bridge crane and lifting yoke, uprighting the cask on the carrier, lifting and transferring the cask to a rail-mounted transfer cart, positioning the cask vertically on the cart, and disengaging the crane and yoke from the cask. A transfer cart will be positioned at the entrance to each of five parallel handling lines: three wet uncanistered SNF handling lines and two dry canistered waste handling lines.

Figure 7.3-1. Waste Handling Building

7.3.1.2 Recovery

Shipping casks provide a significant level of shielding such that personnel will be permitted in the vicinity of the loaded cask for brief periods of time to perform contact recovery operations.

A failed tow vehicle will be replaced. Failed components of the rail/truck carriers will be temporarily repaired, in-place, to allow carrier positioning and cask removal. The carrier will then be removed from the WHB for repair or replacement. Overhead bridge crane failures may require bridge and trolley retrieval systems, and a backup hoist operating system, to allow the cask to be replaced on the carrier or positioned on the transfer cart, such that the crane could be repaired by contact operations in a maintenance area of the Carrier Bay.

7.3.2 Assembly Transfer System-Wet Operations

7.3.2.1 Operations

Shipping casks containing bare SFAs or DPCs will be processed in each of the three wet handling lines. Each wet handling line consists of an independent operating module containing a dry cask preparation area, three interconnected cask/DPC unloading pools, a lag storage pool, a SFA transfer canal, and a maintenance area. Each wet operating module will be serviced by an overhead bridge crane. The preparation area will be equipped with a robotic/remote manipulator for the performance of remote cask preparation operations and a wet SNF transfer machine.

A shipping cask will be transferred from the Carrier Bay into the dry cask preparation area through an isolation door by means of the rail-mounted cask transfer cart.

Cask preparation activities will include: 1) cask interior venting, purging, sampling, cavity cooling and water filling; 2) cask lid bolt detensioning and removal; and 3) installation of a cask lid lifting fixture. The radiation dose levels at the surface of the shipping cask will limit the period of time that personnel can be in the vicinity of the cask. Therefore, cask preparation activities will be performed remotely using a robotic/remote manipulator, miscellaneous remote tools (e.g., impact wrench, etc.), and the overhead bridge crane. Shipping cask fasteners, port covers, manifolds, hose connections, etc., will have to be configured to support remote cask preparation operations.

To initiate wet handling area operations, the overhead bridge crane and cask lifting yoke will be used to remotely lift the shipping cask off the transfer cart and place the cask in the cask prep (shallow) pool. Once the cask is submerged in the pool, the remaining cask, DPC and SFA operations can be performed by personnel positioned on the wet SNF transfer machine platform above the pool.

Pool operations include cask transfer, cask lid removal, DPC preparation (venting, purging and water filling), DPC lifting fixture installation, DPC transfer, DPC lid severing and removal, and SFA transfer to the pool lag storage racks. Personnel will perform the pool operations using the wet SNF transfer machine (SFA grapple, hoist system, mast system, etc.), the overhead bridge crane, the cask lifting yoke, the cask lid lifting fixture, a DPC lid severing and removal system, and a variety of underwater tools.

Bare SFAs will be transferred from the open casks and DPCs to the underwater lag storage rack by the wet SNF transfer machine. The storage rack will be designed to hold multiple SFAs. The wet SNF transfer machine will then be used to transfer the SFAs from the storage rack to a transfer canal conveyor basket, which will subsequently transfer the SFAs up an inclined transfer canal to the dry SFA staging hot cell. The conveyor basket will hold multiple SFAs.

The empty casks and DPCs will be removed from the pools using the overhead crane, yokes and handling fixtures and pool tools (the cask and DPC lids will be replaced and secured prior to pool removal). The casks and the DPCs will be drained and transferred to the dry cask preparation area. The cask or DPC will be placed on the transfer cart, the interior dried, the exterior surveyed and decontaminated, and the cask or DPC transferred by the cart to the Cask Carrier Bay.

7.3.2.2 Recovery

Recovery from failure of the robotic/remote manipulator and associated remote tools, will require return of the cask to the carrier bay and personnel entry into the preparation area for contact replacement/repair of failed components. Recovery from failure of the wet SNF transfer machine, or the crane bridge/trolley will require retrieval of these systems to a maintenance area for contact replacement/repair of failed components. Bridge crane hoist failure during load handling operations, will require a backup system to facilitate lowering and releasing of the load in a safe location prior to transfer of the bridge crane to the maintenance area.

Recovery from failure of the transfer canal conveyor system will require removal and transfer of the SFAs to the lag storage rack. Underwater conveyor components will be removed from the pool and transferred to the maintenance area for repair/replacement. Failure of the transfer canal conveyor will require a backup system to allow the conveyor cart and basket to be returned to the bottom of the transfer canal for removal and repair/replacement.

If the radiation level of the DPC and lid cannot be reduced to a level that is acceptable for transfer to the Carrier Bay, the DPC and lid may have to be transferred out of the wet handling cell by a dedicated transfer tunnel or by overpack via the Carrier Bay. The transfer tunnel would be equipped with shielded hatch access to the wet handling cell and a waste processing/packaging cell.

Components removed from the pool will have to be washed down and possibly decontaminated prior to contact repair/replacement of components in the maintenance area. If components requiring replacement are too large and heavy to be transferred out of the wet handling area through airlocks, an overhead transfer hatch will be required. The components will be wrapped and removed from the wet handling area through the hatch by a mobile crane. The components may be transferred to a maintenance area or a waste processing/packaging cell.

7.3.3 Assembly Transfer System-Dry Operations

7.3.3.1 Operations

A shielded dry spent fuel handling and DC loading hot cell line is interconnected to each wet handling module described in Section 7.3.2. Each hot cell line will provide the capability to receive SFAs from the wet handling module, dry and load the SFAs into DCs, weld inner lids in the DCs, decontaminate the DCs, and transfer the DCs to the DC cell. Each hot cell line consists of an SFA staging hot cell and three DC processing cells: a DC load cell, a DC inner lid welding cell, and a DC decontamination cell. The SFA staging hot cell is interconnected to the DC load cell by means of a SFA transfer port equipped with a port/plug shield block. The DC processing cells and the DC cell are interconnected by rail-mounted transfer carts and shield/ isolation doors.

Due to the expected high radiation levels of the SFAs, all dry spent fuel handling and packaging operations will be performed remotely. The SFA staging hot cell will be equipped with a dry SNF transfer machine. The DC decontamination cell will be equipped with a robotic/remote manipulator to perform DC and transfer cart remote survey and decontamination operations.

In the SFA staging hot cell, SFAs will be removed from the transfer canal conveyor basket by the dry SNF transfer machine and loaded into drying vessels. After the SFAs are dried, the SFAs will be transferred by the dry SNF transfer machine to lag storage racks. An empty, unlidded DC will be transferred from the DC cell into the DC load cell by the transfer cart and a contamination barrier on the SFA transfer port will be extended to interface with the top of the open DC. After opening of the port/plug shield block, the dry SNF transfer machine in the SFA staging hot cell will remove individual SFAs from the storage racks and load them through the transfer port into the DC. When the DC is full, the port/plug shield block will be replaced, the contamination barrier retracted, and the DC transferred to the DC inner lid welding cell by the transfer cart. A dedicated welding machine will install and weld an inner lid in the DC. The cart will then transfer the DC to the next cell where the DC will be decontaminated and vacuumed. The cart will then transfer the DC into the DC cell. The DC cell will handle both empty and loaded DCs.

7.3.3.2 Recovery

Recovery from failure of the dry SNF transfer machine in the SFA staging hot cell will require retrieval of the failed system to a dedicated maintenance area where personnel will perform contact replacement/repair of failed components. Shielding doors will be required for the maintenance area and the personnel will require anti-contamination suits and breathing apparatus. Shield blocks on the lag storage racks and the SFA transfer port will provide shielding as required during recovery operations.

Failure of the dry SNF transfer machine hoist and grapple systems will require backup systems operated by a bridge-mounted robotic/remote manipulator to allow the SFAs to be returned to the storage racks or placed in the DC prior to transfer of the machine to the maintenance area.

Failure of drying vessel mechanical components will require use of an overhead bridge crane and the bridge-mounted robotic/remote manipulator equipped with remote tools. If complete modules must be replaced, such as the SNF transfer machine trolley or the drying vessel, an overhead transfer gallery or a transfer tunnel will be required. The gallery or tunnel would be equipped with shielded hatches accessing the staging hot cell maintenance area, a waste processing/packaging area and an equipment/material supply area.

Recovery from failure of the transfer port contamination barrier system in the DC load cell will require closing of the port/plug shield block and extension/retraction of the barrier using backup systems operated by a robotic/remote manipulator in the SFA staging hot cell. After transfer of the DC and cart to an adjacent cell and closure of the isolation doors, personnel will enter the DC load cell for contamination barrier system component replacement/repair.

Recovery from failure of the DC inner lid welding machine, the DC survey and decontamination system, or the decontamination cell robotic/remote manipulator will require transfer of the DC and cart to an adjacent cell and closure of the isolation doors. Personnel would then enter the cell for system component replacement/repair.

Recovery from transfer cart failure will require a backup system to allow the cart containing the DC to be transferred from cell to cell to perform the required DC loading, welding, and decontamination activities. The DC and cart will be transferred into the DC cell by the backup system and the DC will be removed. The cart will be returned to the decontamination cell, the shield doors closed, and personnel will perform contact replacement/repair of failed cart components.

Recovery from failure of any of the isolation/shield doors between the DC processing cells, will require opening or closing of the door by a backup system, transfer of the DC to an adjacent cell, and personnel entry into the appropriate cell for contact replacement/repair of failed components.

If any of the large modules or components of the DC processing cells must be replaced, the transfer cart or a device using the transfer cart rails will be used to transfer these items between the processing cells and the DC cell.

7.3.4 Canister Transfer System

7.3.4.1 Operations

Shipping casks containing SFAs in MPCs and DHLW canisters will be processed in each of two dry handling lines. Each dry handling line consists of an enclosed operating cell for cask preparation, cask decontamination (empty casks), cask lid removal, canister unloading, and DC loading. The MPC and DHLW canisters processed in the dry handling cell are not expected to be contaminated. However, since the canisters provide very little shielding, all canister operations in the dry handling cells will be performed remotely. Each cask preparation area will be equipped with a robotic/remote manipulator. The lid removal, canister unloading, and DC loading areas of the cell will be serviced by an overhead bridge crane. An airlock with shield/isolation doors interconnects each dry handling cell with the Carrier Bay. Each DC load cell interconnects directly with the DC cell.

During canistered waste processing through each dry handling line, a shipping cask will be transferred by a rail-mounted cart from the Carrier Bay, through an airlock into the dry handling cell, and through each operating station in the dry handling cell, terminating at the canister unload station. A separate rail-mounted cart will interconnect each DC load area with the DC cell. Isolation doors will provide shielding and maintain containment between the airlock, the cask prep-lid unbolt area and the canister unload-DC load area.

Cask preparation activities involve cask interior purging and venting, cask lid bolt detensioning and removal, and cask lid lifting fixture installation. After cask lid removal, the overhead bridge crane, in conjunction with a DHLW canister grapple or the MPC lifting fixture, will remove the canister from the cask and load the canister into a lag storage rack. The canister will be removed from the storage rack and transferred through a loading port into a DC positioned in the DC load cell. The canister may be removed from the cask and loaded directly into the DC. The DC will then be transferred into the DC cell by transfer cart. Due to the expected lack of contamination during canister handling and processing, the loading port will not be equipped with an contamination barrier. The lids will be replaced on the empty casks, the cask exteriors and cart surveyed and decontaminated, and the empty cask transferred to the Cask Carrier Bay.

7.3.4.2 Recovery

Recovery from failure of the robotic/remote manipulator in the cask preparation area will require return of the cask to the carrier bay and personnel entry into the area for contact replacement/repair of failed components.

Recovery from failure of the overhead bridge crane will require retrieval of the crane, using a backup retrieval system, to a dedicated maintenance area where personnel will perform contact replacement/repair of failed components. Shielding doors will be required for the maintenance area and the personnel may require anti-contamination suits and breathing apparatus. Bridge crane hoist failure during load handling operations would require a backup system to allow lowering and release of the load in a safe location, prior to transfer of the crane to the maintenance area. If complete modules must be replaced in a dry handling cell, such as the crane trolley, an overhead transfer gallery or transfer tunnel will be required. The transfer gallery or transfer tunnel would provide shielded hatch access to the crane maintenance area, a waste processing/packaging area and an equipment/material supply area.

Recovery from transfer cart failure during cask transfer through the dry cell operating areas will require a retrieval system to transfer the cask between process stations. The retrieval system would then be used to transfer the cart and empty cask to the cask preparation area for cart component repair/replacement. Recovery from DC transfer cart failure will require a backup system to transfer the DC to the DC cell for DC removal. The cart and DC would be returned to the DC load area, the shield doors closed, and personnel would perform contact replacement/repair of failed cart components. Recovery from failure of any of the isolation or shield doors will require opening or closing of the door by a backup system, transfer of the cask or DC to an adjacent area, and personnel entry into the area for contact replacement/repair of failed components.

Recovery from failure of the DHLW canister grapple will require replacement of the DHLW canister in the cask and operation of the grapple backup device by a robotic/remote manipulator to release the grapple from the canister. The overhead bridge crane and grapple will then be transferred to the dedicated maintenance area where personnel will perform contact replacement/repair of the grapple.

7.3.5 Disposal Container Transfer System

7.3.5.1 Operations

The three SNF wet handling lines and the two dry canister handling lines addressed in Sections 7.3.2, 7.3.3, and 7.3.4, exit into two separate identical DC staging and welding hot cells which make up the DC cell. The DC staging and welding hot cells will receive the loaded DCs and will perform the inner lid welding and the final outer lid closure welding. DCs containing only bare SFAs will require only final outer lid

closure welding in the DC staging and welding hot cells as a result of inner lid welding previously performed in the uncanistered waste handling hot cells. A loaded, welded, and inspected DC is called a WP in this analysis. The WPs will then be transferred to a common enclosure consisting of interconnected hot cells. The interconnected hot cells will be used for final WP inspection and decontamination, loading on a WP transporter, and transfer of the WP by the transporter to the subsurface repository.

The DCs or WPs processed in the dry handling lines and the DC cell are not expected to be contaminated, however, since the DCs/WPs do not provide sufficient shielding, all DC/WP operations will be performed remotely. Each DC staging and welding hot cell will be equipped with an overhead bridge crane, a lifting device configured to handle both unwelded DCs and welded DCs (WPs), multiple remote welding stations, DC lag storage and staging areas, robotic/remote manipulators in selective locations, and a remotely operated WP horizontalizer.

The horizontalizer in each DC staging and welding hot cell will be connected by a rail system to a single hot cell containing a turntable and a WP final decontamination and inspection area. The turntable/final decontamination cell will interconnect with a WP load cell which will interface with the WP transporter and airlock. Shield doors will separate the turntable/final decontamination cell from the DC staging and welding hot cells and the WP load cell. The WP load cell will house a mobile gantry. The turntable and final decontamination cell will be equipped with a robotic/remote manipulator to perform remote decontamination, inspection, and recovery operations.

In the DC staging and welding hot cells, the DCs will be transferred by the bridge crane and lifting fixtures from the transfer carts to the lag storage positions or to the welding stations. The DC lids will be installed, welded, and inspected (inner and/or outer lids as required for specific DCs). The WPs will be transferred from the welding stations to staging areas or to the horizontalizer. The horizontalizer will rotate the WP to a horizontal orientation and then transfer the WP onto the turntable. The mobile gantry will travel from the WP load cell to the turntable, lift the WP off of the horizontalizer, and transfer the WP to the decontamination and inspection area. After WP survey, decontamination, final inspection, certification and tagging, the gantry will transfer the WP into the WP load cell and position the WP over the previously positioned transporter rail car. The gantry will place the WP on the rail car, the rail car and WP will be retracted into the shielded WP transporter, and the transporter will transfer the WP into the subsurface repository.

7.3.5.2 Recovery

Recovery from failure of an overhead crane bridge or trolley in a DC staging and welding hot cell will require retrieval of these items by a backup retrieval system to a dedicated maintenance area where personnel will perform contact replacement/repair of failed components. Shielding doors will be required for the maintenance area and

the personnel may require anti-contamination suits and breathing apparatus. Failure of the bridge crane hoist or the DC/WP lifting device during DC/WP handling operations would require backup systems to facilitate lowering and releasing of the load in a safe location, prior to transfer of the crane to the maintenance area. If complete modules must be replaced, such as the crane trolley or DC/WP lifting device, an overhead transfer gallery will be required. It would be equipped with an overhead bridge crane and shielded hatches to access the hot cell maintenance area.

Recovery from failure of a welding station will require removal of the DC/WP, identification of the source of failure and remote repair/replacement of the failed component using the robotic/remote manipulator, remote tools and the overhead bridge crane. To support recovery, a shielded enclosure may be required around each welding station. Recovery would require removal of the DC/WP, personnel entry into the shielded enclosure and failed component repair/replacement. Personnel may require anti-contamination suits and breathing apparatus. If a complete welding station must be replaced, a dedicated welding station removal and transfer system will be required.

Recovery from failure of the horizontalizer during WP rotation will require a backup system to return the WP to a vertical orientation, transfer of the WP to the staging area, and repair/replacement of the failed components using a robotic/remote manipulator and remote tools. Failure of the horizontalizer during WP transfer to the turntable would require a backup system to return the WP to the DC cell, removal of the WP, and repair/replacement of the failed components using the robotic/remote manipulator and remote tools. The rail-mounted horizontalizer may also be transferred to the turntable/final decontamination cell for contact repair/replacement of components.

Recovery from failure of the turntable will require a backup drive system to rotate the turntable using the robotic/remote manipulator and remote tools. The WP and horizontalizer will be returned to the DC cell, the shield/containment doors closed, and personnel will enter the turntable cell for failed component repair/replacement. Personnel may require anti-contamination suits and breathing apparatus.

Recovery from failure of the gantry drive system or the gantry WP lifting system will require backup systems, operated by the robotic/remote manipulator, to replace the WP on the horizontalizer with the gantry and return the WP and horizontalizer to the DC cell. The shield/containment doors will be closed and the failed gantry components repaired/replaced contact by personnel in the turntable final decontamination cell. Personnel may require anti-contamination suits and breathing apparatus.

Recovery from failure of any of the shield/isolation doors will require opening or closing of the door by a backup system, transfer of the WP on the gantry or horizontalizer to an adjacent area, and personnel entry for contact replacement/repair of failed components. Recovery from failure of any the decontamination system components in the decontamination cell will require WP removal and personnel entry for repair/replacement of failed components.

7.4 WASTE FORM ANOMALIES

In addition to the operational and equipment failures and recommended recovery requirements identified in Section 7.3, the WHB must also accommodate anomalies expected in the incoming waste forms.

Recovery from the waste form anomalies as identified in Assumption 4.3, will require specialized procedures, and specialized equipment and facility design features. In the wet handling pools, distorted SFAs may be difficult to remove from the casks and DPCs. To remove a distorted SFA, the wet SNF transfer machine grapple will be attached to the SFA. Recovery personnel, working from the gantry platform, will use special underwater tools to loosen the SFA and allow it to be lifted out of the cask or DPC. The SFA will be placed into recovery baskets (several removable recovery baskets can be positioned in the pool). Subsequently, the baskets containing the SFAs will be transferred to the dry SFA staging cell, drained, dried, stored, and loaded into a DC.

If a SFA with a damaged end fitting cannot be engaged by the wet SNF transfer machine grapple, an adapter or special underwater tool (e.g., snare, hook, or clamp) will be required. The adapter/tool will facilitate SFA removal from the cask/DPC with the overhead bridge crane for placement in one of the pool recovery baskets. The basket and SFA will be transferred and loaded into a DC as described above. The consideration of special tools is based on readily available nuclear industry data and experience.

Leaking or broken SFAs will be removed from the casks/DPCs with the wet SNF transfer machine grapple and placed in one of the pool recovery baskets. Using special underwater tools, recovery personnel working from the gantry platform will retrieve any large fuel pieces from the interior of the cask or the bottom of the pool and place the pieces into the pool basket containing the damaged SFA. Personnel, operating from the wet SNF transfer machine, will maneuver a vacuum wand to vacuum the bottom of the cask and pool to remove fuel debris and sludge. The vacuum system for the pool vacuum wand system will be integrated into the normal pool water treatment system. Subsequently, the baskets containing SFAs and debris will be transferred and loaded into a DC as described above.

In the dry canister handling area, if a DHLW canister with a damaged pintle or a MPC with damaged lifting fixture provisions cannot be engaged by the DHLW canister grapple or MPC lifting device, a crane-mounted special adapter or lifting device will be used to engage the canister and load it into a DC.

7.5 EQUIPMENT AND FACILITY CONFIGURATION FOR RECOVERY

7.5.1 Equipment Features

The operating equipment that will be performing the waste handling operations in each of the WHB operating areas will require specific design features to permit safe and efficient recovery from the equipment and operational failures.

Bridge and trolley retrieval systems will be required on the overhead bridge cranes, bridge-mounted robotic/remote manipulators, and SNF transfer machines to allow safe placement of the loads and retrieval of the equipment to the designated maintenance areas. The hoist systems associated with these bridge-mounted devices will require redundant/backup provisions to prevent single-failure release of loads and to allow controlled lowering and disengagement of the loads prior to transfer of the bridge-mounted devices to the maintenance areas. The grapples and mechanized lifting fixtures associated with the waste handling equipment will require redundant drives or mechanical override devices to allow safe disengagement from a SFA or canister using a robotic/remote manipulator and impact wrench.

The transfer carts, horizontalizer, and WP mobile gantry will require retrieval systems to allow these devices to be retrieved to a safe location for repair/replacement of components. The horizontalizer WP rotation system, mobile gantry WP lift system, and turntable will require redundant drives or mechanical override devices to allow orientation, positioning or placement of the WP using a robotic/remote manipulator and impact wrench. Shield and isolation doors will also require backup systems to allow opening or closing of the doors and subsequent repair/replacement of failed components. The transfer canal conveyor system will require a backup drive/conveyance system to allow lowering of the cart on the canal inclined track to the pool bottom for removal for repair/replacement. Individual actuators on the SFA transfer port contamination barrier and the SFA drying vessels will require redundant drives or mechanical override devices to allow operation of the actuators in support of port/vessel maintenance and recovery operations.

7.5.2 Recovery Equipment

Specific recovery equipment will be required in various operating areas of the WHB to support safe and efficient recovery from equipment and operational failures. The equipment may also be utilized to support normal waste handling operations and miscellaneous maintenance tasks.

An overhead bridge crane and a bridge-mounted robotic/remote manipulator with associated remote tools, will be required in each uncanistered waste SFA staging hot cell. The manipulator and crane will be utilized to operate waste handling equipment mechanical override devices, safely transfer and release loads, and assist module and equipment replacement during recovery operations.

A bridge-mounted robotic/remote manipulator will also be required in each canistered waste cask unload and DC load area. The manipulator with associated remote tools, will be utilized to operate waste handling equipment override devices, assist safe transfer and release of loads and assist module and equipment replacement during recovery operations.

7.5.3 Maintenance Areas

All operational areas of the WHB, with the exception of the Carrier Bay, which utilize overhead bridge cranes, bridge-mounted robotic/remote manipulators or fuel handling machines, will require dedicated maintenance areas for the performance of maintenance and recovery operations. The Carrier Bay will require ladders and walkways for recovery access to the overhead bridge crane and elevated platforms at the ends of the bay for crane component repair/replacement. Addition of maintenance recovery areas to the SFA staging hot cells may require additional building space.

Personnel performing maintenance/recovery operations in the maintenance area of the wet handling area, will be shielded from the bare SFAs and DPCs by the depth of the water in the pool. The maintenance areas in the remaining operating areas (SFA staging hot cell, canistered waste dry handling cell and DC staging and welding hot cell) will require shield doors to limit radiation exposure during contact maintenance/recovery operations. In addition, the potential contamination levels in the maintenance areas will require provisions for personnel anti-contamination suits, breathing apparatus and personnel comfort control. Platforms will also be required in the maintenance areas for personnel access to equipment positioned at various elevations.

7.5.4 Overhead Transfer Galleries

Overhead transfer galleries, transfer tunnels, or other alternative recovery arrangements, will be required for transfer and replacement of hot cell equipment and components during WHB maintenance and recovery operations. The transfer provisions could also provide access to the operating cells for initial installation of large equipment.

The overhead transfer galleries would be equipped with overhead bridge cranes for lifting and transferring the cell equipment and possibly a bridge-mounted robotic/remote manipulator. Transfer tunnels would be equipped with transfer carts for supporting and transferring equipment. Shielded or unshielded hatches will provide access to the cell maintenance areas. A waste processing/packaging cell and a non-radioactive equipment and material storage/supply area would be interfaced with the transfer gallery/tunnels.

8. CONCLUSIONS

Waste handling system designs must provide the capability to safely and efficiently recover from a wide variety of expected equipment failures and waste anomalies. Recovery from these failures and anomalies will often need to be performed in a hostile environment that presents both high radiation and contamination risks to personnel. Such failures may also impact the repository waste packaging and emplacement schedule. Equipment performing the recovery task must have a high

degree of flexibility and dexterity to manipulate, move, secure, repair, or replace the failed item or problem waste form.

This analysis identifies expected equipment failures for each of the major waste handling systems defined in *Waste Handling Systems Configuration Analysis* (Reference 5.1). A brief analysis of the expected type of problems with arriving waste forms is also performed. For each of these anticipated operational problems, a recommended recovery procedure is identified, including the required equipment and facility design features necessary to perform the recovery task. The operational risks associated with the recovery task are also identified.

Based on the recovery operations evaluated in this analysis, general equipment and facility design features, and specialized support equipment are recommended. These include the following:

- The inclusion of dedicated maintenance areas with shield doors that will permit personnel to repair retrieved equipment while radioactive sources remain in the operating cells.
- Hoisting equipment mechanical features that permit safe lowering and disengagement of the load, to enable the equipment to be transferred into maintenance areas for repair/replacement of hoisting system components.
- Operating equipment mechanical features that permit safe retrieval of the equipment after failure, including backup drive systems, and systems to enable remote retrieval of failed equipment into maintenance areas that can be shielded for personnel entry.
- Specialized recovery equipment to allow operation of waste handling equipment override devices and to assist in waste handling equipment replacement.
- The inclusion of overhead transfer galleries or transfer tunnels for the transfer and replacement of large equipment. The overhead galleries would be equipped with bridge cranes for lifting and transfer of failed cell equipment to equipment decontamination and waste processing/packaging cells. An area would also be provided for staging of new non-radioactive equipment and for storage of material. The transfer tunnels would be equipped with transfer carts for support and transfer of equipment. Shielded hatches would provide gallery/tunnel access to the strategic locations within the operating cells.
- Special underwater tools and adapters to loosen distorted SFAs in casks, handle SFAs with damaged end fittings and pintles, and retrieve fuel pieces and debris from casks or the bottom of the pool.

9. ATTACHMENTS

ATTACHMENT	DESCRIPTION
I	Operational Failures and Recovery Procedures Table - Carrier/Cask Handling System
II	Operational Failures and Recovery Procedures Table - Assembly Transfer System-Wet Operations
III	Operational Failures and Recovery Procedures Table - Assembly Transfer System-Dry Operations
IV	Operational Failures and Recovery Procedures Table - Canister Transfer System
V	Operational Failures and Recovery Procedures Table - Disposal Container Handling System

Operational Failures and Recovery Procedures Table - Carrier/Cask Waste Handling System

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
Carrier Bay					
Transfer truck/rail carriers into WHB	<ul style="list-style-type: none"> - Tow vehicles - Rail carrier - Truck carrier 	Vehicle	Replace/repair vehicle.	Spare parts	Minimal radiation and industrial hazard risk
		Carrier (wheels, tires, axles, bearings, etc.)	Repair/replace failed component.	Spare parts	Minimal radiation and industrial hazard risk
Engage cask yoke with Carrier Bay crane, transfer yoke to carrier and engage cask trunnions	Overhead bridge crane	Bridge and trolley systems (motor, drive system, bearings, limit switches, power/control umbilical system, etc.)	Retrieve crane to maintenance area; identify source of failure and replace/repair.	Bridge and trolley retrieval systems.	Minimal radiation and industrial hazard risk
		Hoist system	Using backup hoist system, lower and release cask in safe location; transfer crane to maintenance area; replace/repair hoist.	Backup hoist system	Minimal radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None
Upright cask on carrier, transfer cask to transfer cart, place cask on cart and disengage yoke	Overhead bridge crane	Bridge and trolley systems (motor, drive system, bearings, limit switches, power/control umbilical system, etc.)	Operate bridge/trolley retrieval systems; place cask on transfer cart; retrieve crane to maintenance area; identify source of failure and replace/repair.	Bridge and trolley retrieval systems.	Minimal radiation and industrial hazard risk
		Hoist system	Using backup hoist system, place cask on transfer cart; transfer crane to maintenance area; replace/repair hoist.	Backup hoist system	Minimal radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None

Operational Failures and Recovery Procedures Table -Assembly Transfer System - Wet Operations

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
CASK PREPARATION AREA					
Transfer cask to preparation area	Cask transfer cart	Motor, drive system (gear reducer, bearings, axle, etc.), power/control umbilical, and limit switches/sensors	Personnel entry and replace/repair in place or retrieve cart to Carrier Bay for replacement/repair.	Cart retrieval system	Minimal radiation and industrial hazard risk
		Control system (operating gallery)	Identify source of failure and replace/repair.	Spare parts	None
	Isolation door	Motor, drive system (gear reducer, rollers, etc.), limit switches, and seals	Open/close door with auxiliary system and replace/repair in place.	Auxiliary door operating system	Minimal radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None
		Track obstruction	Identify obstruction and remove.	Spare parts	Minimal radiation and industrial hazard risk
Cask preparation and transfer of cask to preparation pool.	Robotic and Remote Manipulator	Manipulator component failure (motors, drives, cables, limit switches, etc.)	Personnel entry; identify source of failure and replace/repair.	Spare parts	Minimal radiation and industrial hazard risk
		Impact wrench or remote tool	Personnel entry into area and replace tool.	Spare parts	Minimum radiation, contamination and industrial hazard risk
		Major manipulator component failure	Personnel entry; identify source of failure and replace/repair. Major component replacement may require transfer system.	Spare parts	Minimum radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None

Operational Failures and Recovery Procedures Table -Assembly Transfer System - Wet Operations

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
	Overhead bridge crane	Bridge and trolley systems (motor, drive system, bearings, limit switches, power/control umbilical system, etc.)	Using retrieval systems, retrieve crane to maintenance area; personnel entry; identify source of failure and replace/repair. Major component replacement may require transfer system.	Bridge and trolley retrieval systems.	Minimal radiation and industrial hazard risk
		Hoist system	Using backup hoist system, place load in safe location; transfer crane to maintenance area; personnel entry; replace/repair hoist. Hoist replacement may require transfer system.	Backup hoist system.	Minimal radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None
	Purge/vent lines	Hoses or connectors	Personnel entry into cell and replace/repair.	Spare parts	Minimal radiation and contamination hazard risk
	Cavity cooling/water fill line	Hoses or connectors	Personnel entry into cell and replace/repair.	Spare parts	Minimal radiation and contamination hazard risk

Operational Failures and Recovery Procedures Table -Assembly Transfer System - Wet Operations

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
WET HANDLING AREA - DPC OPERATIONS					
Cask lid removal; install DPC lifting device; transfer cask to unloading pool; transfer DPC to DPC unloading pool; DPC preparation, remove DPC lid	Overhead bridge crane	Bridge and trolley systems (motor, drive system, bearings, limit switches, power/control umbilical system, etc.)	Release load in safe location; retrieve crane to maintenance area; personnel entry; identify source of failure and replace/repair. Replacement may require transfer system.	Bridge and trolley retrieval systems.	Minimal radiation and industrial hazard risk
		Hoist system	Using backup hoist system, release load in safe location; transfer crane to maintenance area; personnel entry; replace/repair hoist. Hoist replacement may require transfer system.	Backup hoist system	Minimal radiation and industrial hazard risk
	Pool tools	Pool tools	Replace/repair.	Spare parts	None
WET HANDLING AREA - SNF OPERATIONS					
Transfer cask to cask prep pool; cask lid removal	Overhead bridge crane	Bridge and trolley systems (motor, drive system, bearings, limit switches, power/control umbilical system, etc.)	Using retrieval systems, lower and release load in safe location; retrieve crane to maintenance area; personnel entry into cell; identify source of failure and replace/repair. Replacement may require transfer system.	Bridge and trolley retrieval systems. Personnel protection (breathing apparatus, etc.)	Minimal radiation and industrial hazard risk

Operational Failures and Recovery Procedures Table -Assembly Transfer System - Wet Operations

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
		Hoist system	Using backup hoist system, lower and release load in safe location; transfer crane to maintenance area; personnel entry in cell; replace/repair hoist. Hoist replacement may require transfer system.	Backup hoist system.	Minimal radiation and industrial hazard risk
DPC/SNF OPERATIONS					
Transfer SFAs to lag storage rack; transfer SFAs to transfer canal conveyor basket	Wet SNF transfer machine	Drive system (motor, drive system, bearings, control system, power/control umbilical system, etc.)	Retrieve machine to maintenance area; personnel entry; identify source of failure and replace/repair.	Machine retrieval system	Minimal radiation and contamination hazard risk
		SFA handling system (mast system, motor drive system, wire rope system, SNF grapple, control system, and power/umbilicals.	Retrieve machine to maintenance area; personnel entry; identify source of failure and replace/repair. Large component replacement may require transfer system.	Backup hoist system; backup grapple system	Minimal radiation and industrial hazard risk

Operational Failures and Recovery Procedures Table -Assembly Transfer System - Wet Operations

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
EMPTY CASK PROCESSING					
Transfer cask from cask unload pool to cask preparation pool; install cask lid and attach vent/drain lines; withdraw cask from pool	Overhead bridge crane	Bridge and trolley systems (motor, drive system, bearings, limit switches, power/control umbilical system, etc.)	Using retrieval systems, retrieve crane to maintenance area; personnel entry; identify source of failure and replace/repair. Replacement may require transfer system.	Bridge and trolley retrieval systems.	Minimal radiation and industrial hazard risk
		Hoist system	Using backup hoist system, place load in safe location; transfer crane to maintenance area; personnel entry; repair/replace hoist. Hoist replacement may require transfer system.	Backup hoist system	Minimal radiation and industrial hazard risk
	Pool tools	Pool tools	Replace/repair.	Spare parts	None
	Vent/water drain lines	Hoses or connectors	Personnel entry into cell and replace/repair.	Spare parts	Minimal radiation and contamination hazard risk
Drain water from cask (as cask is withdrawn from pool)	Water removal system	Pump	Personnel entry; replace/repair.	Spare parts	Minimal radiation and contamination hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None
Transfer cask to dry cask preparation area and install on cart	Overhead bridge crane	Bridge and trolley systems (motor, drive system, bearings, limit switches, power/control umbilical system, etc.)	Using retrieval systems, retrieve crane to maintenance area; personnel entry; identify source of failure and replace/repair. Replacement may require transfer system.	Bridge and trolley retrieval systems.	Minimal radiation and industrial hazard risk

Operational Failures and Recovery Procedures Table -Assembly Transfer System - Wet Operations

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
		Hoist system	Using backup hoist system, lower and release load in safe location; transfer crane to maintenance area; personnel entry in cell; replace/repair hoist. Hoist replacement may require transfer system.	Backup hoist system	Minimal radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	None	None
	Isolation door	Motor, drive system (gear reducer, rollers, etc.), limit switches, and seals	Open/close door with auxiliary system and replace/repair in place.	Auxiliary door operating system	Minimal radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None
		Track obstruction	Identify obstruction and remove.	Spare parts	Minimal radiation and industrial hazard risk
Dry cask interior	Vacuum system	Vacuum system	Personnel entry and replace/repair.	Spare parts	Minimal radiation and contamination hazard risk
Survey and decontaminate cask and cart as required	Contamination survey system	Radiation monitoring device	Personnel entry and replace/repair.	Spare parts	Minimal radiation and contamination hazard risk
	Spray decontamination systems (water, detergent, and chemicals)	Process system (pumps, tanks, valves, etc.)	Identify source of failure and repair/replace.	Spare parts	Minimal radiation and contamination hazard risk
		In-cell decontamination system (valves, hoses, and nozzles)	Personnel entry and replace/repair.	Spare parts	Minimal radiation and contamination hazard risk
Cask transfer to Carrier Bay	Cask transfer cart	Motor, drive system (gear reducer, bearings, axle, etc.), power/control umbilical, and limit switches/sensors	Personnel entry and replace/repair in place or retrieve to Carrier Bay.	Cart retrieval system	Minimal radiation and industrial hazard risk

Operational Failures and Recovery Procedures Table -Assembly Transfer System - Wet Operations

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
		Control system	Identify source of failure and replace/repair.	Spare parts	None
	Shield/isolation door	Motor, drive system (gear reducer, rollers, etc.), limit switches, and seals	Open/close door with auxiliary system and replace/repair in place.	Auxiliary door operating system	Minimal radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None
		Track obstruction	Identify obstruction and remove.	Spare parts	Minimal radiation and industrial hazard risk
EMPTY DPC PROCESSING					
Transfer empty DPC from DPC unload pool to cask preparation pool; place and secure DPC lid on DPC; remove DPC from cask preparation pool; drain DPC and place DPC in cask preparation area	Overhead bridge crane	Bridge and trolley systems (motor, drive system, bearings, limit switches, power/control umbilical system, etc.)	Using retrieval systems, retrieve crane to maintenance area; personnel entry; identify source of failure and replace/repair. Replacement may require transfer system.	Bridge and trolley retrieval systems.	Minimal radiation and industrial hazard risk
		Hoist system	Using backup hoist system, place load in safe location; transfer crane to maintenance area; personnel entry; replace/repair hoist. Hoist replacement may require transfer system.	Backup hoist system	Minimal radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None
	Pool tools	Pool tools	Replace/repair.	None	None
	Water removal system	Pump system	Personnel entry and replace or repair.	Spare parts	Minimal radiation and contamination hazard risk

Operational Failures and Recovery Procedures Table -Assembly Transfer System - Wet Operations

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
Survey and decontaminate DPC and DPC lid	Contamination survey system	Radiation monitoring device	Personnel entry and replace/repair.	Spare parts	Minimal radiation and contamination hazard risk
	Spray decontamination systems (water, detergent, and chemicals)	Process system (pumps, tanks, valves, etc.)	Identify source of failure and repair/replace.	Spare parts	Minimal radiation and contamination hazard risk
		In-cell decontamination system (valves, hoses, and nozzles)	Personnel entry and replace/repair .	Spare parts	Minimal radiation and contamination hazard risk
SNF TRANSFER CANAL					
Transfer SFAs basket to SNF staging hot cell	Transfer canal conveyor system	Wire rope winch system (motor, gear reducer)	Personnel entry and repair in place or replace.	- Overhead crane - Auxiliary hoist	Minimal radiation and industrial hazard risk
		Wire rope system (sheaves, wire ropes, fittings, etc.)	Using backup system, return basket to bottom of transfer canal; personnel entry; remove from pool; repair/replace components.	- Overhead crane - Pool tools - Conveyor backup system	Minimal radiation and industrial hazard risk
		Cart (wheels, bearings, etc.)	Using backup system, return basket to bottom of transfer canal; personnel entry; remove cart from pool and transfer to maintenance area; repair/replace components. Cart replacement may require transfer system.	- Overhead crane - Pool tools - Conveyor backup system	Minimal radiation and industrial hazard risk

Operational Failures and Recovery Procedures Table - Assembly Transfer System - Dry Operations

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
SNF STAGING HOT CELL					
Transfer SFAs from transfer canal conveyor and place in drying vessel	Overhead bridge crane (required for recovery/maintenance operations)	Bridge and trolley systems (motor, drive system, bearings, limit switches, power/control umbilical system, etc.)	Using retrieval systems, retrieve crane to maintenance area; personnel entry; identify source of failure and replace/repair. Replacement may require transfer system.	Bridge and trolley retrieval systems.	Moderate radiation, contamination and industrial hazard risk
		Hoist system	Using backup hoist system, place load in safe location; transfer crane to maintenance area; personnel entry into maintenance area; replace/repair hoist. Hoist replacement may require transfer system.	Backup hoist system	Moderate radiation, contamination and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None
Close drying vessel lid, dry SFAs; and open vessel lid	Drying vessel lid operating system	Lid actuator (motor, limit switches, power control cable, etc.)	Using overhead crane and robotic/remote manipulator, close vessel lid and replace lid actuator.	- Overhead crane - Manipulator - Remote tools	None
		Control system	Identify source of failure and replace/repair.	Spare parts	None
	Drying vessel	Vacuum system located out of cell (motor, vacuum pump, press switches, etc.)	Identify source of failure and repair/replace.	Spare parts	Minimal radiation and industrial hazard risk

Operational Failures and Recovery Procedures Table - Assembly Transfer System - Dry Operations

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
Open/close port/plug shield block	Port/plug shield block system	Shield block operating system (motor, drive system, limit switches, rollers, etc.	Using robotic/remote manipulator and crane, open/close shield block; identify source of failure and replace/repair. Large component replacement may require transfer system.	- Manipulator - Remote tools - Overhead crane	None
		Control System	Identify source of failure and replace/repair.	None	None
Remove SFAs from dryer and place in lag storage rack; transfer SFAs from lag storage rack and load into DC	Dry SNF transfer machine	Bridge and trolley systems (motor, drive system, bearings, limit switches, power/control umbilical system, etc.)	Using retrieval system, replace SFA in lag storage rack; retrieve fuel handling machine to shielded maintenance area; personnel entry into maintenance area; decontaminate fuel handling machine; identify source of failure and replace/repair. Large component replacement may require transfer system.	- Bridge and trolley retrieval systems - Decontamination system in shielded maintenance area	Moderate radiation contamination and industrial hazard risk
		SNF handling system (mast system, motor drive system, wire rope system, SNF grapple, control system, and power/umbilicals)	Return fuel handling machine to lag storage rack. Using robotic/remote manipulator and impact wrench, replace SFA in rack. Large component replacement may require transfer system.	- Manipulator - Impact wrench - SNF handling system and grapple backup drive systems	Moderate radiation, contamination and industrial hazard risk

Operational Failures and Recovery Procedures Table - Assembly Transfer System - Dry Operations

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
		Control system	Identify source of failure and replace/repair.	- Spare parts - Single failure proof control system (to prevent collision or accident)	None
DC PROCESSING CELLS					
Transfer of DC on transfer cart between DC cell, decontamination cell, inner lid weld cell, and DC load cell	DC transfer cart	Motor, drive system (gear reducer, bearings, axle, etc.), power/control umbilical, and limit switches/sensors	Move cart and DC from cell to cell using cart retrieval system; complete DC processing; return DC to DC cell; return cart to decon cell; personnel entry; replace/repair in place.	Cart retrieval system	Moderate radiation, contamination and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None
	Shield/isolation doors	Motor, drive system (gear reducer, rollers, etc.), limit switches, and seals	Open/close door with auxiliary system and replace/repair in place.	Auxiliary door operating system	Moderate radiation, contamination and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None
		Track obstruction	Identify obstruction and remove.	None	Moderate radiation, contamination and industrial hazard risk
Port/plug shield block remains closed; lower/raise contamination barrier as required to engage/disengage DC	Port room contamination barrier system	Linear actuators, sensors/limit switches	Extend/retract barrier using a robotic/remote manipulator in staging hot cell; cart and DC removed from cell; personnel entry; identify source of failure and replace/repair.	Auxiliary drive system, access platforms	Moderate radiation, contamination and industrial hazard risk

Operational Failures and Recovery Procedures Table - Assembly Transfer System - Dry Operations

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
(DC positioned in inner lid weld cell) place inner lid in DC	Welding machine	Lid installation system (remote jib crane/robotic/ remote manipulator and inner lid lifting fixture, sensors/ limit switches, power/ control umbilicals, etc.)	Identifying source of failure and replace/repair failed component or replace entire device using manipulator and remote tools (impact wrench, etc.). Replacement of welding machine will utilize transfer cart rail system.	- Manipulator - Remote tools - Overhead hoist - Lid installation system	None
		Control system	Identifying source of failure and replace/repair	Spare parts	None
Weld and inspect inner lid	Welding machine	Lid welding system (weld head, wire feed, gas system, sensors/limit switches, motors, drives, inspection components, power/control umbilicals, etc.)	Identify source of failure and replace/repair failed component or replace entire device using manipulator and remote tools (impact wrench, etc.). Replacement of welding machine may require transfer system.	- Manipulator - Remote tools - Overhead bridge crane	None
		Control system	Identify source of failure and replace/repair	None	None

Operational Failures and Recovery Procedures Table - Assembly Transfer System - Dry Operations

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
Decontaminate upper area of DC and Lid	Contamination survey system using robotic/remote manipulator	- Manipulator - Swipe specimen transfer system	Transfer cart and DC to inner lid weld cell; personnel entry into cell; replace/repair failed components Complete replacement of manipulator will utilize transfer cart rail system to supply new manipulator and remove replaced system.	- Access platforms - Hoist for system handling - Cart for transfer of components/complete system	Moderate radiation, contamination and industrial hazard risk.
	CO ₂ and vacuum decontamination system	-CO ₂ system - Vacuum system (located out of cell)	Identify source of failure and replace/repair	None	Minimal radiation and contamination hazard risk
		Control system	Identify source of failure and replace/repair	None	None

Operational Failures and Recovery Procedures Table - Canister Transfer System

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
CASK PREPARATION AREA					
Cask transfer from Carrier Bay into cask preparation cell; transfer cart to lid removal cell; transfer cart to canister unload area; transfer empty cask to decontamination cell; transfer cask to carrier bay	Cask transfer cart	Motor, drive system (gear reducer, bearings, axle, etc.), power/control umbilical, and limit switches/sensors	Personnel entry into corridor, airlock, or cell and replace/repair in place or retrieve to Carrier Bay.	Cart retrieval system	Minimal radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None
	Shield/isolation doors	Motor, drive system (gear reducer, rollers, etc.), limit switches, and seals	Open/close door with auxiliary system and replace/repair in place.	Auxiliary door operating system	Minimal radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None
		Track obstruction	Identify obstruction and remove.	None	Minimal radiation and industrial hazard risk
Cask preparation	Robotic/remote manipulator	Manipulator component failure (motors, drives, cables, limit switches, etc.)	Return cask to carrier bay; personnel entry into preparation area, identify source of failure and replace/repair.	Spare parts	Minimal radiation and industrial hazard risk
		Impact wrench or remote tool	Personnel entry into preparation area and replace tool.	Spare parts	Minimum radiation, contamination and industrial hazard risk
		Major manipulator component failure (trolley, bridge, telescoping column, EMM, etc.)	Personnel entry; identify source of failure and replace/repair. Replacement may require transfer system.	Spare parts	Minimal radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None
	Purge/vent lines	Hoses or connectors	Personnel entry into cell and replace/repair.	None	Minimal radiation and contamination hazard risk

Operational Failures and Recovery Procedures Table - Canister Transfer System

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
DHLW OPERATIONS					
Cask lid removal; engage DHLW canister grapple; transfer DHLW canister to lag storage; remove DHLW canister from lag storage rack and load into DC	Overhead bridge crane	Bridge and trolley systems (motor, drive system, bearings, limit switches, power/control umbilical system, etc.)	Using retrieval systems, retrieve crane to maintenance area; personnel entry; identify source of failure and replace/repair. Large component replacement may require transfer system.	Bridge and trolley retrieval systems	Minimal radiation and industrial hazard risk
		Hoist system	Using backup hoist system, lower and release load in safe location; transfer crane to maintenance area; personnel entry; replace/repair hoist. Hoist replacement may require transfer system.	Backup hoist system	Minimal radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None
	Bridge-mounted robotic/ remote manipulator (required for recovery/ maintenance operations)	Manipulator component failure (motors, drives, cables, limit switches, etc.)	Retrieve manipulator to maintenance area, personnel entry; identify source of failure and replace/repair.	- Manipulator retrieval system - Port/shield blocks	Minimal radiation and industrial hazard risk
		Impact wrench or remote tool	Remote replacement or personnel entry into cell and replace tool.	Tool change-out station or maintenance area	Minimum radiation, contamination and industrial hazard risk

Operational Failures and Recovery Procedures Table - Canister Transfer System

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
		Major manipulator component failure (trolley, bridge, telescoping column, manipulator, etc.)	Using retrieval systems, retrieve manipulator to maintenance area; personnel entry; identify source of failure and replace/repair. Large component replacement may require transfer system.	Bridge and trolley retrieval systems	Minimum radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair	Spare Parts	None
	DHLW canister grapple	Motor, drive components, sensors/limit switches, load cell, power/control cables, etc.	Replace DHLW canister in cask, release grapple from canister pintle by operating grapple backup device using manipulator and impact wrench. Transfer overhead crane and grapple to maintenance area; personnel entry; identify source of failure and replace/repair.	<ul style="list-style-type: none"> - Manipulator - Impact wrench - Grapple backup release system - Crane maintenance area 	Minimal radiation and contamination hazard risk
		Control system	Identify source of failure and replace/repair.	<ul style="list-style-type: none"> - Spare parts - Single failure proof controls (backup system) 	None
	DC transfer cart	Motor, drive system (gear reducer, bearings, axle, etc.), power/control umbilical, and limit switches/sensors	Retrieve cart to DC cell; remove DC; return cart to DC load cell; repair cart in place.	Cart retrieval system	Moderate radiation, contamination and industrial hazard risk
		Control system	Identify source of failure and replace/repair.	Spare parts	None
Transfer unlidded DC on transfer cart to DC load cell (DC loaded on transfer cart in DC cell); transfer loaded DC to DC cell	Shield/isolation doors	Motor, drive system (gear reducer, rollers, etc.), limit switches, and seals	Open/close door with auxiliary system and replace/repair in place.	Auxiliary door operating system	Minimal radiation and industrial hazard risk

Operational Failures and Recovery Procedures Table - Canister Transfer System

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
		Control system	Identify source of failure and replace/repair.	Spare parts	None
		Track obstruction	Identify obstruction and remove.	None	Moderate radiation, contamination and industrial hazard risk
MPC OPERATIONS					
Install MPC lifting device on MPC, assist with EMM; transfer MPC from cask to lag storage rack; remove MPCs from lag storage rack and load into DC	Overhead bridge crane	Bridge and trolley systems (motor, drive system, bearings, limit switches, power/control umbilical system, etc.)	Using retrieval systems, place load in safe location; retrieve crane to maintenance area; personnel entry; identify source of failure and replace/repair Large component/trolley replacement may require transfer system.	Bridge and trolley retrieval systems	Minimal radiation and industrial hazard risk
		Hoist system	Lower and release load in safe location, transfer crane to maintenance area; personnel entry; replace/repair hoist. Hoist replacement may require transfer system.	Backup hoist system	Minimal radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair	Spare parts	None
	Bridge-mounted robotic/ remote manipulator (required for recovery/ maintenance operations)	Manipulator component failure (motors, drives, cables, limit switches, etc.),	Retrieve manipulator to maintenance area, personnel entry; identify source of failure and replace/repair	- Manipulator retrieval system - Port/shield blocks	Minimal radiation and industrial hazard risk
		Impact wrench or remote tool	Remove replacement or personnel entry into cell and replace tool	Tool change-out station or maintenance area	Minimum radiation, contamination and industrial hazard risk

Operational Failures and Recovery Procedures Table - Canister Transfer System

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
		Major manipulator component failure (trolley, bridge, telescoping column,	Using retrieval systems, lower and release load in safe location; retrieve manipulator to maintenance area; personnel entry; repair/replace components. Manipulator replacement may require transfer system.	Bridge and trolley retrieval systems	Minimum radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair	None	None
Transfer unlidded empty DC on transfer cart to DC load cell (DC loaded on transfer cart in DC cell)	DC transfer cart	Motor, drive system (gear reducer, bearings, axle, etc.), power/control umbilical, and limit switches/sensors	Retrieve cart to DC cell; remove empty DC; return cart to DC load cell; and repair cart in place.	Cart retrieval system	Moderate radiation, contamination and industrial hazard risk
		Control system	Identify source of failure and replace/repair	Spare parts	None
	Shield/isolation door	Motor, drive system (gear reducer, rollers, etc.), limit switches, and seals	Open/close door with auxiliary system and replace/repair in place	Auxiliary door operating system	Minimal radiation and industrial hazard risk
Cask lid replacement	Overhead bridge crane (Cask lid handled by auxiliary hoist and lid handling fixture)	Bridge and trolley systems (motor, drive system, bearings, limit switches, power/control umbilical system, etc.)	Using retrieval systems, place load in safe location; retrieve crane to maintenance area; personnel entry; identify source of failure and replace/repair. Large component/trolley replacement may require transfer system.	Bridge and trolley retrieval systems	Minimal radiation and industrial hazard risk

Operational Failures and Recovery Procedures Table - Canister Transfer System

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
		Hoist system	Using backup hoist system, lower and release load in safe location; transfer crane to maintenance area; personnel entry; replace/repair hoist. Hoist replacement may require transfer system.	Backup hoist system	Minimal radiation and industrial hazard risk
		Control system	Identify source of failure and replace/repair	Spare parts	None
Survey and decontaminate cask and cart as required	Contamination survey system	Radiation monitoring device	Personnel entry and replace/repair	Spare parts	Minimal radiation and contamination hazard risk
	Spray decontamination systems (water, detergent, and chemicals)	Process system (pumps, tanks, valves, etc.)	Identify source of failure and repair/replace	Spare parts	Minimal radiation and contamination hazard risk
		In-cell decontamination system (valves, hoses, and nozzles)	Personnel entry and replace/repair	Spare parts	Minimal radiation and contamination hazard risk

Operational Failures and Recovery Procedures Table - Disposal Container Handling System

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
DC CELLS					
Engage DC with lifting fixture and transfer DC from transfer cart to DC storage position; transfer DC from storage position to welding station	Overhead bridge crane with main hoist for DC lifting fixture	Bridge and trolley systems (motor, drive system, bearings, limit switches, power/control umbilical system, etc.)	Using main hoist, place DC in safe location; retrieve crane to maintenance area; personnel entry; identify source of failure and replace/repair. Replacement may require transfer system.	- Bridge and trolley retrieval systems - Maintenance area	Minimal radiation and industrial hazard risk.
		Hoist system	Using backup hoist system, lower and release DC in safe location; transfer crane to maintenance area; personnel entry; replace/repair hoist. Replacement may require transfer system	Backup hoist system.	Minimal radiation and industrial hazard risk.
		Control system	Identify source of failure and replace/repair	Spare parts	None
	DC lifting fixture	Actuators, sensors/limit switches, load cells, power/control cabling, etc. (Fixture will not release from DC)	Return DC to storage position. Using manipulator, operate lifting fixture backup feature to disengage from DC. Transfer crane and lifting fixture to maintenance area. Personnel entry. Identify source of failure and repair/replace. Replacement may require transfer system.	- DC lifting fixture backup operating system - Robotic/remote manipulator	Minimal radiation and contamination hazard risk.

Operational Failures and Recovery Procedures Table - Disposal Container Handling System

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
		Control system	Identify source of failure	Spare parts	None and replace/repair
Place inner lid in DC (DCs containing DHLW Canisters and MPCs only). Place outer lid in DC	Welding machine	Lid installation system (remote jib crane and inner lid lifting fixture, sensors/limit switches, power/control umbilicals, etc.)	Identify source of failure and replace/repair failed component or replace entire device using manipulator remote tools (impact wrench, etc.) and overhead bridge crane. Replacement of welding machine may require transfer system.	- Manipulator - Remote tools - Overhead bridge crane - Lid installation system - Personnel protection (breathing apparatus, etc.)	None
		Control system	Identify source of failure and replace/repair	Spare parts	None
Weld and inspect DC outer lid upon successful welding of outer lid, DC becomes WP	Welding machine	Lid welding system (weld head, wire feed, gas system, sensors/limit switches, motors, drives, inspection components, power/control umbilicals, etc.)	Identify source of failure and replace/repair failed component or replace entire device using manipulator remote tools (impact wrench, etc.). Replacement of welding machine may require transfer system.	- Manipulator - Remote tools - Overhead bridge crane - Personnel protection (breathing apparatus, etc.)	None
		Control system	Identify source of failure and replace/repair	None	None
Engage WP with lifting fixture and transfer WP from welding station and install in horizontalizer (operation may include intermediate WP staging)	Overhead bridge crane with WP lifting fixture attached to main hoist	Bridge and trolley systems (motor, drive system, bearings, limit switches, power/control umbilical system, etc.)	Using main hoist, place DC in safe location; retrieve crane to maintenance area; personnel entry; identify source of failure and replace/repair. Replacement may require transfer system.	Bridge and trolley retrieval systems	Minimal radiation and industrial hazard risk.

Operational Failures and Recovery Procedures Table - Disposal Container Handling System

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
		Hoist system	Using backup hoist system, lower and release DC in safe location; transfer crane to maintenance area; personnel entry; replace/repair hoist. Replacement of large components may require transfer system.	Backup hoist system.	Minimal radiation and industrial hazard risk.
		Control system	Identify source of failure and replace/repair	Spare parts	None
	WP lifting fixture	Actuators, sensors/limit switches, load cells, power/control cabling, etc. (Fixture will not release from DC)	Return DC to storage position. Using manipulator, operate lifting fixture backup feature to disengage from DC. Transfer crane and lifting fixture to maintenance area. Personnel entry; identify source of failure and repair/replace. Replacement of large components may require transfer system.	- DC lifting fixture backup operating system - Manipulator	Minimal radiation and contamination hazard risk.
		Control system	Identify source of failure and replace/repair	Spare parts	None

Operational Failures and Recovery Procedures Table - Disposal Container Handling System

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
Rotate WP to horizontal orientation	Horizontalizer	Motors, drive system, sensors/limit switches, power/control umbilicals, etc.	Using horizontalizer backup drive and manipulator with impact wrench, rotate WP to vertical orientation, return WP to staging area; Identify source of failure and replace/repair failed component or module using manipulator remote tools (impact wrench, etc.) and overhead bridge crane auxiliary hoist. The horizontalizer may be transferred to the turntable/final decontamination cell for contact repair	<ul style="list-style-type: none"> - Manipulator - Remote tools - Overhead bridge crane - Module lifting fixtures/slugs 	None
		Control system	Identify source of failure and replace/repair	Spare parts	None

Operational Failures and Recovery Procedures Table - Disposal Container Handling System

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
Transfer horizontalizer and WP into turntable/ final decontamination cell and close shield doors	Horizontalizer	Motors, drive system, sensors/limit switches, power/control umbilicals, etc.	Using horizontalizer retrieval system, return horizontalizer and WP to horizontalizer station, rotate WP to vertical orientation, return WP to staging area; Identify source of failure and replace/repair failed component or module using manipulator remote tools (impact wrench, etc.) and overhead bridge crane auxiliary hoist. The horizontalizer may be transferred to the turntable/final decontamination cell for contact repair.	<ul style="list-style-type: none"> - Manipulator - Remote manipulator tools - Overhead bridge crane - Module lifting fixtures/slings - Horizontalizer retrieval system 	None
		Control system	Identify source of failure and replace/repair	Spare parts	None
	Shield/enclosure doors	Motor, drive system (gear reducer, rollers, etc.) limit switches and seals.	Open/close doors with auxiliary system; return horizontalizer and WP to horizontalizer station; personnel entry; Identify source of failure and replace/repair failed component or module.	<ul style="list-style-type: none"> - Auxiliary door operating system - Overhead bridge crane - Module lifting fixtures/slings 	None
		Control system	Identify source of failure and replace/repair	Spare parts	None

Operational Failures and Recovery Procedures Table - Disposal Container Handling System

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
TURNTABLE/FINAL DECONTAMINATION CELL AND WP LOAD CELL					
Rotate turntable to align horizontalizer and WP with gantry tracks	Turntable	Motors, drive system, limit switches	Rotate turntable using backup drive, using manipulator and remote impact wrench; return horizontalizer and WP to horizontalizer station; close shielding door; personnel entry; Identify source of failure and replace/repair failed component or module by contact	<ul style="list-style-type: none"> - Backup override system - Personnel protection (breathing apparatus, etc.) 	None
		Control system	Identify source of failure and replace/repair	Spare parts	None
Open WP load cell shield door and move gantry into turntable/final decontamination cell and position over horizontal WP	Gantry	Motors, drive system, limit switches	Using gantry retrieval system, return gantry to WP load cell and close shield door; Identify source of failure and replace/repair failed component or module using manipulator, remote tools (impact wrench, etc.) and overhead crane. When shield doors are closed, personnel may enter cell for contact repair.	<ul style="list-style-type: none"> - Gantry retrieval system - Manipulator - Remote manipulator tools - Overhead crane - Module lifting fixtures/slugs - Personnel protection (breathing apparatus, etc.) 	None
		Control system	Identify source of failure and replace/repair	None	None

Operational Failures and Recovery Procedures Table - Disposal Container Handling System

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
	Shield/enclosure doors	Motor, drive system (gear reducer, rollers, etc.) limit switches and seals.	Open shield door with auxiliary system (if door fails closed), move gantry to turntable/final decontamination cell and close shield door; personnel entry; Identify source of failure and replace/repair failed component or module.	- Auxiliary door operating system	None
		Control system	Identify source of failure and replace/repair	None	None
Engage WP with gantry and lift WP off of horizontalizer	Gantry WP lift system	Motors, drives, actuators, limit switches, power/control umbilicals, etc.	Using gantry backup system operated by manipulator and impact wrench, replace WP on horizontalizer; transfer horizontalizer and WP to DC cell and close shield door; personnel entry; Identify source of failure and replace/repair failed component or module.	- Gantry backup WP lift system - Manipulator - Remote tools - Personnel protection (breathing apparatus, etc.)	None
		Control system	Identify source of failure and replace/repair	Spare parts	None
WP contamination survey and WP decontamination	Contamination survey system using manipulator and swipe specimen cell transfer system	- Swipe specimen cell transfer system (Located out of cell)	Personnel entry; identify source of failure and repair/replace.	Spare parts	Minimal radiation and contamination hazard risk.
	CO ₂ and vacuum decontamination system	- CO ₂ system - Vacuum system (located out of cell)	Personnel entry; identify source of failure and replace/repair.	Spare parts	Minimal radiation and contamination hazard risk
	Spray decontamination systems (water, detergent, and chemicals)	Process system (pumps, tanks, valves, etc.) (Located out of cell)	Identify source of failure and repair/replace	Spare parts	Minimal radiation and contamination hazard risk.

Operational Failures and Recovery Procedures Table - Disposal Container Handling System

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
	In-cell decontamination components for CO ₂ and spray decontamination systems	Hoses, nozzles, connectors, etc.	Personnel entry; identify source of failure and replace/repair failed items	- Spare parts	None
	Control system for all decontamination and survey systems	Control system	Identify source of failure and replace/repair	Spare parts	None
(Prior to this operation, the shielded WP transporter will be moved into the airlock and interfaced with the gantry cell door opening. The rail car will be extended from the transporter into the gantry cell.) Open the gantry cell shield door, transfer the gantry into the cell and position the WP over the rail car.	Gantry	Motors, drive systems, bearings, limit switches, power/control umbilicals, etc.	Using gantry retrieval system, return gantry to turntable/final decontamination cell and close shield door; replace WP on horizontalizer; return WP to DC cell; close shield doors; personnel entry; Identify source of failure and replace/repair failed component or module.	- Gantry retrieval system - Personnel protection (breathing apparatus, etc.)	None
		Control system	Identify source of failure and replace/repair	Spare parts	None

Operational Failures and Recovery Procedures Table - Disposal Container Handling System

Operation	Equipment	Expected Component Failures	Recovery Procedure	Recovery Equipment/Facility Features	Specific Recovery Risks
Lower WP into rail car and disengage gantry; retract the rail car and WP into the transporter and close the transporter shield doors.	Gantry WP lift system	Motors, drives, actuators, limit switches, power/control umbilicals, etc.	Using gantry backup system operated by manipulator and impact wrench, replace WP on horizontalizer; return gantry to gantry cell and close shield door; Identify source of failure and replace/repair failed component or module using manipulator, remote tools (impact wrench, etc.) and overhead bridge crane or contact methods.	<ul style="list-style-type: none"> - Gantry backup WP lift system - Manipulator - Remote tools - Overhead bridge crane - Module lifting fixtures/slugs 	None
		Control system	Identify source of failure and replace/repair	Spare parts	None