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ACRONYMS AND ABBREVIATIONS

Acronyms

BOP	balance of plant
BSC	Bechtel SAIC Company, LLC
CFR	Code of Federal Regulations
CRCF	Canister Receipt and Closure Facility
CSNF	commercial spent nuclear fuel
DOE	U.S. Department of Energy
DPC	dual-purpose canister
EDGF	Emergency Diesel Generator Facility
ESD	event sequence diagram
GROA	geologic repository operations area
HAM	horizontal aging module
HAZOP	hazard and operability
HDPC	horizontal dual-purpose canister
HEPA	high efficiency particulate air
HIC	high-integrity container
HLW	high-level radioactive waste
HSTC	horizontal shielded transfer cask
HTC	a transportation cask that is never upended
HVAC	heating, ventilation, and air conditioning
IHF	Initial Handling Facility
ISO	Intra-Site Operations
ITC	important to criticality
ITS	important to safety
LLW	low-level radioactive waste
LLWF	Low-Level Waste Facility
MCO	multicanister overpack
MLD	master logic diagram
NA	not applicable
NRC	U.S. Nuclear Regulatory Commission
PCSA	preclosure safety analysis
PFD	process flow diagram
PRA	probabilistic risk assessment

ACRONYMS AND ABBREVIATIONS (Continued)

QA	quality assurance
RF	Receipt Facility
SNF	spent nuclear fuel
SPM	site prime mover
SSC	structure, system, or component
SSCs	structure, system, and component
TAD	transportation, aging, and disposal
TEV	transport and emplacement vehicle
UCSNF	uncanistered commercial spent nuclear fuel
WHF	Wet Handling Facility
YMP	Yucca Mountain Project

Abbreviations

ft	feet
gal	gallon
hr	hour
in.	inch
kW	kilowatt
lbf	pounds of force
lbs	pounds
m	meter
mph	miles per hour
mrem	milli röentgen-equivalent-man

1. PURPOSE

This document, along with its companion document entitled *Intra-Site Operations and BOP Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1), constitutes a portion of the preclosure safety analysis (PCSA) that is described in its entirety in the safety analysis report that will be submitted to the U.S. Nuclear Regulatory Commission (NRC) as part of the license application. These documents are part of a collection of analysis reports that encompass all waste handling activities and facilities of the geologic repository operations area (GROA) from beginning of operation to the end of the preclosure period. This document describes the identification of initiating events and the development of potential event sequences that emanate from them. The categorization analysis for Intra-Site Operations (Ref. 2.4.1) uses these event sequences to perform a quantitative analysis for categorization in accordance with the definition provided by 10 CFR 63.2 (Ref. 2.3.1).

The PCSA uses probabilistic risk assessment (PRA) technology derived from both nuclear power plant and aerospace methods and applications in order to perform analyses to comply with the risk informed aspects of 10 CFR 63.111 and 10 CFR 63.112 and to be responsive to the acceptance criteria articulated in the *Yucca Mountain Review Plan, Final Report* (Ref. 2.2.55). The PCSA, however, limits the use of PRA technology to identification and development of event sequences that might lead to direct exposure of workers or onsite members of the public, radiological releases that may affect the public or workers (onsite and offsite), and criticality.

The radiological consequence assessment relies on bounding inputs with deterministic methods to obtain bounding dose estimates. These are developed using broad categories of scenarios that might cause a radiological release or direct exposure to workers and the public, both onsite and offsite. These broad categories of scenarios are characterized by conservative meteorology and dispersion parameters, conservative estimates of materials at risk, conservative source terms, conservative leak path factors, and filtration of releases via facility high efficiency particulate air (HEPA) filters when applicable. After completion of the event sequence development in the present analysis and its companion document, each Category 1 and Category 2 event sequence is conservatively matched with one of the categories of dose estimates. Note that the event sequence analyses also identify the event sequences and end states where conditions leading to criticality are in Category 1 or 2.

"Event sequence" is defined in 10 CFR 63.2, *Energy: Disposal of High-Level Radioactive Waste in Geologic Repository at Yucca Mountain, Nevada* (Ref. 2.3.1) as follows:

> Event sequence means a series of actions and/or occurrences within the natural and engineered components of a geologic repository operations area that could potentially lead to exposure of individuals to radiation. An event sequence includes one or more initiating events and associated combinations of repository system component failures, including those produced by the action or inaction of operating personnel.

> Those event sequences that are expected to occur one or more times before permanent closure of the geologic repository operations area are referred to as Category 1 event sequences. Other event sequences that have at least one chance in 10,000 of occurring before permanent closure are referred to as Category 2 event sequences.

An event sequence with a probability of occurrence before permanent closure that is less than one chance in 10,000 is categorized as Beyond Category 2. Consequence analyses are not required for these event sequences.

10 CFR 63.112, Paragraph (e) and Subparagraph (e)(6) (Ref. 2.3.1) requires analyses to identify the controls that are relied upon to limit or prevent potential event sequences or mitigate their consequences. Subparagraph (e)(6) specifically notes that the analyses should include consideration of "means to prevent and control criticality." The PCSA criticality analyses employ specialized deterministic methods, which are beyond the scope of the present analysis. However, the event sequence analyses serve as input to the PCSA criticality analyses by identifying the event sequences and end states where conditions leading to criticality are in Category 1 or 2. Some event sequence end states include the phrase "important to criticality." This indicates that the event sequence has a potential for reactivity increase that should be analyzed to determine if reactivity can exceed the upper subcriticality limit.

In order to determine the criticality potential for each waste form and associated facility and handling operations, criticality sensitivity calculations are performed. These calculations evaluate the impact on system reactivity of variations in each of the parameters important to criticality during the preclosure period, which are: waste form characteristics, reflection, interaction, neutron absorbers (fixed and soluble), geometry, and moderation. The criticality sensitivity calculations determine the sensitivity of the effective neutron multiplication factor (k_{eff}) to variations in any of these parameters as a function of the other parameters. The analysis determined the parameters that this event sequence analysis should include. Presence of moderator in association with a path to exposed fuel is required to be explicitly modeled in the event sequence analysis because such events could not be deterministically found to be incapable of exceeding the upper subcriticality limit. Other situations treated in the event sequence analysis for a similar reason are multiple U.S. Department of Energy (DOE) spent nuclear fuel (SNF) canisters in the Canister Receipt and Closure Facility (CRCF) in the same general location and presence of sufficient soluble boron in the pool in the Wet Handling Facility (WHF).

The initiating events considered in the PCSA are limited to those that constitute a hazard to a waste form while it is present in the GROA, per the definition of event sequence in 10 CFR 63.2. That is, an internal event due to a waste processing operation conducted in the GROA, or an external event that imposes a potential hazard to a waste form, or waste processing systems, or personnel (e.g., seismic or wind energy, flood waters) define initiating events that could occur within the site boundary. Such initiating events are included when developing event sequences for the PCSA. However, initiating events that are associated with conditions introduced in structures, systems, and components (SSCs) before they reach the site (e.g., drops of casks, canisters, or fuel assemblies during loading at a reactor site, improper drying, closing, or inerting at the reactor site, rail accidents during transport, tornadoes, missile strikes on a transportation cask) or during cask or canister manufacture (i.e., resulting in a reduction of containment strength) are not within the scope of the PCSA. Such potential precursors are subject to deterministic regulations (e.g., 10 CFR 50, 71 and 72) and associated quality assurance (QA) programs. As a result of compliance to such regulations, the SSCs are deemed to pose no undue risk to health and safety. Although the analyses do not address quantitative probabilities, it is clear that very conservative design criteria and QA result in very unlikely exposures to radiation.

A risk informed approach to event sequence identification is followed. SSC and personnel activities that are associated with the direct handling of high-level radioactive waste (HLW) and low-level radioactive waste (LLW) are included in the event sequence analysis because these activities are much more safety significant than the non-waste-handling activities (e.g., movement of empty aging overpacks). However, earthquake induced interactions of SSCs not involved in waste handling activities with those that are involved with waste handling activities are quantitatively analyzed elsewhere in a separate seismic event sequence analysis, and are not included herein. Other such interactions are analyzed qualitatively and are documented in a separate analysis, also not included herein.

Other boundary conditions used in the PCSA include:

- Plant operational state. Initial state of the facility is normal with each system operating within its vendor prescribed operating conditions.

- No other simultaneous initiating events. It is standard practice to not consider the occurrence of other initiating events (human-induced or naturally occurring) during the time span of an event sequence because: (a) the probability of two simultaneous initiating events within the time window is small and, (b) each initiating event will cease operations of the waste handling facility, which further reduces the conditional probability of the occurrence of a second initiating event, given the first has occurred.

- Component failure modes. The failure mode of a structure, system, or component (SSC) corresponds to that required to make the initiating or pivotal event occur.

- Fundamental to the basis for the use of industry-wide reliability parameters within the PCSA, such as failure rates, is the use of SSCs within the GROA that conform to NRC accepted consensus codes and standards, and other regulatory guidance.

- Intentional malevolent acts, such as sabotage and other security threats, are not addressed in this analysis

The scope of the present analysis includes the following activities:

- Site transportation activities

  - Security and radiological inspections

  - Movement of transportation casks from the GROA boundary to buffer areas and to waste handling facilities

  - Transfer of aging overpacks and horizontal casks between the Aging Facility and waste handling facilities
  - Transfer of aging overpacks and horizontal casks among waste handling facilities.
- Aging Facility activities
  - Positioning of aging overpacks containing vertical canisters
  - Loading of horizontal canisters in stationary horizontal aging modules (HAMs)
  - Canister aging and monitoring
  - Retrieval of aged canisters.
- Low-Level Radioactive Waste (LLW) management
  - Onsite loading at satellite collection areas
  - Onsite transfer between waste handling facility satellite collection areas and the Low-Level Waste Facility (LLWF)
  - Unloading at LLWF
  - Storage at LLWF
  - Disposal offsite (offsite vendor collects, processes, and disposes of LLW).
- Emergency Diesel Generator Facility (EDGF)
  - The EDGF provides emergency power in the event offsite electrical power is lost.
- Balance of Plant (BOP)
  - The support systems for the GROA operations (i.e., site roadways and railways)
  - Non-nuclear facilities, such as the craft shop, equipment yard, and Heavy Equipment Maintenance Facility.

As part of the calculation, this analysis includes: a process flow diagram (PFD), a master logic diagram (MLD), a hazard and operability evaluation (HAZOP), event sequence diagrams (ESDs), and event trees. Initiating events identified or considered in this analysis include internal events (i.e., events that are initiated within the Intra-Site Operations analytical boundary), as well as external events (i.e., events that are initiated from outside the Intra-Site Operations analytical boundary). Note that external events identified are analyzed and documented separately.

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Some of the design inputs to this analysis are from output designated QA: NA. Documentation that these sources are suitable for their intended uses is provided in Section 4.1.

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ENG.20080107.0002; ENG.20080107.0016; ENG.20080107.0017; ENG.20080131.0006.

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2.3 DESIGN CONSTRAINTS

2.3.1 10 CFR 63. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada.

2.3.2 10 CFR 71. 2007. Energy: Packaging and Transportation of Radioactive Material. ACC: MOL.20070829.0114.

2.4 DESIGN OUTPUTS

This document may be used as input for other calculations, analyses, and/or other Yucca Mountain Project documents, including the license application. It is particularly used as input to the following analysis:

2.4.1 BSC 2008. *Intra-Site Operations and BOP Reliability and Event Sequence Categorization Analysis.* 000-PSA-MGR0-00900-000-00A. Las Vegas, Nevada: Bechtel SAIC Company.

3. ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

None used.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

None used.

4. METHODOLOGY

4.1 QUALITY ASSURANCE

This analysis is prepared in accordance with the procedures *Calculations and Analyses* (Ref. 2.1.1) and *Preclosure Safety Analyses Process* (Ref. 2.1.4). Therefore, the approved version is designated as "QA: QA." This analysis addresses the applicable criteria in Section 7 of the *Project Design Criteria Document* (Ref. 2.2.40).

Information used in the development of this analysis is obtained from many sources, such as mechanical handling system block flow diagrams and engineering drawings. In general, input designated QA:QA was used. However, some engineering drawings are designated QA:NA. The suitability of these diagrams for the intended use here is justified as follows:

Documentation of suitability for intended use of QA:NA drawings. Engineering drawings are treated the same whether they are designated QA:NA or QA:QA. They are prepared using the QA:QA procedure *Engineering Drawings* (Ref. 2.1.2). This means that they are checked by an independent checker and reviewed for constructability and coordination before review and approval by the Engineering Group Supervisor and the Discipline Engineering Manager (Ref. 2.1.4, Attachment 1). The check, review, and approval process provides assurance that these drawings accurately document the design and operational philosophy of the facility.

Documentation of suitability for intended use of other inputs. Some of the descriptive material in Attachments A and B that is related to the waste forms is taken from the supplier documents that are cited there. This information is presented to give the reader a basic understanding of the processes involved. The supplier documents cited provide suitable descriptive information on waste package closure equipment that has been designed specifically for repository use.

4.2 USE OF SOFTWARE

Visio Professional 2003 (11.3216.8122) and Word 2003 (11.8106.8122), which are both Microsoft programs, are used in this analysis for the generation of graphics and word-processing. This software as used in this analysis is classified as Level 2 software usage as defined in *Software Management* (Ref. 2.1.3), and is listed in *Repository Project Management Automation Plan* ((Ref. 2.1.5), Table 10-1 and Figure 3-2). The visual information is verified by inspection as a part of the preparation, checking, and review processes.

The computer code, SAPHIRE, Version 7.26 (Software Tracking Number: 10325-7.27-00; (Refs. 2.2.57; 2.2.58), is used in this analysis but only to develop event trees, which are graphical representations of event sequences suitable for quantification. The visual information displayed is verified by visual inspection as a part of the preparation, checking, and review processes. No other computations are performed with this software. Therefore, as used in this analysis, this software is classified as Level 2 software usage as defined in *Software Management* (Ref. 2.1.3). The listed software is installed on a personal computer and operated under one of more of the following:

- Microsoft Windows 2000 Professional
- Windows XP
- Windows XP running inside a VMware virtual machine with VMware Player.

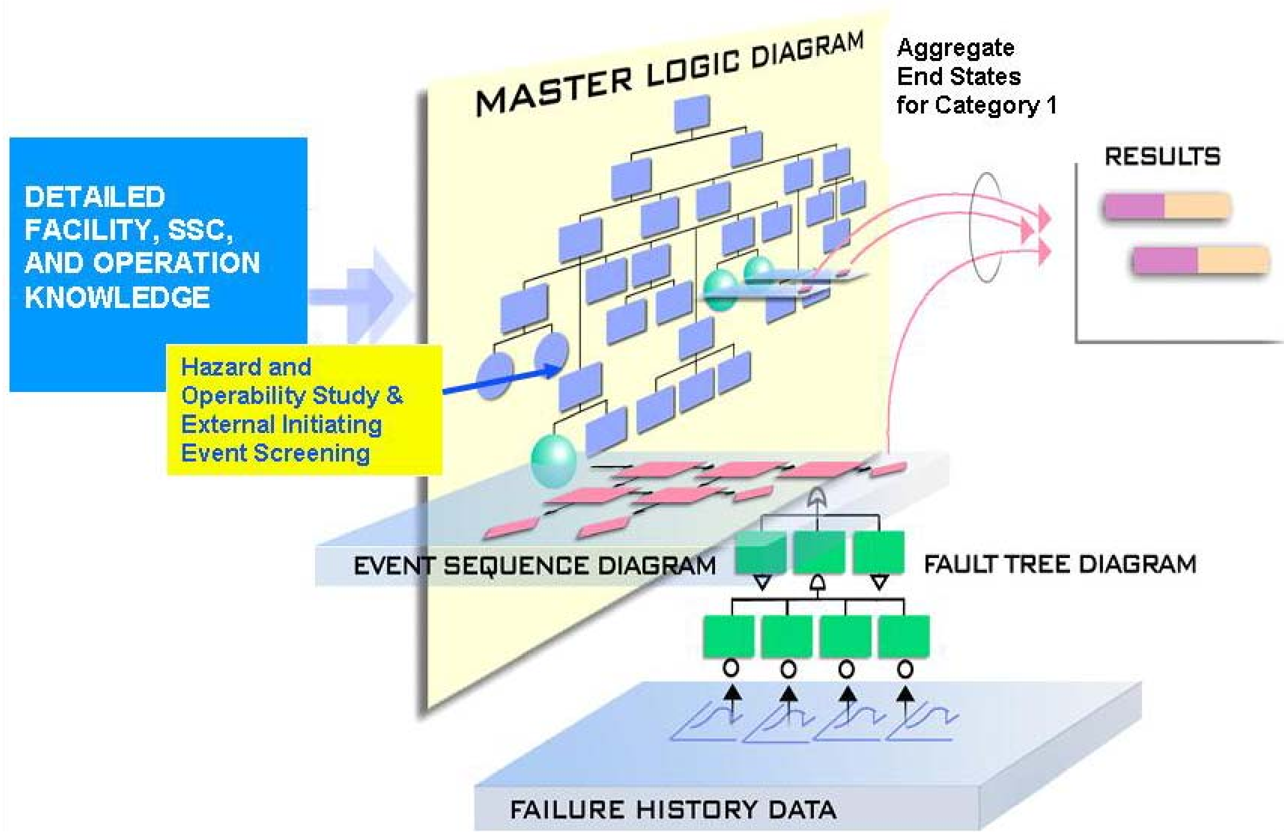
4.3 APPROACH AND ANALYSIS METHODS

This section presents the PCSA approach and analysis methods in the context of overall repository operations. As such, it includes a discussion of operations that may not apply directly to Intra-Site Operations. Specific features of Intra-Site Operations are not discussed until Section 6, where the methods described here are applied. The PCSA uses the technology of PRA as described in references such as American Society of Mechanical Engineers RA-S-2002 (Ref. 2.2.3). The PRA answers three questions:

1. What can go wrong?
2. What are the consequences?
3. How likely is it?

PRA may be thought of as an investigation into the responses of a system to perturbations or deviations from its normal operation or environment. In a very real sense, the PCSA is a simulation of how a system acts when something goes wrong. The relationship of the methods of this PCSA is depicted in Figure 1. Phrases in ***bold italics*** in this section indicate methods and ideas depicted in Figure 1. Phrases in normal italics indicate key concepts.

Identification of initiating events answers part of the question "What can go wrong?" The PCSA uses two methods for identifying initiating events: the MLD and the hazard and operability (HAZOP) technique, which is an accepted method of identifying and evaluating industrial hazards.



Source: Modified from *Master Logic Diagram* (Ref. 2.2.59).

Figure 1. Event Sequence Analysis Process

The basis of the PCSA is the development of event sequences. Simply stated, event sequences are thought of as strings of events that begin at initiating events and eventually lead to potential consequences. Between initiating events and end states, within a scenario, are *pivotal events* that determine whether and how an initiating event propagates to an end state. An event sequence completes the answer to the question "What can go wrong?," and is defined by one or more initiating events, one or more pivotal events, and one end state. In the PCSA, event sequences end in ***end states***. In this analysis, the end states of interest are: Direct Exposure, Degraded or Loss of Shielding; Radionuclide Release, Filtered; Radionuclide Release, Unfiltered; Radionuclide Release, Filtered, Important to Criticality; Radionuclide Release, Unfiltered, Important to Criticality; Important to Criticality; or "OK" to indicate none of the above. The PCSA uses ***ESDs, event trees,*** and ***fault trees*** to diagram event sequences.

The answer to the question "What are the consequences?" requires consideration of radiation exposure and the potential for criticality for Category 1 and Category 2 event sequences. Consideration of the consequences of event sequences that are Beyond Category 2 is not required. Radiation doses to individuals from direct exposure and radionuclide release are addressed in a companion consequence analysis by modeling the effects of bounding event sequences related to the various waste forms and the facilities that handle them.

The radiological consequence analysis develops a set of bounding consequences. Each bounding consequence represents a group of like event sequences. The group (or bin) is based on such factors as waste form and like factors in an event sequence such as availability of HEPA filtration, occurrence in water or air, and surrounding material such as transportation cask and waste package. Each event sequence is mapped to one of the bounding consequences, for which conservative doses have been calculated.

Criticality analyses are performed to ensure that event sequences terminating in ***end states*** that are important to criticality would not result in a criticality. In order to determine the criticality potential for each waste form and associated facility and handling operations, criticality sensitivity calculations are performed. These calculations evaluate the impact on system reactivity of variations in each of the parameters important to criticality during the preclosure period, which are: waste form characteristics, reflection, interaction, neutron absorbers (fixed and soluble), geometry, and moderation. The criticality sensitivity calculations determine the sensitivity of the effective neutron multiplication factor to variations in any of these parameters as a function of the other parameters. The deterministic sensitivity analysis and the event sequence analysis, which includes moderator intrusion, is sufficient to cover all repository configurations that are important to criticality.

The estimation of event sequence frequencies follows the development of event sequences, and answers the question "How likely is it?" The PCSA uses ***failure history*** records, for example, *Nonelectronic Parts Reliability Data 1995* (Ref. 2.2.47) and the *Nuclear Computerized Library for Assessing Reactor Reliability* (Ref. 2.2.49); structural reliability analysis, thermal stress analysis, and engineering and scientific knowledge about the design, as the basis for estimation of probabilities and frequencies. These sources coupled with the techniques of probability and statistics, for example, *Handbook of Parameter Estimation for Probabilistic Risk Assessment*. NUREG/CR-6823 (Ref. 2.2.4) are used to estimate frequencies of initiating events and event sequences, and the conditional probabilities of pivotal events.

Pivotal events are characterized by *conditional probabilities* because their values rely on the conditions set by previous events in an event sequence. For example, the failure of electrical/electronic equipment depends on the temperature at which it operates. Therefore, if a previous event in a scenario is a failure of a cooling system, then the probability of the electronic equipment failure would depend on the operation or not of the cooling system. The frequency of occurrence of an event sequence is the product of the frequency of its initiating event and the conditional probabilities of pivotal events. The level of detail of initiating events is such that they often are at a level of equipment assembly for which industry-wide reliability information does not exist. Fault trees are used to disaggregate or decompose the equipment (such as a crane) to SSCs for which reliability information is available. The PCSA, therefore, relies on ESDs and fault trees to represent the facility, equipment, and personnel responses to an initiating event.

The notion of the PCSA as a system simulation is important in that any simulation or model is an approximate representation of reality. Approximations lead to uncertainties regarding the frequencies of event sequences. The event sequence quantification quantifies the uncertainties regarding the frequencies of event sequences using Bayesian and Monte Carlo techniques. Figure 1 illustrates the results as horizontal bars in order to depict the uncertainties which give rise to potential ranges of results.

As required by the performance objectives for the GROA through permanent closure (10 CFR 63.111 (Ref. 2.3.1)), each event sequence is categorized based on its frequency. Therefore, the focus of this analysis is to:

1. Identify potential internal initiating events, and external events relevant to this analysis, as described in Section 4.3.1.

2. Construct ESDs and event trees to describe the event sequences associated with the initiating events.

The activities required to accomplish these two objectives are illustrated in Figure 2.

Event sequences are developed based upon a description of GROA operations as depicted in the PFD of Section 6 and the equipment and operations descriptions of Attachments A and B. Accordingly, an event sequence, represented in an ESD, is particular to a given operational activity in a given operational area.

A MLD, supplemented by references describing operations, incidents and failures in similar facilities and operations, is the principal method for the identification of internal initiating events.

The initiating events identified in the MLD are grouped into ESDs according to whether they elicit a similar response of SSCs and operations personnel. Index numbers allow tracing of the initiating events to the ESDs in Attachment F. The ESDs show small circles surrounding (i.e., feeding into) a larger circle. Each small circle is a grouping of initiating events (from the MLD) that has not only the same SSCs and operations response, but also the same pivotal event conditional probabilities. The larger circle is termed an aggregated initiating event[1]. Within a given ESD and for a given waste form configuration, it is appropriate for purposes of categorization to combine (add) event sequences that elicit the same combination of failure and success of pivotal events. Categorization, therefore, is based on each event sequence that emanates from the larger circle for each waste form.

[1] This is not to be confused with the aggregation of doses for normal operations and Category 1 event sequences described in 10 CFR 63.111a (Ref. 2.3.1).

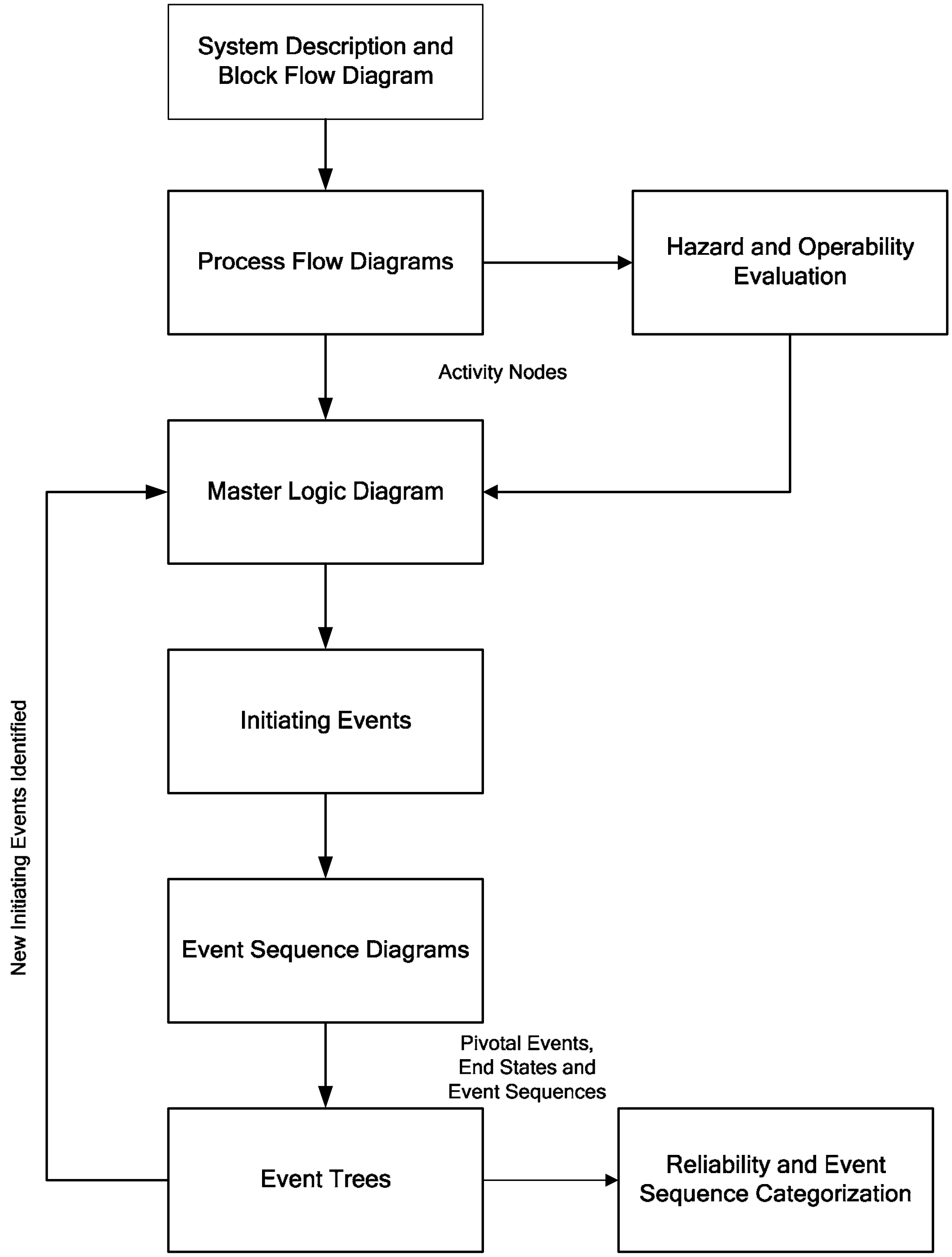


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Figure 2. Preclosure Safety Analysis Process

A HAZOP type of process is used to supplement the MLD with respect to identification of initiating events. A HAZOP is a common method in the chemical process industry that is typically used for a comprehensive identification of operational mishaps, failures, and sequences of events (hardware and human) that might lead to an undesired event. It is used in a more limited way in the PCSA because the PCSA uses event sequence diagrams and fault trees (consistent with PRA methodology and described above) to identify the sequences of events, operational mishaps, and failures. In the PCSA, a HAZOP was performed solely as a supplementary method to identify initiating events. If a HAZOP identified an initiating event that was not covered by the MLD, the initiating event was added. Typically, the HAZOP addressed deviations in more detail than the MLD identified initiating events. The initiating events identified by the MLD are more appropriate for the PRA methodology used in the PCSA than are the deviations considered in the HAZOP. Deviations identified in the HAZOP were often already identified on the MLD; therefore, initiating events on the MLD, as indicated by index numbers, were matched with each HAZOP deviation. When a match could not be made, an additional initiating event was added to the MLD to cover it. The MLD, then, constituted the means to diagram the comprehensive set of initiating events found from both the MLD and HAZOP. Table 7 gives an example of the coordination of the MLD and HAZOP. The complete MLD is provided in Attachment D, and the complete HAZOP results are provided in Attachment E.

4.3.1 Initiating Event Development

The identification of initiating events is accomplished through a series of logically related activities that begins with understanding the facility and the operations and processes that occur within the facility, including the capabilities of the facility to protect against external hazards and challenges. The process, described herein, concludes with identification of initiating events categorized at a level that is conducive to subsequent reliability analysis using fault trees in combination with historical records to estimate frequencies of occurrence. The process begins with a review of facility systems, processes, and operations. From this information a simplified PFD, as described in Section 4.3.1.1, is developed, which clearly delineates the process and sequence of operations to be considered within the analysis. The analyst then uses the PFD to guide development of an MLD. The MLD as a tool for initiating event development is described in the *PRA Procedures Guide, A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants* (Ref. 2.2.54, Section 3.4.2.2).

Development of an MLD, as described in Section 4.3.1.2, is accomplished by deriving specific failures from a generalized statement of the undesired state. There are a number of ways that the preclosure safety analyst develops an understanding of how a system can fail. One way is to review engineering drawings and other design documents, including mechanical handling block flow diagrams, mechanical engineering envelope diagrams, mechanical handling design reports, building layout drawings, process and instrumentation diagrams, ventilation and instrumentation diagrams, electrical diagrams, and fire hazard analyses. The analyst may review an engineering document simply as a user of the document. However, review in the context of the engineering design review process is another important way by which the analyst develops an understanding of how equipment could fail. The formal engineering design review process involves using preclosure safety analysts as reviewers. As a design reviewer, the analyst considers how the equipment could fail and often suggests design changes to improve safety. As noted in Attachment B, the description of operations in Section 6.1 and Attachment B emerged from a cooperative effort involving PCSA personnel (facility leads, human reliability analysts, and equipment reliability analysts), nuclear operations personnel, and other engineering personnel.

Thus, the MLD is developed in a thoroughly integrated environment in which failure modes are identified by the preclosure safety analyst and discussed with equipment and facility designers and operations personnel.

Another way that the preclosure safety analyst develops an understanding of how event sequences may be initiated is by reviewing descriptions of operations and accident initiators for similar facilities, equipment, and operations elsewhere. The following illustrates the kinds of materials that have been examined:

- *Fires in or at Industrial Chemical, Hazardous Chemical and Plastic Manufacturing Facilities, 1988-1997 Unallocated Annual Averages and Narratives*. (Ref. 2.2.1)

- *Probabilistic Risk Assessment (PRA) of Bolted Storage Casks, Updated Quantification and Analysis Report* (Ref. 2.2.45).

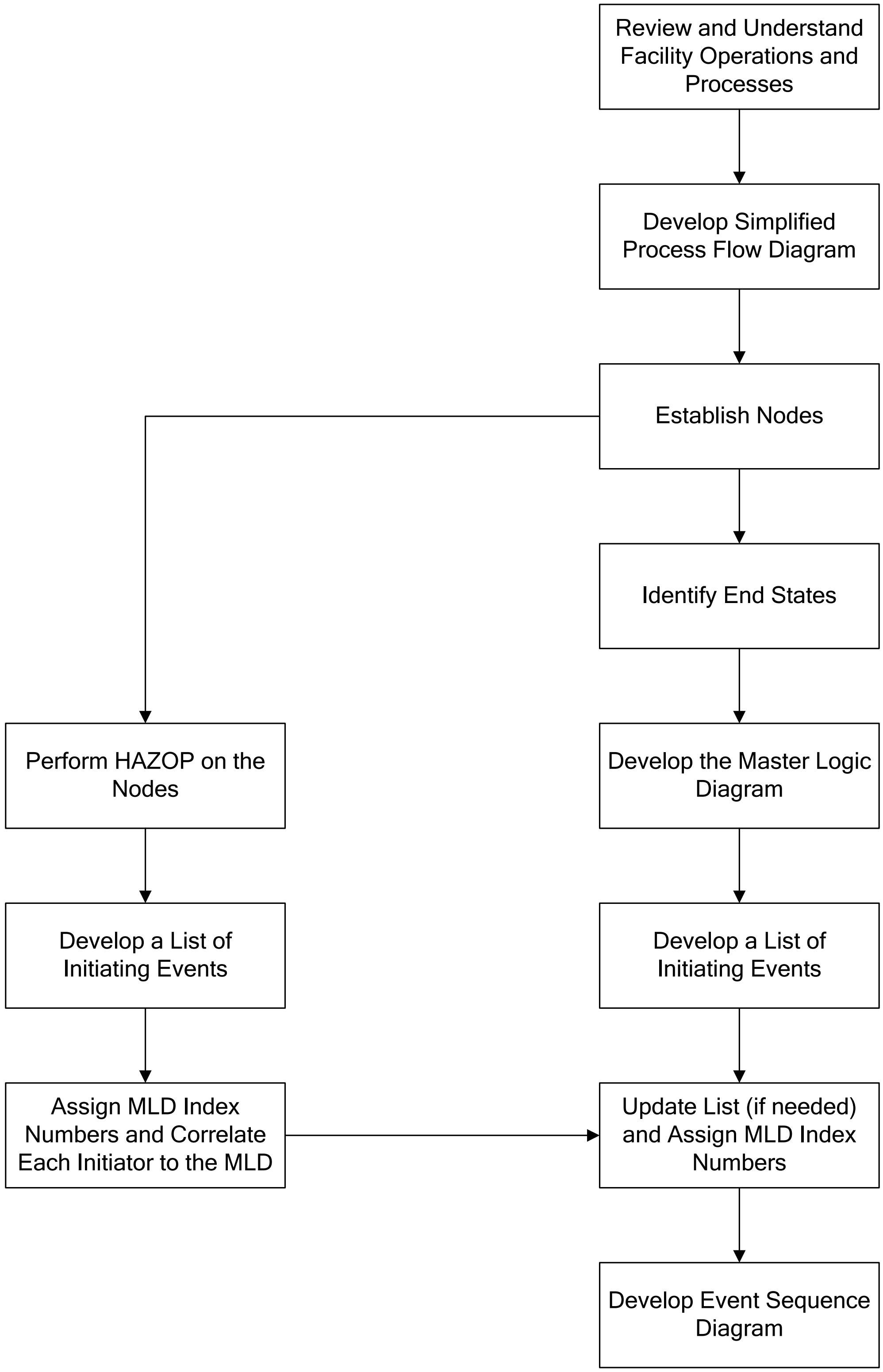
- *Safety Analysis Report, Idaho Spent Fuel Facility*. (Ref. 2.2.50)

- *A Survey of Crane Operating Experience at U.S. Nuclear Power Plants from 1968 through 2002.* (Ref. 2.2.51)

- *Control of Heavy Loads at Nuclear Power Plants.* (Ref. 2.2.53).

The MLD is cross-checked to the HAZOP, which is performed on the facility processes and operations and based on nodes, that is, specifically defined portions of site transportation and aging activities, established in the PFD. Although the repository is in some ways to be the first of its kind, the operations are based on established technologies: transportation cask movement by truck and rail, crane transfers, rail-based trolleys, air-based conveyances, robotic welding, and the like. The team assembled for the HAZOP (and available on call when questions arose) has experience with such technologies and is well equipped to perform a HAZOP. As has already been noted, the MLD is modified to include any initiators that are identified in the HAZOP but are not already included in the MLD. The entire process, depicted in Figure 3, is iterative in nature with insights from succeeding steps often feeding back to predecessors ensuring a comprehensive and complete listing of initiating events.

The top-down MLD and the bottom-up HAZOP provide a diversity of viewpoints that adds confidence that no important initiating events are omitted. The HAZOP process focuses on identifying potential initiators that are depicted in the lower levels of the MLD. The following subsections further describe the way the PFD, MLD, and HAZOP are used for defining initiating events, and the methodology for grouping of initiating events.



Source: Original

Figure 3. Initiating Event Identification

Two key elements of the PCSA methodology are establishing and maintaining traceability among the PFD, MLD, and HAZOP. A PFD is broken down into nodes that group operational activities within a facility such as receipt, preparation, transfer, etc. Individual blocks within the nodes are used to *identify* specific processes and operations that are evaluated with both a MLD and HAZOP to identify potential initiators. Following this *identification* step, initiating events are then assigned a specific MLD index number (e.g., EX-501) in the example HAZOP table (refer to Table 6). This MLD index number correlates the initiator on the HAZOP to a corresponding initiator on the MLD. Any unique initiator index number can be traced back to the specific "node of origin" in its associated PFD in order to pinpoint the basis for a given event. This index number is then carried forward in developing the ESD, providing the traceability that ties MLD and HAZOP initiators to the initiators on the ESD. Figure 3 and Table 10 in Section 6 illustrate the above methodology as applied to the actual analysis.

4.3.1.1 Process Flow Diagram

A PFD is a simplified representation of a facility's processes and operations. It graphically represents information derived from the facility mechanical handling system block flow diagram and indicates how the mechanical equipment is to be operated. It is simplified because only information relevant to event sequences (potentially leading to dose or criticality) is depicted. In accordance with Figure 3 and as shown in the example PFD (Figure 8), the general flow and relationships of the major operations and related systems that comprise a specific process are aggregated into nodes (refer also to the example PFD, Figure 8). These nodes represent groups of sequential steps in a process. The boundaries of each node are subjectively chosen to enable the analyst to easily keep in mind the operations within the node while considering what could go wrong within the node.

For this analysis, the analyst defines nodes in the PFD to identify those activities or processes that are evaluated for the potential to initiate an event. The individual blocks within nodes are used to identify processes and operations that are further evaluated in the MLD (described in Section 4.3.1.2). A detailed description of the nodes used for this analysis is provided in Section 6.1.

4.3.1.2 Master Logic Diagram

The MLD technique is a structured, systematic process to develop a set of initiating events for a system and is described in *PRA Procedures Guide, A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants* (Ref. 2.2.54, Section 3.4.2.2). The method is adapted to the waste repository risk-informed PCSA. As a "top-down" analysis, the MLD starts with a top event, which represents a generalized undesired state. For this analysis, the top event includes direct exposure to radiation and exposure as result of a release of radioactive material. The basic question answered by the MLD is "How can the top event occur?" Each successively lower level in the MLD hierarchy divides the identified ways in which the top event can occur with the aim of eventually identifying specific initiating events that may cause the top event. In an MLD, the initiating events are shown at the next-to-lowest level. The lowest level provides examples of the initiating event.

For example, initiating events may be defined at either a categorical level (e.g., "crane drops load") that can be attributed to a specific crane (e.g., the 300-ton cask handling crane), down to a very specific level, such as a subsystem or component failure (e.g., "crane cable breaks") or a human failure event (e.g., "operator opens cask grapple").

A generalized logic structure for the PCSA MLD is presented below, and in Figure 4. In the development of a specific MLD (demonstrated per the example facility MLD shown in Section 4.3.4.2, Figures 9 and 10), this structure is generally followed for each branch until initiators are identified. Once initiators are identified, the process is terminated in that branch.

- Level 0: The entry point into the MLD is an expression of the undesired condition for a given facility. Level 0 is the top event of the MLD. In the MLD framework shown in Figure 4, the top event is expressed as "Unplanned exposure of individuals to radiation or radioactive materials due to operations in the facility." This top event includes direct exposure to radiation sources, or exposure as result of release of airborne radioactive material or conditions that could lead to a criticality. The basic question answered by the MLD through the decomposition is "How can the top event occur?"

- Level 1: This level differentiates between internal events and external events. The external event development at this level would be for initiating events that affect the entire facility (e.g., extreme winds). Common cause initiating events that affect less than the entire facility are incorporated at the appropriate level in the MLD.

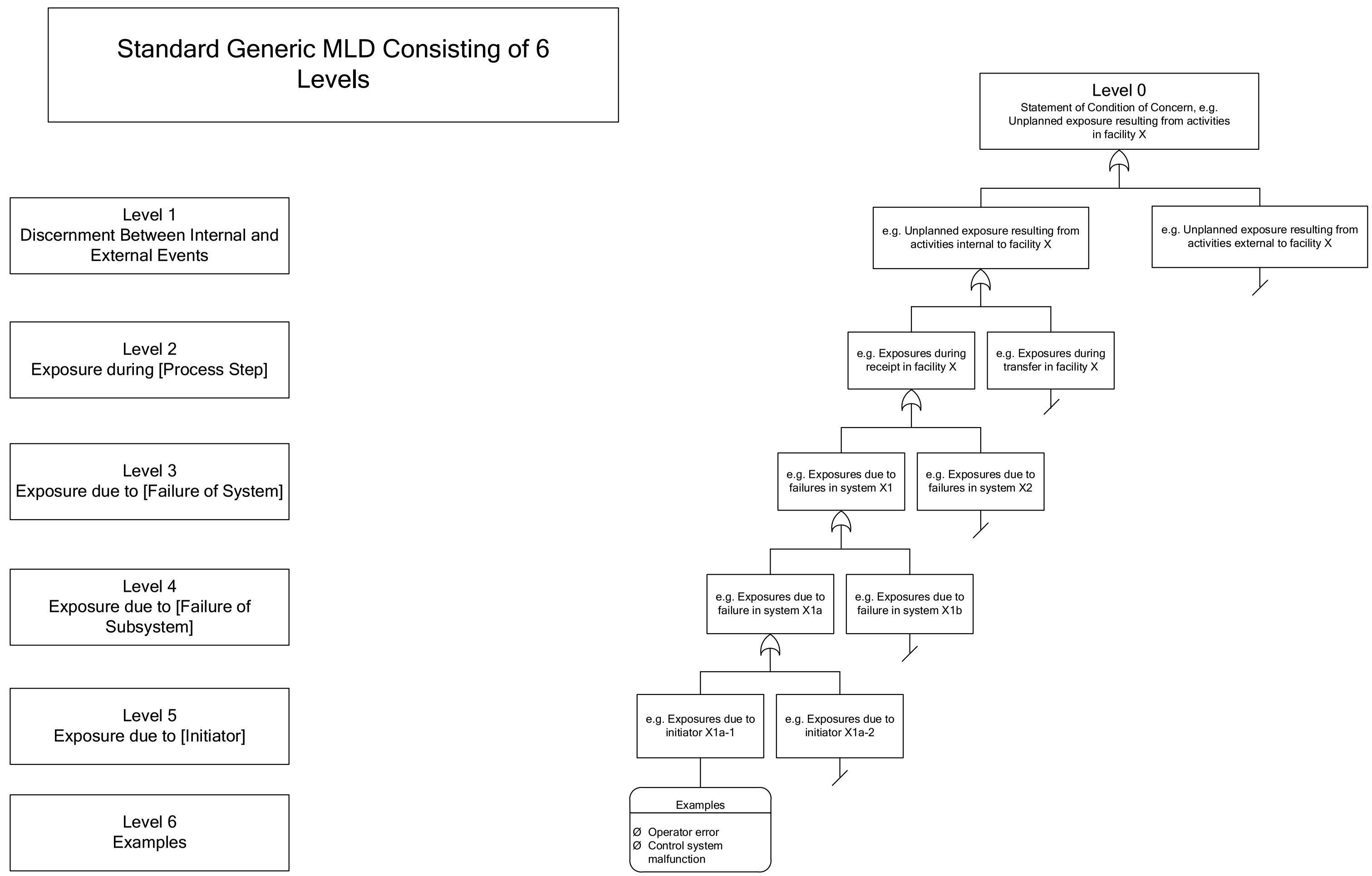
- Level 2: This level identifies the operational area or process step where the initiating events can occur.

- Level 3: This level also identifies the functional system (or subsystem) failure for the operational areas identified in Level 2.

- Level 4: This level also identifies the functional system or subsystem failures in somewhat more detail.

- Level 5: This level specifies the initiating event, usually in terms of equipment or component failure modes, that can result in the failure of subsystems or systems. In the MLD used herein to describe typical (example) Intra-Site Operations, each of the initiating event boxes is given an initiating event identifier (e.g., EX-503) which carries over to the corresponding ESD or ESDs. Level 5 is considered the appropriate grouping of initiating events for purposes of subsequent fault tree analysis.

- Level 6: This level provides a short list of examples (one or two) to help elucidate the interpretation of the Level 5 initiating event group. Consistent with Figure 1, each Level 5 initiating event is modeled in detail by a combination of fault trees and/or direct use of empirical information. Level 6 entries, therefore, are found as failure modes in fault trees.



Source: Original

Figure 4. Master Logic Diagram Framework

4.3.1.3 Hazard and Operability Evaluation

As previously discussed, the MLD and HAZOP are strongly interrelated. Development of an MLD, as described in Section 4.3.1, is accomplished by deriving specific failures from a generalized statement of the undesired state. The MLD is then supplemented by performing a HAZOP of the facility processes and operations. Any additional initiators identified by the HAZOP are added to the MLD as appropriate. The entire process is iterative in nature with insights from succeeding steps often feeding back to predecessors ensuring a comprehensive and complete listing of initiating events.

The HAZOP process focuses on identifying potential initiators that are depicted in the lower levels of the MLD. Initiating events are assigned a specific MLD index number (e.g., EX-501) in the HAZOP table. The MLD index number correlates the initiator associated with the HAZOP with a corresponding initiator on the MLD. This correlation is reflected in Sections 4.3.4.2 and 4.3.4.3, and Tables 6 and 7.

As discussed in Section 4.3.1, the HAZOP is conducted to supplement the MLD results. The HAZOP is a "bottom-up" analysis used to supplement the "top-down" approach of the MLD (Ref. 2.2.2). It is a systematic study of the operations in each facility during the preclosure phase. The operations are divided into nodes, as shown in the example PFD (Section 4.3.1.1 and Figure 8). The purpose of defining nodes is to break down the overall facility operations into small pieces that can be examined in detail. The analysis of each node is completed before moving on to another node. The intended function of each node is first defined. The "intention" is a statement of what the node is supposed to accomplish as part of the overall operation. For example, Node 3 of the PFD for the example facility in Section 4.3.4.1, Figure 8 is entitled "Move TC [transportation cask] to Railcar Buffer Area."

A "deviation" is any out-of-tolerance variation from the normal values of parameters specified for the intention. Each potential variation may be identified in terms of one of the seven standard guidewords shown in Table 1.

Table 1. Standard Hazard and Operability Guidewords and Meanings

Guidewords	Meaning	Comments
No	Negation of the Design Intention	No part of the design intention is achieved, or nothing else occurs
Less (Lower)	Quantitative Decrease	Refers to quantities less than required for success of the intention
More (Higher)	Quantitative Increase	Refers to quantities greater than required for success of the intention
Part Of	Qualitative Decrease	Only some of the intentions are achieved; some are not
As Well As	Qualitative Increase	All of the design and operating intentions are achieved together with some additional activity
Reverse	Logical Opposite of the Intention	Examples are reverse flow or chemical reaction or movement of container in wrong direction
Other Than	Complete Substitution	No part of the original intention is achieved. Something quite different happens

Source: Modified from *Guidelines for Hazard Evaluation Procedures* (Ref. 2.2.2, Table 6.14)

Each potential initiating event is first identified as a specific "deviation" from the well-defined, intended functions and behavior of each operational node. Deviations that have the potential for resulting in a radiological consequence are identified as a potential initiating event, i.e., an initiating event that may result in an event sequence per the definition in 10 CFR 63.2 (Ref. 2.3.1).

The HAZOP process ensures that potential hazards are considered in the evaluation through a formalized application of "guidewords" that represent a set of potential deviations from normal (i.e., intended) operations. The HAZOP is performed by a multi-disciplinary team that is well-versed in the design, operations, safety and reliability issues, as well as human factors and human reliability. An experienced team leader leads, stimulates, and focuses the analysis to ensure that the HAZOP is conducted efficiently and productively.

The processes and definitions of terms for conducting a HAZOP have been widely applied in chemical and nuclear processing facilities for decades. The terminology commonly used in a HAZOP is presented in Table 2. The application to the repository PCSA applies the HAZOP process with modifications to fit the nature of the facilities, operations, and level of information on design and operations. The modifications include the selection of parameters such as drop, transfer, transport, lift, speed and direction instead of pressure, flow, composition and phase change that are usually associated with chemical processes.

Table 2. Common Hazard and Operability Terminology

Term	Definition
STUDY NODES (or Process Sections)	Sections of equipment with definite boundaries (e.g., a line between two vessels) within which process parameters are investigated for deviations. The locations (on piping and instrumentation drawings, diagrams, and procedures) at which the process parameters are investigated for deviations.
OPERATING STEPS	Discrete actions in a batch process or a procedure analyzed by a HAZOP team. Steps may be manual, automatic, or software-implemented actions. The deviations applied to each process step are different than deviations that may be defined for a continuous process.
INTENTION	Defines how the plant or process node is expected to operate in the absence of deviations at the study nodes. This can take a number of forms and can either be descriptive or diagrammatic (e.g., flow sheets, line diagrams, piping and instrumentation diagrams).
GUIDEWORDS	Simple words which are used to qualify or quantify the intention in order to guide and stimulate the brainstorming process and so discover deviations. The guidewords shown in Table 1 are the ones most often used in a HAZOP. However, the list may be made more application-specific to guide the team more quickly to the areas where prior operations or experience have identified problems. Each guideword is applied to the process variables at the point in the plant (study node) which is being examined.
PROCESS PARAMETER	Physical or chemical property associated with the process. This includes general terms like mixing, concentration and specific items such as temperature, pressure, flow, and phase for processes, or general terms like lift, relocate, and specific terms like lift height and speed of movement for handling of containers.
DEVIATIONS	Departures from the intention that are discovered by systematically applying the guidewords to process parameters (e.g., "more pressure", "too high lift height"). This provides a list of potential deviations for the team to consider for each node. Teams may supplement the list of deviations with ad hoc items.

Table 2. Common Hazard and Operability Terminology (Continued)

Term	Definition
CAUSES	Reasons why deviations might occur. Once a deviation has been shown to have a credible cause, it can be treated as a meaningful deviation. These causes can be hardware failures, human failure events, an unanticipated process state (e.g., change of composition, or introduction of an over-weight or over-sized container into the handling facility), external disruptions (e.g., loss of power), etc.
CONSEQUENCES	Results of the deviations should they occur (e.g., release of radioactive or toxic materials, exposure to radiation). Normally, the team assumes that active protection systems or safeguards fail to work. Consequences that are unrelated to the study objective are not considered. Minor consequences, relative to the study objective, are dropped.
SAFEGUARDS	Engineering or administrative controls that are used to prevent the causes or mitigate the consequences of deviations (e.g., alarms, interlocks, procedures). Safeguards are not credited when defining consequences of a deviation, but are addressed in evaluating the need for actions or recommendations.
ACTIONS (or Recommendations, Comments)	Suggestions for design or procedural changes (i.e., to provide new or additional safeguards) or areas for further study (e.g., analyses of reliability of active or passive systems credited as safeguards, human reliability analysis, or radiological consequence analyses).

Source: Modified from *Guidelines for Hazard Evaluation Procedures* (Ref. 2.2.2, Table 6.1.3)

This PCSA follows the HAZOP guidance provided in the American Institute of Chemical Engineers *Guidelines for Hazard Evaluation Procedures* (Ref. 2.2.2). The *Yucca Mountain Review Plan, Final Report* (Ref. 2.2.55, Section 2.1.1.3.5), lists the American Institute of Chemical Engineers guidelines as a principal reference for performing a hazards evaluation. Consistent with the MLD, this HAZOP is focused on potential radiological hazards for the preclosure period that could lead to event sequences.

The HAZOP applies seven guidewords that, in principal, cover possible deviations that can occur in a given node of a given process. Table 1 lists the seven guidewords that are crafted to ensure that potential deviations are addressed in a systematic process. In practice, the application of the guidewords requires the knowledge and imagination of the HAZOP team to ensure that the set of deviations and hazards identified is reasonably complete. In addition to the specific definition shown in Table 1, the guideword "other than" is applied as a kind of miscellaneous category to capture deviations not identified by the other six standard guidewords.

Each deviation is examined for potential consequences, as shown in Table 3. Each deviation that could result in an undesired effect is marked as a potential initiating event, even if safeguards are present in the design to prevent the deviation or to mitigate the consequences. Each deviation is examined to identify its potential causes. The HAZOP team may note and record the design or operational procedure that may be used to prevent or mitigate the consequences of an event. This information may be used, if needed, later in the event sequence analysis.

Table 3. Examples of Deviations for a Chemical Process

Guidewords	Intention (Parameter)	Deviation
No	Flow	No Flow
More	Pressure	High Pressure
As Well As	One Phase	Two Phase
Other Than	Operation	Maintenance

Source: *Guidelines for Hazard Evaluation Procedures* (Ref. 2.2.2, p. 132)

For many process parameters, meaningful deviations are generated for each guideword. Moreover, it is not unusual to have more than one deviation from the application of one guideword.

After the HAZOP is completed, the results are compared with the MLD to verify the accuracy and completeness of the MLD. Deviations are matched one by one to the MLD. Initiating events were added to the MLD to encompass all deviations not previously included in the MLD.

4.3.2 Internal Event Sequence Development

An event sequence is a series of actions and/or occurrences within the natural and engineered components of a GROA that could potentially lead to exposure of individuals to radiation. An event sequence begins with an initiating event and unfolds as a combination of failures and successes of intermediate events, called "pivotal events." An event sequence terminates with an end state that identifies the type of radiation exposure or potential criticality, if any, resulting from the event sequence.

Event sequences are developed with the following objectives:

1. Provide an accurate description of event sequences that could occur before permanent closure

2. Identify the end state associated with each event sequence to enable the subsequent evaluation of radiological consequences

3. Identify the systems, structures, and components (SSCs), the associated safety functions, and the procedural safety controls that are relied upon to control the frequency of occurrence of event sequences or to mitigate the consequences.

The first two objectives are addressed in this analysis. The third objective is addressed in *Intra-Site Operations and BOP Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1).

It is important to recognize that the ESDs are used to identify potential future event sequences before operation begins. An event may or may not occur during the lifetime of the preclosure period; therefore, a probabilistic framework is important. The uncertainty in occurrence is represented by probabilities or frequencies of occurrence, which are developed and documented in the *Intra-Site Operations and BOP Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1) document. These probabilities or frequencies, themselves, are uncertain and such uncertainty is typically represented by a probability distribution, also again developed and documented in the *Intra-Site Operations and BOP Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1).

4.3.2.1 Event Sequence Diagrams

An ESD is a block flow diagram that displays the combinations of pivotal events that reflect the responses of SSCs and personnel after an initiating event or group of initiating events (Ref. 2.2.54, Section 3.4.3.2). To construct an ESD, the analyst begins with the initiating events that were identified by the MLD and HAZOP and then, in effect, answers the question "What can happen next?" until an end state is reached. ESDs are designed to logically depict the progression of event sequences from the initiating event up to and including the end state. ESDs identify the key safety functions necessary to reach an end state after the initiating event as well as the associated structure, system, or component responses. Although operator actions are not shown explicitly on the ESDs in this analysis, human failure events are implicit in some of the initiating events and pivotal events. An ESD is structured as a decision tree in which pivotal events are queried with two possible results: a yes/success (desired) outcome and a no/failure (undesired) outcome. The structure allows for a straightforward transposition of ESDs into event trees. In this PCSA, ESDs and the associated event trees consider human, mechanical, electrical, electronic, controller, structural, thermal and naturally occurring events. However, as noted in Section 1, event sequences for external events are not developed in this analysis. External events and any associated event sequences are evaluated and documented separately.

Five end states are considered in the ESDs as follows:

1. "OK"–Indicates the absence of the other end states.

2. Direct Exposure–Indicates a potential exposure of individuals to direct or reflected radiation (shine). This excludes radionuclide release from containment and the indication of a nuclear reactivity increase. In the PSCA, containment is provided by welded closed canisters, bolted and sealed transportation casks, and bolted and sealed shielded transfer casks.

3. Radionuclide Release–Indicates radiation exposure resulting from a release of radioactive material from containment.

4. Radionuclide Release, Also Important to Criticality–This end state refers to a situation in which criticality should be investigated and a radionuclide release occurs.

5. Important to Criticality–This end state refers to a situation in which a criticality investigation is indicated for Category 1 or 2 event sequences.

For the development of event trees, the above end states are further developed to differentiate the consequences of the various states of release and exposure. The eight mutually exclusive end states include:

1. "OK"–Indicates the absence of the other end states.

2. Direct Exposure, Degraded Shielding–Applies to event sequences where an SSC providing shielding is not breached, but the shielding function is jeopardized. An example is a lead-shielded transportation cask that is dropped from a height great enough for the lead to slump toward the bottom of the cask at impact, leaving a partially shielded path for radiation to stream. This excludes radionuclide release from containment and an indication of a reactivity increase.

3. Direct Exposure, Loss of Shielding–Applies to event sequences where an SSC providing shielding fails, leaving a direct path for radiation to stream. For example, this end state applies to a breached transportation cask, with the dual-purpose canister

(DPC) or transportation, aging and disposal (TAD) canister inside maintaining its containment function. In another example, this end state applies to shield doors inadvertently opened. This excludes radionuclide release from containment and an indication of a reactivity increase.

4. Radionuclide Release, Filtered–Indicates a release of radioactive material from its containment, through a filtered path, to the environment. The release is filtered when it is confined and filtered through the successful operation of the heating, ventilation, and air-conditioning (HVAC) system over its mission time. This excludes nuclear reactivity increases.

5. Radionuclide Release, Unfiltered–Indicates a release of radioactive material from its confinement, through the pool of the WHF or through an unfiltered path, to the environment. This excludes nuclear reactivity increases.

6. Radionuclide Release, Filtered, Also Important to Criticality–For dry operations with canistered SNF, this end state refers to a situation in which a breach of a canister has occurred (resulting a radionuclide release), and a moderator, such as unborated water, has entered the canister. For dry operations with uncanistered commercial spent nuclear fuel (UCSNF), this end state refers to a situation in which a breach of a transportation cask has occurred (resulting in a radionuclide release), and a moderator, such as unborated water, has entered the cask. The release of the radioactive material to the environment is through a filtered path.

7. Radionuclide Release, Unfiltered, Also Important to Criticality–This end state refers to a situation in which an unfiltered radionuclide release occurs and (unless the associated event sequence is Beyond Category 2) a criticality investigation is indicated.

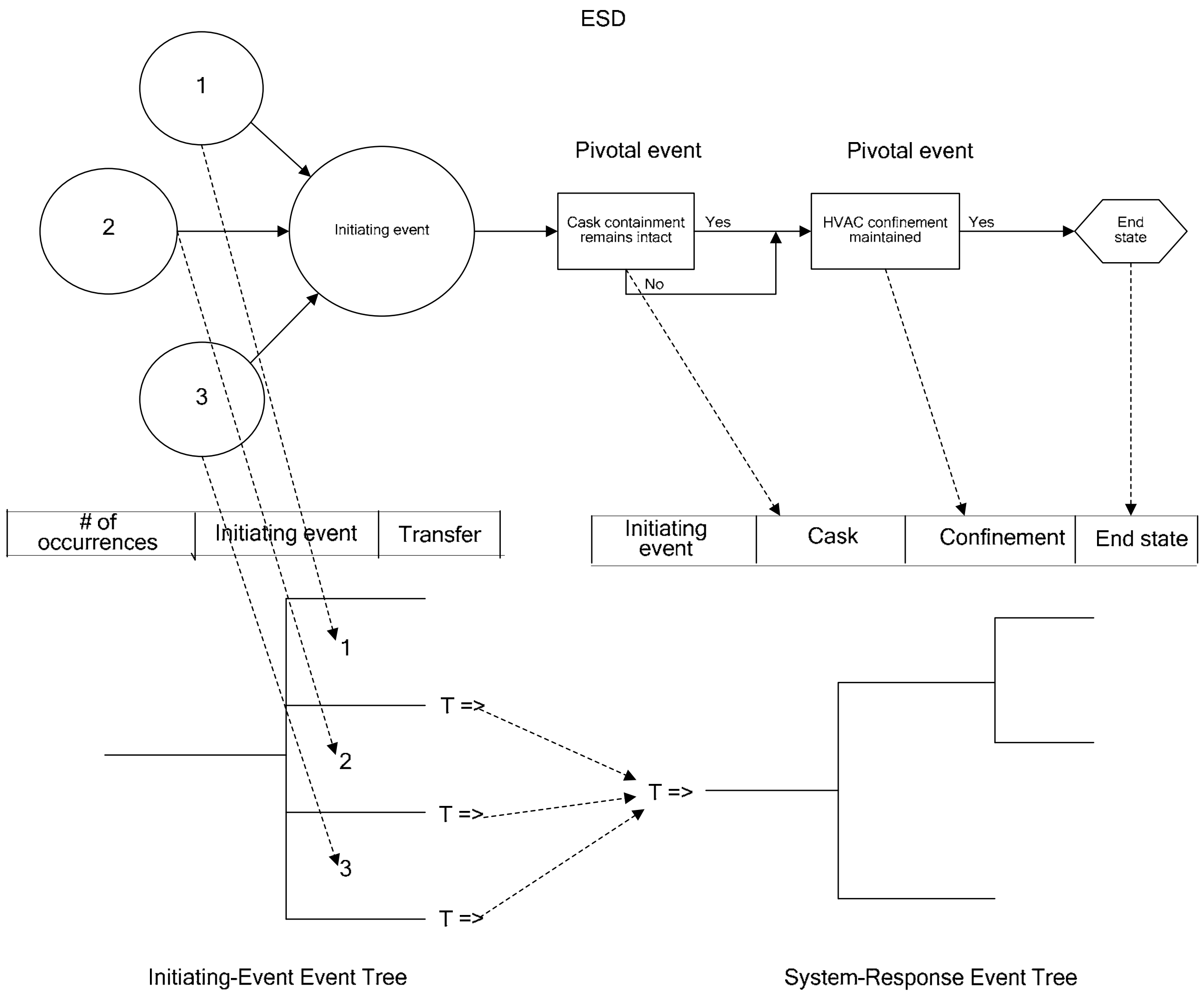
8. Important to Criticality–This end state refers to a situation in which there has been no radionuclide release and (unless the associated event sequence is Beyond Category 2) a criticality investigation is indicated.

The end states radionuclide release (filtered or unfiltered), also important to criticality and important to criticality segregate event sequences for which some of the conditions leading to a criticality event have been met. This does not imply, however, that a criticality event is inevitable.

As has already been noted, the criticality parameter “moderation” is used as a basis for the development of event sequences important to criticality. The reason that the event sequence development includes only moderation is explained in Section 1. Under normal conditions, sealed canisters containing dry waste are received in sealed transportation casks, or uncanistered dry CSNF is received in sealed transportation casks. Category 1 and Category 2 event sequences involving moderator introduction into the canister (or cask, for uncanistered waste) result in an end state that needs to be evaluated in a separate analysis for criticality potential. Moderator could be introduced, for example, by actuation of the fire-suppression system or other water-distribution system, or by failure of lubricating oil reservoirs associated with cranes. Therefore, event sequences involving radiological release are identified as also important to criticality if they result in contact between liquid moderator and the waste form.

4.3.2.2 Event Trees

Event tree construction is the next step in the development of event sequences according to *PRA Procedures Guide, A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants* (Ref. 2.2.54, Section 3.4.4.2). As shown in Figure 5, an event tree is a logic diagram that delineates the event sequences of an ESD.



Source: Original

Figure 5. Event Sequence Diagram–Event Tree Relationship

Event sequences are described and graphically depicted using one or two event trees depending on whether the ESD considered has one or more initiating events. When the ESD has only one initiating event, only a system response event tree is needed. The system response event tree structure has a one-to-one correspondence to that of the ESD. The system response event tree has a horizontal tree structure that starts with the initiating event, splits into upward and downward branches at nodes that represent pivotal events, and terminates into end states. Each path from the initiating event to an end state corresponds to an event sequence.

When the ESD has more than one initiating event, the system response event tree is preceded by an initiator event tree (indicated as initiating event-event tree in Figure 5). The initiator event tree has one node from which as many branches are created as there are initiating events on the ESD. The initiator event tree assigns an initiating event to each branch, which terminates into a transfer to the same system response event tree. Since the conditional probability of one or more pivotal events may be specific to the initiating event assigned to each branch of the initiator event tree, the same system response event tree is quantified as many times as there are initiating events in the initiator event tree, using different pivotal event probabilities as needed.

The description of the pivotal events, given the headings of the system response event tree, is by convention, expressed in terms of successful performance; an upward branch at a node represents success, and a downward branch represents failure. As indicated in the ESD, if a pivotal event does not appear in a particular event sequence, the event tree does not branch at that pivotal event.

Figure 5 illustrates the relationships between the ESD, initiator event trees, and the system response event trees. The ESD is shown at the top of the figure. The circles to the left, also known as small circles, represent individual initiators. The larger circle, also known as a big circle, to the right of the small circles represents the aggregated initiator. The cask and confinement rectangles to the right of the big circle represent pivotal events leading to the end state. A horizontal line to the right of pivotal event box represents success of a system or component. A vertical line below the pivotal event box represents failure of a system or component. The link between the initiators in the ESD and the initiator event tree are shown as dashed lines from the small circles to individual branches on the initiator event tree. The link between pivotal events on the ESD and pivotal events on the system response event tree are also shown as dashed lines from the pivotal events on the ESD to the pivotal events on the system response event tree.

Initiators on the initiator event tree transfer to the initiating event in the system response event tree. This construction of the event trees is a feature of SAPHIRE that allows the user to specify basic rules to assign pivotal event probabilities in the system response event trees to account for the conditions associated with each individual initiating event in the initiator event tree.

4.3.2.3 Internal Fire and Flooding Event Analysis

Fire initiating events identified in the MLDs are analyzed in *Intra-Site Operations and BOP Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1). The MLD and HAZOP did not identify internal flooding event sequences for Intra-Site and BOP operations that would threaten a waste form.

4.3.3 Non-seismic External Events

Analyses for non-seismic external initiating events are performed and documented separately as external events, as discussed in Section 1.

4.3.4 Example Facility Analysis

This section illustrates the overall event sequence development approach using example typical intra-site operations. It is particularly useful for understanding the relationships among the PFD, MLD, HAZOP, ESDs and event trees. This example portrays Intra-Site example operations in which the design and operations are generalized; as such, some of the specific details differ from similar features of the actual Intra-Site Operations.

Intra-Site Operations involves movement of various waste forms in casks, and may include SNF or high-level radioactive waste (HLW). Also included in the scope is movement and storage of facility-generated LLW in containers. Intra-Site Operations includes transfer operations related to the movement of waste materials between handling facilities, aging pads, and (for LLW in containers only) the LLWF. Intra-Site Operations also covers the transfer of LLW to outside agents that transfer LLW to offsite storage areas operated by others. Figure C-1 of Attachment C shows the layout of the GROA. There are two transportation methods applicable to Intra-Site Operations depicted on the figure:

1. Transport of waste forms by rail and truck into various waste handling facilities, such as the CRCF

2. Transport of aging overpacks and horizontal aging casks to or from the Aging Facility.

This example provides a simplified summary of Intra-Site Operations and shows the PFD, MLD, HAZOP, ESD, and event tree based upon activities associated with a railcar derailment. The objective of this example is to demonstrate how event sequences are developed employing the methodologies identified above. A simplified description of the Intra-Site Operations is covered below.

Intra-Site Operations Overview

Intra-Site Operations and facilities are quite different when compared with the main waste handling facilities, namely the CRCF, WHF, Initial Handling Facility (IHF) and Receipt Facility (RF), or with the repository storage facility (Subsurface Operations). The functions associated with Intra-Site include the transportation of SNF, HLW, and LLW around the complex, along with the placement, aging, and removal of both vertical and horizontal canisters that require thermal management in aging overpacks or HAMs on the aging pads. This does not include transportation of loaded waste packages from IHF or CRCF to the underground repository, which is part of Subsurface Operations and carried out by the transport and emplacement vehicle (TEV). Aging overpacks contain vertical canisters and are composed of steel and concrete for personnel shielding. TAD canisters and vertical DPCs are transported between buildings and to or from the Aging Facility in aging overpacks carried by the site transporter (Figure 6). Horizontal casks (i.e., transportation casks that are never upended (HTCs) and horizontal shielded transfer casks (HSTCs)) contain horizontal dual-purpose canisters (HDPCs) and are transported among facilities and to or from the Aging Facility using a horizontal cask tractor and cask transfer trailer (Figure 7).

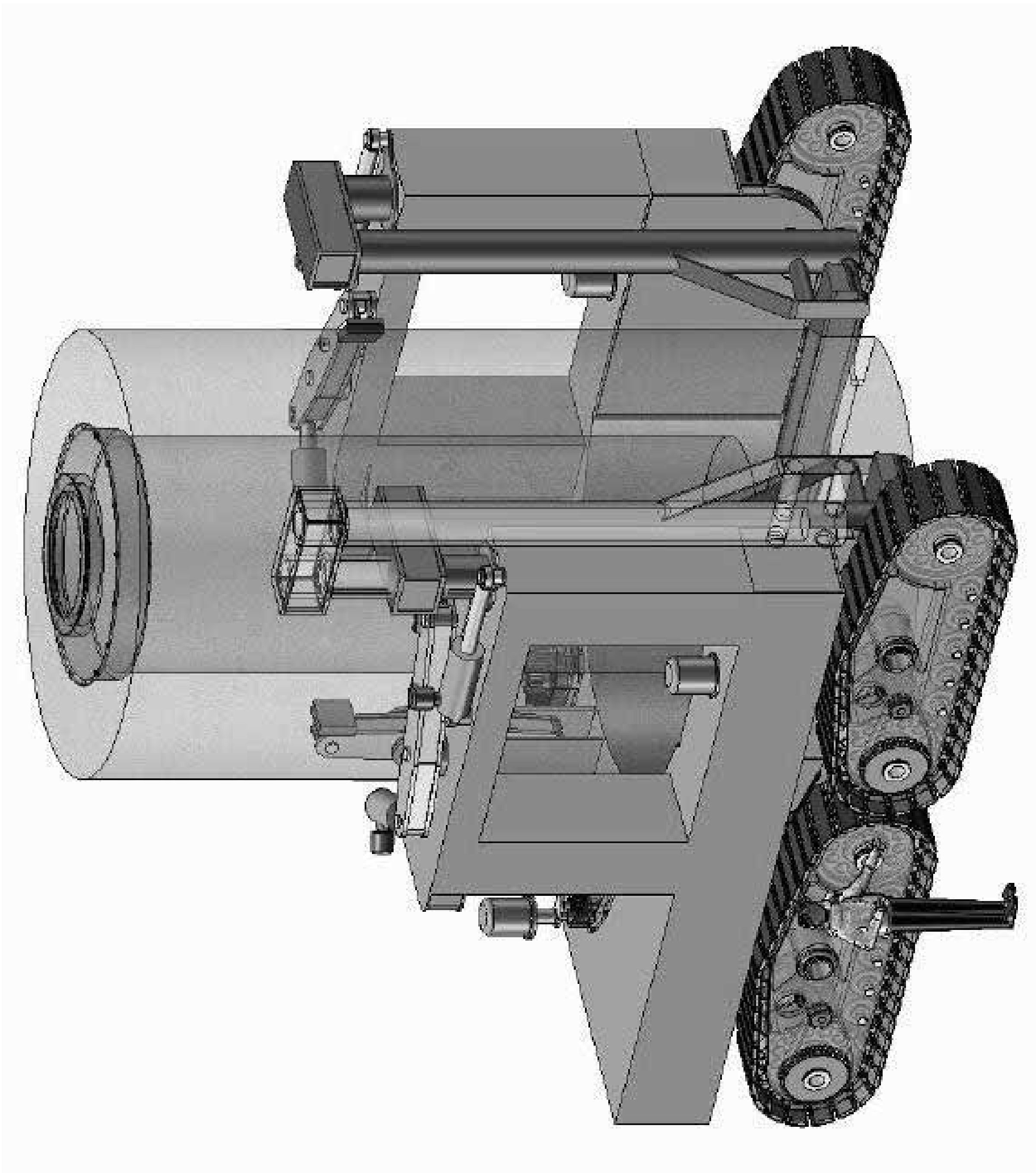
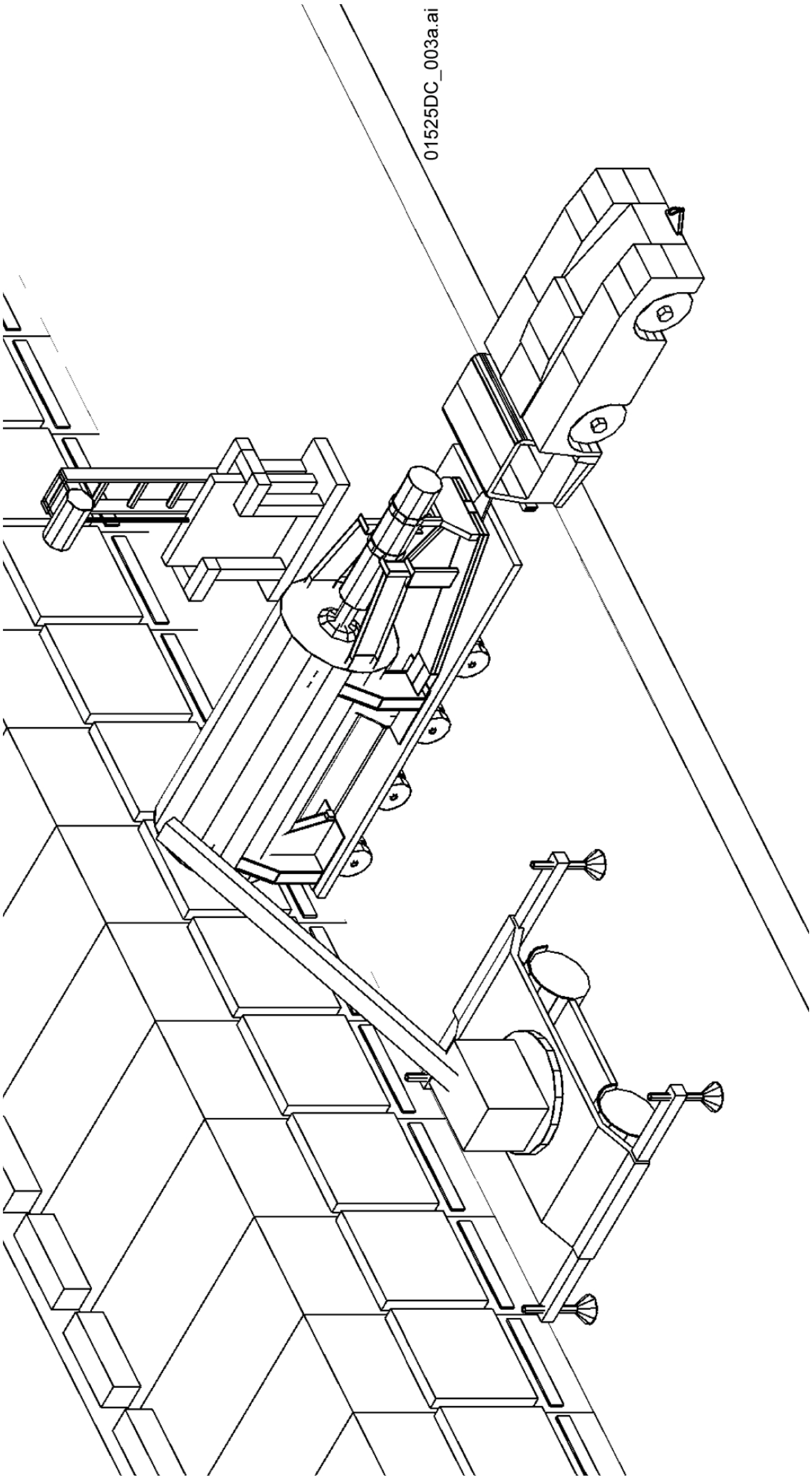


Figure 6. Conceptual Schematic of Site Transporter

Source: Modified from (Ref. 2.2.36)



Source: Modified from (Ref. 2.2.12)

Figure 7. Conceptual Line Drawing of Cask Tractor and Cask Transfer Trailer

A key area of Intra-Site Operations is aging of SNF by placing canisters (in aging overpacks or HAMs) on the aging pads. The time spent at the aging pads depends on the thermal state of the SNF. The SNF arriving from the nuclear power plants may need to be aged in order to meet the requirements set by the thermal limits of the repository drifts in which the canisters are placed.

The aging pads are where the fuel is aged, that is, decay heat of SNF falls to an acceptable value. The aging pads are flat concrete pads, which allow for the placement and storage of approximately 2,400 aging overpacks and 100 HAMs (Ref. 2.2.9) and (Ref. 2.2.10). The two types of aging packs are (vertical) aging overpacks and HAMs. Both are thermally vented and provide shielding. The decay heat generated by SNF is removed by the natural convection allowed by vents in the aging overpacks. To prevent shine (direct radiation from canisters), the vent pathway for the air is circuitous. An aging overpack can hold either a TAD canister or a DPC. A HAM can hold an HDPC.

The site transporter is a vehicle that envelops the vertical aging overpack, lifts, and transports it to the desired location and sets it down. The transporter moves at 2.5 mph. The cask transfer trailer is made up of two major parts: a trailer to transport the cask, and a ram to transfer the canister between a horizontal cask and a HAM. The ram functions to both insert and extract a canister from the HAM. The HAMs have a shield door which has to be opened or closed to allow the canisters to be placed into or extracted from a HAM.

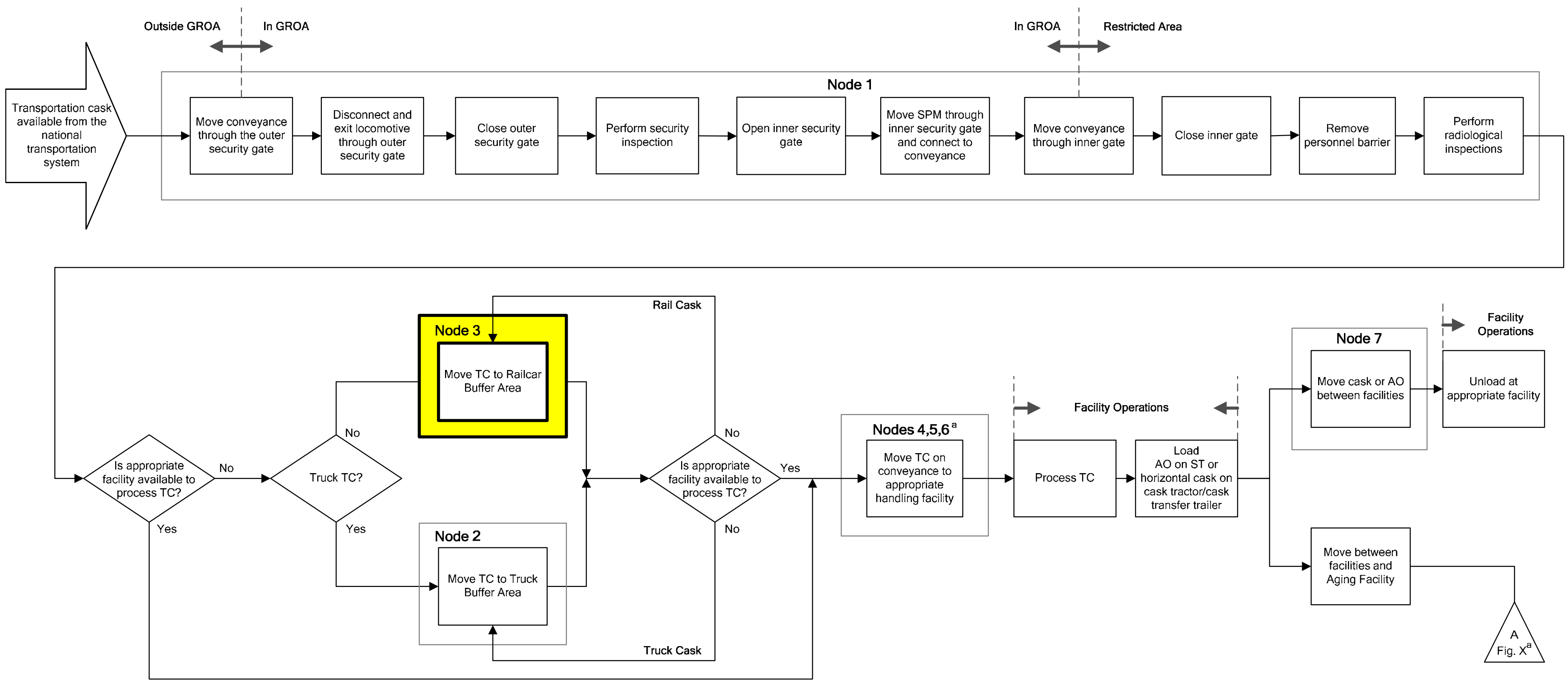
The aging overpacks are positioned by the site transporter in a regular array on the aging pads. The HAMs are positioned side by side in a row at the southern edge of the southern-most pad.

4.3.4.1 Process Flow Diagram Development

Design related information is used to develop a PFD that summarizes the activities associated with the facility operations. The PFD is used as a framework around which to develop initiating events and the event sequences that emanate from them. They are a construct that is synthesized from a variety of information sources but are originated in this analysis.

Individual activities are categorized into distinct nodes in the PFD, and the PFD describes the relationships between them. The PFD for Intra-Site example operations is shown in Figure 8. Brief statements for the operations within the each of the nodes are provided in Table 4. Note that for completeness, additional example nodes are described in Table 4 but do not appear on the example PFD (Figure 8). Descriptions of special equipment used in the example Intra-Site Operations are identified in Table 5.

For this example of typical Intra-Site Operations, Node 3 *"Move TC [transportation cask] to Railcar Buffer Area"* of Figure 8 is examined. This node covers the movement of a transportation cask by railcar to the buffer area. During the operation, it is possible that a derailment accident could occur and this specific deviation from normal activity is used as an example to illustrate the inter-relationships between the MLD, HAZOP, ESDs, and the event trees.



NOTE: [a] "Fig. X" in the triangle represents transfer to a continuation page of the PFD, which is not provided nor discussed in detail for this example. Only the PFD sheet containing the nodes relevant to the Intra-Site Operations example has been included in this section.
AO = aging overpack; GROA = geological repository operations area; SPM = site prime mover; ST = site transporter; TC = transportation cask.

Source: Original

Figure 8. Simplified Example PFD for Intra-Site Operations (with Node 3 Emphasized for Further Discussion)

Table 4. Process Node Descriptions

Node No.	Description
1	Receipt of a transportation cask
2	Movement of a transportation cask to Truck Buffer Area
3	Movement of a transportation cask to Railcar Buffer Area
4	Movement of a transportation cask to the appropriate handling facility
5	Movement of a transportation cask to the appropriate handling facility
6	Movement of a transportation cask to the appropriate handling facility
7	Movement of an AO or horizontal cask between facilities
8	Movement of an AO to/from the aging pads
9	Position and age an AO on the aging pads
10	Movement of a horizontal cask to/from the aging pad (HAM)
11	Alignment of a horizontal cask with HAM
12	Transfer canister to/from HAM
13	Age horizontal canister in HAM
14	Management of other LLW (i.e., dry, liquid or non-resin LLW)
15	Management of resin LLW

NOTE: AO = aging overpack; HAM = horizontal aging module; LLW = low-level radioactive waste

Source: Original

Table 5. Equipment Descriptions

Equipment Type	Description
Site prime mover	Small locomotive-type machine for moving railcars.
Site transporter	A tracked vehicle capable of moving 250-ton vertical aging overpacks
Cask tractor and cask transfer trailer	A tractor capable of moving a special cask transfer trailer, which has equipment, such as a large ram, designed to transfer a canister between a transfer cask (i.e., an HTC or HSTC) and a HAM
Forklift	A forklift used in the LLWF to move LLW containers to and from the various storage areas
50/10 ton gantry crane with a main and auxiliary hooks	This crane is installed at the LLWF to handle HICs and empty DPCs
Common hand tools	An array of common hand tools is available for various purposes
Mobile 30-ton jib crane (diesel powered)	This crane is provided to move the shield doors associated with the HAMs and HTCs

NOTE: DPC = dual-purpose canister; HAM = horizontal aging module; HIC = high-integrity container; HTC = a transportation cask that is never upended; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility.

Source: Original

4.3.4.2 Master Logic Diagram Development

After the PFD is completed, the next step is to develop the MLD. For this example, the MLD top event is "*Unplanned exposure of individuals to radiation or radioactive materials associated with Intra-Site operational activities*". The top event is shown in Figure 9 along with some related sub-events. The sub-events relate to dividing the top event into external and internal events. The external events are identified as a group and cover things such as fires, flood, seismic events, lightning, winds, etc. In this example, the external events are not examined. The sub-event "*Exposure resulting from Intra-Site operational activities (referred to as "internal events")*" is sub-divided into three further categories. These sub-events include activities associated with transportation, the Aging Facility and the LLWF. The activities can be grouped into events resulting from transport activities, from events associated with activities going on with operations at the Aging Facility and events related to LLW transportation to and from the LLWF and operations within the LLWF. The division of events into groups associated with these three items is valid because the activities are independent of each other.

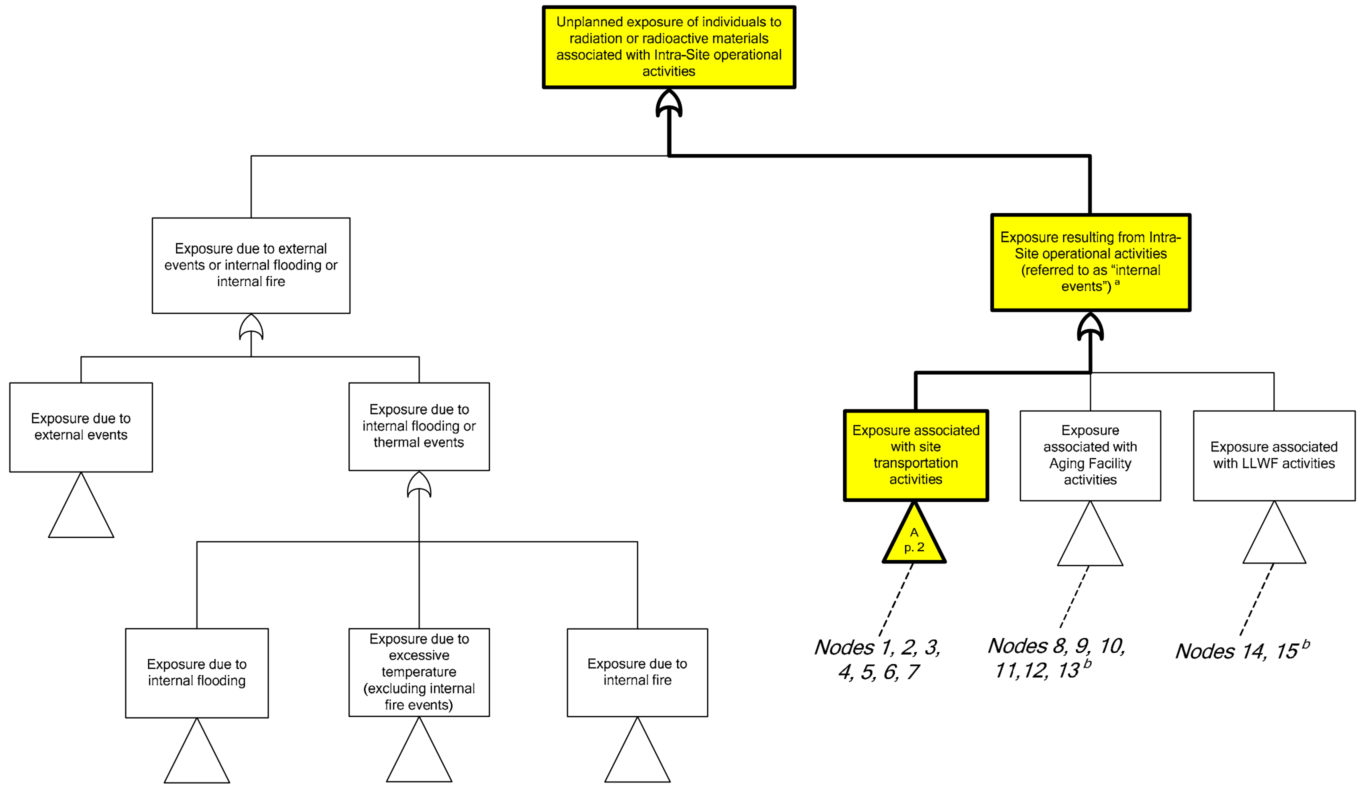
For this example, the sub-event "*Exposure associated with site transportation activities*" was examined further. Figure 10 shows the development of the MLD, when looking down the transportation branch. The next set of headings is associated with events that might occur during transit activities. Events associated with transit activities can lead to collisions between moving and stationary vehicles or structures, and derailments.

In the example, we have focused on the event called "Exposure due to release during RC [railcar] transit." This in turn leads to the item "RC [Railcar] derailment leads to TC [transportation cask] rollover." This is the lowest level of the MLD and identifies the level at which event sequence diagrams are developed. There are a number of individual contributions that could lead to this event. An example contributor is given below each initiating event box.

Each set of initiating events in the MLD is similarly developed and examined. The level at which initiating events are identified is the highest level for which the same system response event tree applies. Lower levels, should they be developed, would indicate causes of the initiating event and therefore can be subsumed within the higher level event if each cause has the same system response as the higher level event. To verify that the MLD is comprehensive in its identification of initiating events a HAZOP is carried out. If any further initiating events are discovered then these are inserted into the MLD set. The section below discusses the HAZOP process as applied in this investigation, and in particular, for this selected example.

4.3.4.3 Hazard and Operability Development

In addition to the MLD development, an independent study of the processes identified in the PFD is conducted by a team of subject matter experts, analysts, and operations personnel. This is a HAZOP (Section 4.3.1.3), which is employed in conjunction with the MLD development to assure that the facility operations are well understood and that comprehensive identification of initiating events is accomplished. The team evaluates each node in the PFD using a set of HAZOP parameters and deviations, and the results of the HAZOP are compared to the results of the MLD development. The MLD becomes the conduit for events identified in the HAZOP for inclusion in the ESDs. Once the HAZOP events are incorporated into the MLD initiating event categories, the HAZOP has no further function in the PCSA.



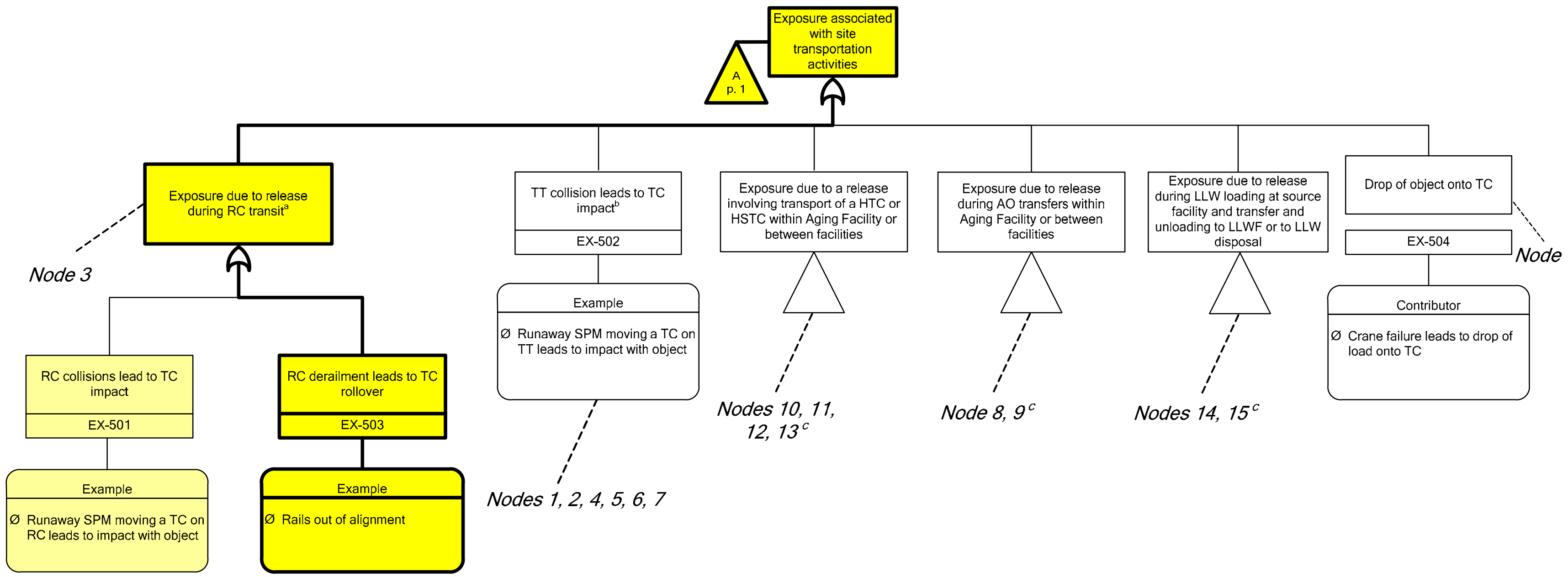
NOTE: [a] Balance of plant activities and facilities are not included in the MLD because they are non-nuclear and are not analyzed further in regard to nuclear safety.

[b] Nodes 8 through 15 are not discussed in detail in the Intra-Site Operations example. For a brief description of the activities associated with these nodes, refer to Table 4.

Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
EX = example; LLWF = Low-Level Waste Facility; MLD = master logic diagram.

Source: Original

Figure 9. Master Logic Diagram (Page 1) Intra-Site Example Operations (with Emphasis on Initiating Event Branch Relevant to Site Transportation Activities)



NOTE: [a] Affected waste forms include (in TCs): MCOs, DOE standardized canisters, Naval, HLW (5 canisters), TAD canisters, DPCs, and uncanistered CSNF.
[b] Affected waste forms include (in TCs): MCOs, DOE standardized canisters, HLW (only 1 canister), TAD canisters, and uncanistered CSNF.
[c] Nodes 8 through 15 are not discussed in detail in the Intra-Site Operations example. For a brief description of the activities associated with these nodes, refer to Table 4.
Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
AO = aging overpack; DOE = Department of Energy; DPC = dual-purpose canister; EX = example; HLW = high-level radioactive waste; HSTC = horizontal shielded transfer cask; HTC = a transportation cask that is never upended; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; MCO = multicanister overpack; RC = railcar; SNF = spent nuclear fuel; SPM = site primer mover; TAD = transportation, aging, and disposal; TC = transportation cask; TT = truck trailer.

Source: Original

Figure 10. Master Logic Diagram (Page 1) Intra-Site Example Operations (with Emphasis on Initiating Event Branch Relevant to Site Transportation Activities)

To demonstrate the HAZOP process for the Intra-Site Operations example, activities involved in railcar transit are examined (shown in the MLD as "Exposure due to release during RC [railcar] transit" Figure 10). As discussed previously, movement of a transportation cask from the Cask Receipt Security Station to the Railcar Buffer Area is identified in Node 3 of the example PFD (Figure 8). Table 6 displays the results of the HAZOP team's deliberations concerning Node 3. The key parameters that the team uses for this investigation are speed, direction, temperature and shielding; however, for this example, only the speed and direction parameters are discussed. The team uses the key parameters to examine the effect on the system as a result of perturbing the system components. Deviations from normal operational movement are considered (i.e., movement that is too fast, too slow, wrong direction), and postulated causes (i.e., human, mechanical, or structural failure), and hypothetical consequences (i.e., radioactive release resulting from canister collision or drop of object on canister), and potential preventive/mitigative design features are identified.

Referring to Table 6, the parameter "Speed" signifies the speed of the site prime mover (SPM) (Node Item Numbers 3.1 through 3.4), and the parameter "Direction" signifies movement of the SPM (Node Item Number 3.5) or the railcar on the rail system (Node Item Numbers 3.6 and 3.7). The deviations studied are based on the HAZOP guidewords. For the parameter "Speed", the guidewords include: "More" (speed is greater than expected); "Less" (speed is less than expected); and, "No" (not moving). For the parameter "Direction," the guidewords "Reverse" (moving backwards) and "Other Than" (moving in a direction other than expected) are used. The conceptual process for each of these deviations is described below. Note that these occurrences and consequences in Table 6 (also summarized in Table 7) are only hypothetical; however, their inclusion is part of the process to develop a comprehensive identification of initiating events:

- The "More" deviation for this operational parameter could impact safety because, if the SPM is moving too fast, it might lead to loss of control of the SPM and a collision with an object.

- The deviation "Less" suggests that the SPM is moving at a speed less than expected. This deviation is not expected to result in any adverse safety consequences.

- The deviation "No" means that the SPM does not move when expected. This deviation is not expected to result in any adverse safety consequences.

- The deviation "Reverse" means that the SPM moves backwards instead of forwards. This deviation could result in a collision.

- The deviation "Other Than" means that the railcar is moving in a direction other than on the established rail system (i.e., a derailment). A railcar derailment could result in a collision or drop of the canister because of rail distortion, mechanical failure or human failure.

Table 6. Example HAZOP for Intra-Site Operations (with Emphasis on Initiating Event Branch Relevant to Site Transportation Activities)

Facility/Operation: Intra-Site Operations — Process: Rail TC Transit

Node 3: TC (TAD Canister, DPC, DC) Movement from Cask Receipt Security Station to Railcar Buffer Area — Process/Equipment: SPM/Railcar

Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of — Consequence Categories: Radioactive Release, Direct Exposure, Criticality

Node Item Number	Parameter	Deviation Considered	Postulated Cause	Consequence(s)	Potential Prevention/Mitigation Design of Operational Feature	Notes	MLD Index Number
3.1	Speed	(More) SPM moves at faster than desired speed	Driver drives SPM faster than desired speed	Potential loss of control or collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration [a] 2 – Speed control feature on SPM engine 3 – Procedures and training	Safe speed of 5 mph or less expected	EX-501
3.2	Speed	(More) SPM moves at faster than desired speed	Mechanical failure of SPM	Potential loss of control or collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	Safe speed of 5 mph or less expected	EX-501
3.3	Speed	(Less) SPM moves at slower than desired speed	Mechanical failure of SPM	No safety consequences			
3.4	Speed	(No) SPM does not move	1 – Human failure 2 – Mechanical failure of SPM	No safety consequences			
3.5	Direction	(Reverse) SPM moves backward instead of going forward	1 – Human failure (chock, set brake) 2 – Failure of brake	Potential collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Brake design		EX-501
3.6	Direction	(Other Than) Derailment of railcar	1 – Human failure 2 – Mechanical failure of railcar	Potential collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Brake design		EX-503
3.7	Direction	(Other Than) Derailment of railcar	Rail distortion due to structural failure	Potential drop leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Rail design		EX-503
3.8	Temperature	(More) Temperature exceeds TC design basis	Fire caused by or involving SPM	1 – Potential radioactive release 2 – Potential criticality	1 – Procedures and training 2 – Combustible materials control	10 CFR Part 71 temperature design basis	EX-F403 [b]
3.9	Temperature	(Less) Temperature does not exceed design basis	Normal condition	No safety consequences	TC in 10 CFR Part 71 configuration	10 CFR Part 71 temperature design basis	
3.10	Shielding	(Less) Displacement of TC shielding	Impact or fire	Potential direct exposure	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Combustible materials control		EX-F403 and EX-502 [b]
3.11	Shielding	(No) Total displacement of TC shielding	No cause identified	N/A	N/A		N/A

NOTE: [a] 10 CFR Part 71 (Ref. 2.3.2).
[b] MLD index numbers EX-F403 and EX-502 are included in the table for completeness. They are not used further in the Intra-Site Operations example.
Guidewords not used in this node: As Well As and Part Of.
DC = disposable canister; DPC = dual-purpose canister; EX = example; MLD = master logic diagram; SPM = site prime mover; TAD = transportation, aging, and disposal; TC = transportation cask.

Source: Original

For every operational node, each deviation for each parameter in the HAZOP is assessed likewise. Any other relevant information is captured in the notes column. Deviations for which safety consequences are identified are then assigned MLD index numbers to correlate the information to a specific event on the MLD. For example, the deviation involving the SPM moving too fast and losing control (Node Item Number 3.1) is assigned the MLD index number EX-501, and the deviation entailing derailment of a railcar due to railcar distortion (Node Item Number 3.7) is assigned the MLD index number EX-503. Referring again to the MLD, Figure 10, these MLD index numbers are denoted for two initiating events. Such correlations between the HAZOP and MLD confirm the comprehensiveness of the MLD and increase confidence that the significant event sequences are identified and developed.

Table 7 is provided to illustrate the interrelating of the information between the PFD, MLD, and the HAZOP for the example of Intra-Site Operations. The table presents the event contributor, event cause, and consequence, and notes whether the contributor was originally included in the MLD or added to the MLD later as a result of the HAZOP.

Table 7. Interfaces between MLD and HAZOP for Intra-Site Operations (with Emphasis on Initiating Events Relevant to SPM Movement and Railcar Derailment)

MLD Index #	Contributor/ Deviation	Event Cause	Consequence	Originally Included in MLD	Added to MLD from HAZOP
EX-501	SPM moves too fast	Driver drives SPM faster than desired speed	Potential loss of control or collision leading to radioactive release	Y	—
EX-501	SPM moves too fast	Mechanical failure of SPM	Potential loss of control or collision leading to radioactive release	Y	—
N/A	SPM moves too slow	Mechanical failure of SPM	No safety consequences	N	Y
N/A	SPM does not move	Human failure or mechanical failure	No safety consequences	N	Y
EX-501	SPM moves in reverse	Human failure or mechanical failure	Potential collision with canister leading to radioactive release	Y	—
EX-503	Derailment of railcar	Human failure or mechanical failure	Potential collision with canister leading to radioactive release	Y	—
EX-503	Derailment of railcar	Rail distortion due to structural failure	Potential drop of canister leading to radioactive release	Y	—

NOTE: EX = example; HAZOP = hazard and operability; MLD = master logic diagram; N = no; SPM = site prime mover; Y = yes.

Source: Original

4.3.4.4 Event Sequence Diagram Development

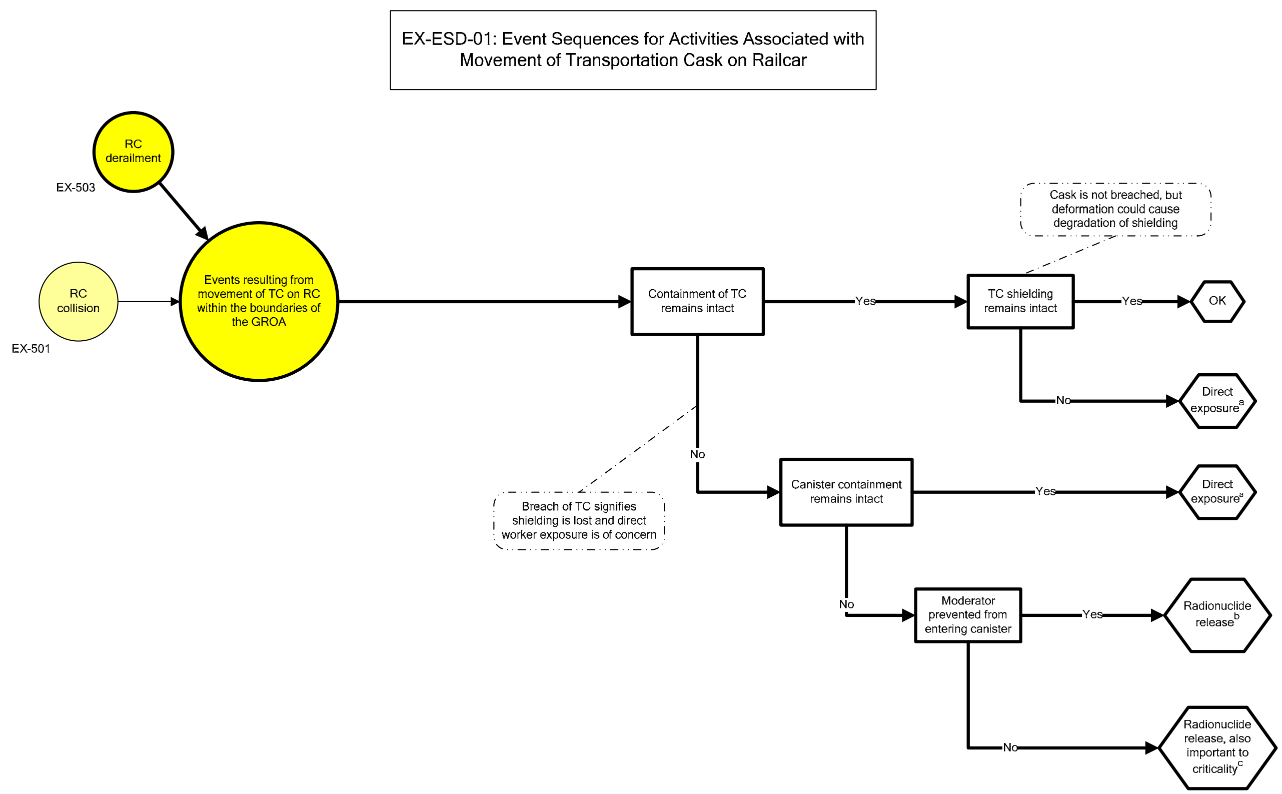
After the HAZOP and MLD results are correlated, the MLD is completed. The analysts group the initiating events by initiator types, system responses and waste forms. Initiating events that pertain to the same operational area/activity, elicit the same pivotal events, and lead to the same end states are grouped in the same event sequence diagram. Based upon the grouping, the ESD development begins.

As detailed in Section 4.3.2.1 and as shown in Figure 11, the ESDs are a graphical communications tool to aid in the understanding of the initiating events and the later development of the event trees. An ESD is read from left to right. Initiating events are depicted as small circles, and a large circle represents the integrated effect of the smaller events. The diagram moves through to the pivotal events (success or failure events) depicted as rectangles, and then terminates in end states depicted as hexagons. The small circles on the left are descriptions that are summarized or paraphrased from one or more initiating events identified in the MLD. More than one MLD initiating event may be represented by a single small circle because events and system responses from different operational nodes are often the same. The set of small circles on an ESD shares the same system responses (pivotal events), but each small circle has a unique set of probabilities for these system responses. (Refer also to Section 4.3.2.2.)

If events are grouped for a small circle on an ESD, the relevant MLD index numbers are listed adjacent to the small circle. For example, for the impacts involving LLW, the impacts can occur during site transport or during loading or unloading operations. These events are reviewed for different operational nodes and therefore appear in different sections of the MLD. However, because both have the same system responses and both pertain to LLW operations, they are appropriately in the same ESD.

Following the flow of the ESD to the right, one can see that the small circles point to a central, large circle. The large circle represents the aggregated initiating event. Each small circle on an ESD can be considered a subset of the large circle which has the same system response but different pivotal event conditional probabilities. Because each small circle represents an initiating event with a unique frequency, the large circle is an aggregated initiating event. As is discussed in the *Intra-Site Operations and BOP Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1), categorization of initiating events is based on the aggregated initiating event (i.e., large circle).

The frequency of occurrence of an event sequence depends on the frequencies of its initiating event and conditional probabilities of pivotal events. The separation into small circles, however, is necessary because the conditional probability of pivotal events in the system response event tree differs for each small circle. To obtain the proper event sequence frequency, therefore, it is necessary to quantify the event sequences emanating from each small circle. Categorization of event sequences to comply with 10 CFR 63.111 (Ref. 2.3.1) is done on the basis of the aggregated initiating event. This is described in more detail in the *Intra-Site Operations and BOP Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1).



NOTE: [a]Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a breach of a waste form container.

Radionuclide release describes a condition where radioactive material has been released from the container creating a potential inhalation or ingestion hazard, accompanied by the potential for immersion in a radioactive plume and direct exposure, as described above.

Radionuclide release, also important to criticality, involves radionuclide release as described above, accompanied by the potential for nuclear criticality, which may arise when liquid moderator is available to enter a breached container.

[b] This ESD applies to DOE and CSNF TCs.

[c] CSNF = commercial spent nuclear fuel; DOE = Department of Energy; ESD = event sequence diagram; EX = example; GROA = geologic repository operations area; RC = railcar; TC = transportation cask.

Source: Original

Figure 11. Example ESD for Intra-Site Operations for Site Transportation Activities (EX-503)

In this example, the derailment of a railcar is considered. The MLD event number is EX-503 and the title of the event is "*RC [railcar] derailment"*, with the associated small circle shown on Figure 11. The flow of the ESD is from the small circles to a large circle titled "*Events resulting from movement of TC [transportation cask] on RC [railcar] within the boundaries of the GROA."* This event sequence also includes the possibility of a rollover of a railcar and the subsequent impact on the transportation cask and canister containment. There is another small circle associated with the large circle that relates to a railcar collision that is not addressed further in this example.

Continuing to the right, the path from the large circle is the logical progression of an event sequence through each pivotal event (displayed as boxes). For the initiating events in Figure 10, the analyst considers the possible events that might follow. The analyst then asks the question, "Is the transportation cask containment intact?" If the answer to this question is "yes", then the analyst asks "Does the shielding remain intact. Continuing to move through the ESD logic, if the answer to the question of whether the containment of the transportation cask remains intact is "no", then the next pivotal event is related to the canister containment remaining intact. If the answer to the question is "yes", the result is possible direct exposure of personnel. If the answer is "no", then the question of whether a moderator is prevented from entering the canister is addressed. If the moderator is prevented from entering the canister, then personnel may be exposed to radiation. If the answer is "no", then there is a possibility of a radioactive release and the potential for criticality should be evaluated. End states (OK, direct exposure, radionuclide release, radionuclide release also important to criticality) are determined by the sequence of yes or no responses to such questions as indicated by the pivotal events.

The pivotal events depicted in Figure 11 are as follows:

- **Containment of transportation cask remains intact.** This pivotal event provides the first barrier against radiological release.

- **Transportation cask shielding remains intact.** The shielding provided by a transportation cask against direct shine of radiation may be compromised even if the transportation cask remains intact.

- **Canister containment.** This pivotal event provides the second barrier against release of radioactivity. If this pivotal event is successful, personnel may be exposed to direct shine of radiation from the canister because the transportation cask containment has failed. If both the canister and transportation cask have been breached, then radionuclide release will occur.

- **Moderator Ingress.** This pivotal event covers the possibility of liquid moderator (e.g., water) ingress into a canister during an event sequence in which the cask has also breached. If the condition exists that water is able to enter a canister, then there is a potential for criticality in addition to the radionuclide release; however, failure to preclude water ingress does <u>not</u> automatically mean that there will be a criticality event.

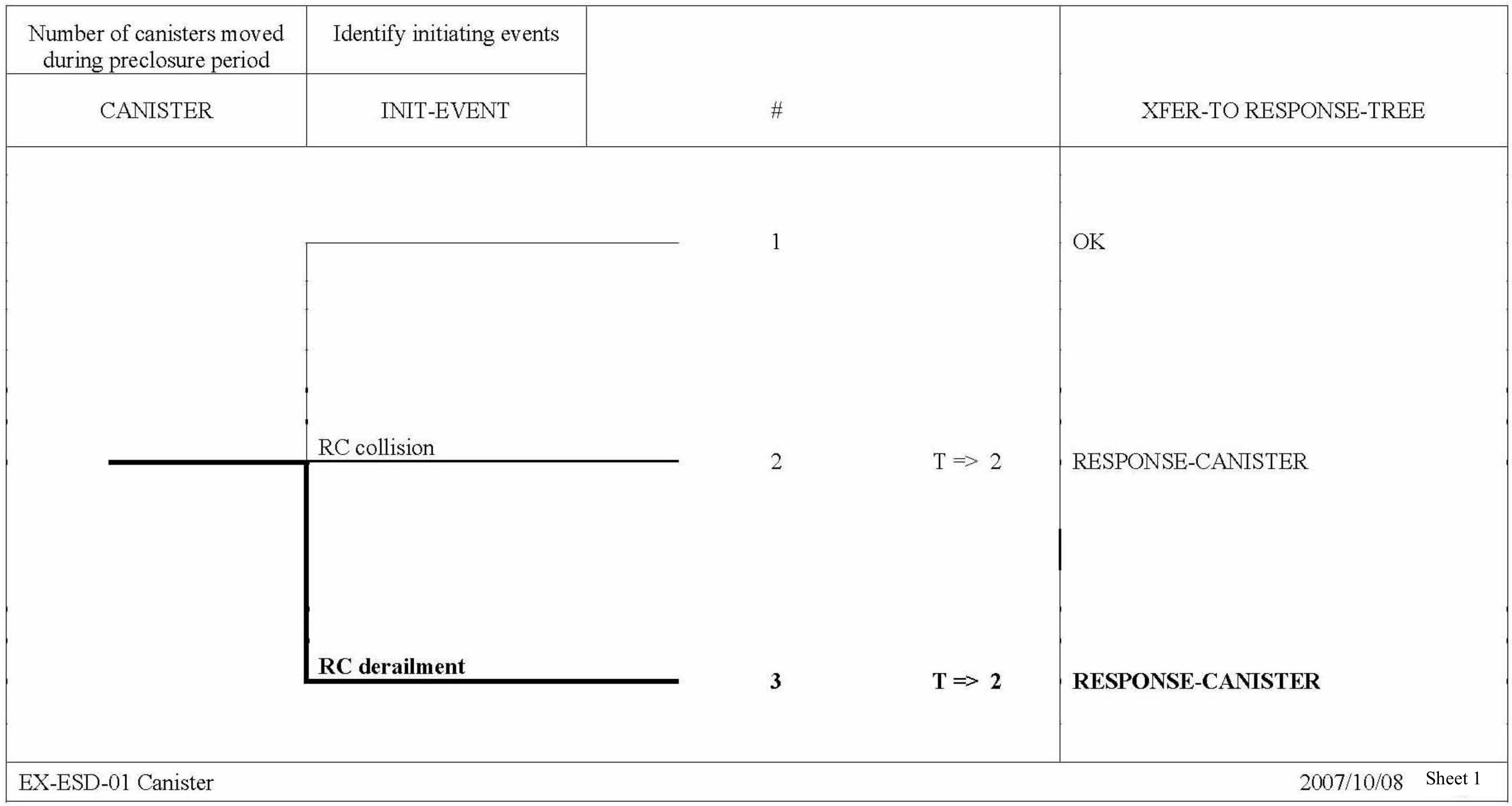
4.3.4.5 Event Tree Development

Event trees developed from the ESDs are graphical logic models used for quantification of event sequences. There is a direct correlation from small circles, boxes, paths and end states of the ESDs to the initiating events, pivotal events, paths and end states of the event trees for the same sequence.

For the example event sequences, the analyst uses SAPHIRE computer software to set up the models. Initiating event frequency and probability values are input into the model for later quantification.

In this example, the two initiating events, railcar derailment and railcar collision are shown as small circles on Figure 11 and are also represented by branches on the initiator event tree in Figure 12. The label on a small circle appears on the initiator event tree. Each branch is expanded further in the system response event tree, using success/failure criteria for each pivotal event of the ESD (Figure 13). The first branch in the initiator event tree is the branch that represents success for each pivotal event; therefore, the end state for this branch is always "OK." The convention used to develop the remaining branches is that the upper branch in a split represents success and the lower branch represents failure. The pivotal events as shown in the ESD are repeated in the event tree shown in Figure 13. The pivotal events are the "*Containment of transportation cask remains intact*", "*Transportation cask shielding remains intact*", "*Canister containment remains intact*", and "*Moderator excluded from entering canister*". For the system response event tree, the end states are OK, Direct exposure, Radionuclide release, and Radionuclide release also important to criticality. The system response tree in Figure 13 is quantified for each initiator in Figure 12 (i.e., for each branch that shows a transfer).

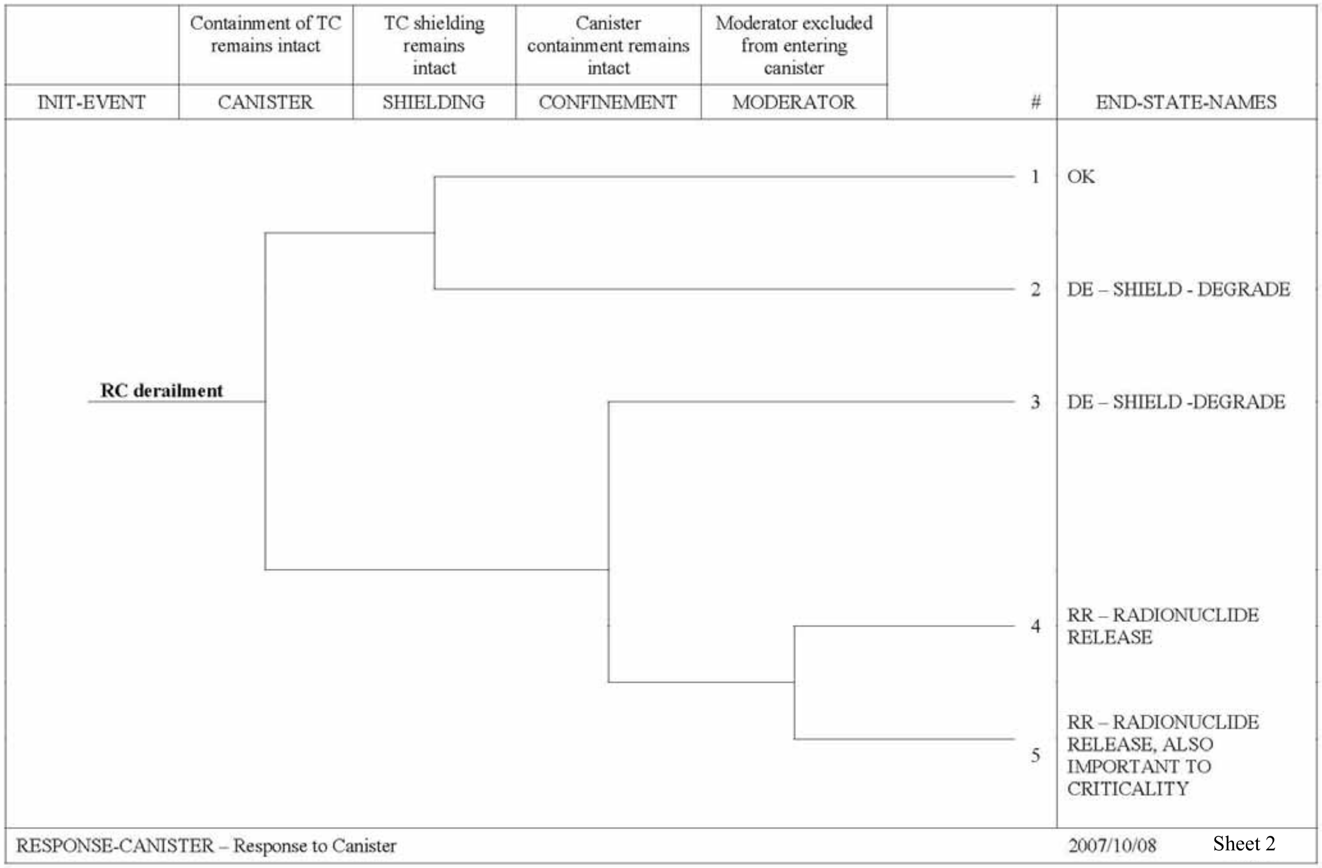
For additional details regarding the development of ESDs and event trees refer to Section 4.3.2.



NOTE: ESD = event sequence diagram; INIT = initiating; RC = railcar.

Source: Original

Figure 12. Example Initiator Event Tree for a Typical Intra-Site Operation Initiating Event



NOTE: INIT = initiating; RC = railcar; TC = transportation cask.

Source: Original

Figure 13. Example System Response Event Tree for a Typical Intra-Site Operation Initiating Event

5. LIST OF ATTACHMENTS

		Number of Pages
Attachment A.	Intra-Site Layout and Equipment Summary	10
Attachment B.	Intra-Site Operational Summary	12
Attachment C.	Overview of Intra-Site Operations within the Geologic Repository Operations Area	2
Attachment D.	Intra-Site Operations Master Logic Diagram	12
Attachment E.	Intra-Site Operations Hazard and Operability Evaluation	16
Attachment F.	Intra-Site Operations Event Sequence Diagrams	10
Attachment G.	Intra-Site Operations Event Trees	38

6. BODY OF CALCULATION

6.1 INITIATING EVENT ANALYSIS

6.1.1 Introduction

Initiating events are identified for the YMP using MLDs that are verified with a HAZOP as described in Section 4. For this analysis, operations within the GROA are grouped into activities or processes with common attributes, as described below, for analysis to ensure that a comprehensive list of initiators was identified for each group. The initiators associated with each of these activities are identified at a level for which historical records exist, for which expert opinion can be obtained, or for which a fault tree model of causes can be developed based on equipment design and intended operations (e.g., human versus automated control). The initiating events identified in this analysis may stem from: (a) external events (analyzed separately), including natural phenomena such as tornadoes, earthquakes, flooding, or lightning, and activities external to the GROA such as aircraft crash or nearby industrial facility activities, or (b) internal events, which include events that could occur randomly within each of these groupings, such as mechanical or electromechanical equipment failure (e.g., crane failure), human failure events associated with the operations of the systems or components (e.g., collision with a structure), and fires or flooding events. These initiating events are depicted in the MLD.

6.1.2 Overview of Intra-Site Operations and Balance of Plant

Consistent with the methodology discussed in Sections 4.3.1.1 and 4.3.4.1, this section contains a brief overview of the Intra-Site Operations including site transportation, Aging Facility, and LLWF, and EDGF activities. BOP activities are discussed briefly, but these facilities are by definition non-nuclear and none of the event sequences developed relate to them. This section provides the basis for the identification of initiating events and the development of event sequences. Operational details are presented at a level that is intended to be sufficient in most cases for development of the MLD, the HAZOP, and the ESDs. Attachments A and B provide supplemental details that may be needed to understand some of the potential initiating events and the subsequent event sequences. Attachment C shows the onsite transportation routes as well as the location of the aging pads, LLWF, and buffer areas within the GROA. BOP facilities within in the GROA are also shown in Attachment C, however, some extend beyond the GROA to provide infrastructure and interface with offsite services and functions (i.e., primary site access road, service roads, South Portal, North Construction Portal, and utilities structures).

The analytical boundary between Intra-Site Operations and each facility is defined based on confinement rather than structure. For the CRCF, the boundary is the outer shield door at the far end of the facility's Entrance Vestibule. For the RF, the boundary terminates at the Cask Preparation Annex confinement door. For the IHF and WHF, the outer door at each facility's Entrance Vestibule entryway demarcates the boundary.

Site transportation includes the movement of waste forms within the GROA using varying casks or overpacks and varying conveyance modes. Loaded transportation casks arrive at the site on either truck trailers or railcars. After initial receipt activities, these conveyances are either moved into the appropriate facility, or they are staged in the Truck or Railcar Buffer Areas until the necessary facility is available to handle the cask and its contents. Site transportation also includes any inter-facility transfers that are required (e.g., the RF cannot load waste packages for emplacement, so all waste forms received there are transferred to another facility for handling).

The Aging Facility provides a location (i.e., two aging pads) where received TAD canisters, DPCs, or HDPCs can be aged safely. If one of these canisters requires thermal management, it is aged and monitored at the designated aging pad location in either an aging overpack (for a TAD canister or DPC) or a HAM (for an HDPC). Each canister remains in the Aging Facility, where it is monitored and maintained, until the decay heat drops to an acceptable level for insertion into a waste package.

LLW management includes transporting LLW generated at any onsite facility to the LLWF (if necessary), and storage and loading for offsite disposal. LLW includes dry solids (dry active waste), liquid, and wet-solid forms that are generated during waste form handling in the GROA. The LLWF is a warehousing facility used to separate, package, and store LLW generated in the GROA pending removal by a contracted vendor to an approved LLW disposal site. The LLWF is a steel framed structure with a number of shielded cells and lay-down areas for storing waste containers. Shielded rooms are used to separate specific LLW products (e.g., empty DPCs), and lay-down areas can be used for storage or sorting. Most of the LLW produced during the pre-closure period results from the waste handling activities in the IHF, CRCF, RF, and, in particular, the WHF.

LLW is handled differently depending on its characteristics. There are three types of LLW: dry active (solid), wet-solid, and liquid. Most LLW can be moved within the LLWF using forklifts and an overhead crane. Forklifts are used for handling pallets and containers. A handling crane runs the extent of the building to handle heavier items such as high-integrity containers (HICs) or empty DPCs.

Liquid waste is accumulated in tanks, the dry wastes (e.g., HEPA filters) are accumulated in staging areas, and spent resin is directly sluiced into a commercial waste contractor's truck-mounted HIC for disposal. All accumulated waste is collected by contractors for handling and for preparation for transfer to an offsite LLW disposal site.

The EDGF is provided to enclose the emergency diesel generators that provide emergency power to the HVAC confinement system, in the event offsite electrical power is lost.

The diesel fuel oil storage tank (Area 70A) stores the fuel necessary for operations equipment (e.g., site transporters and cask tractors). It is a balance of plant facility located within the GROA boundary outside of the security fencing that surrounds the handling facilities.

The remaining BOP facilities provide the space, layout, and embedded facilities that directly or indirectly support the site's infrastructure and operating services systems. The BOP facilities provide infrastructure and services for waste handling operations and waste emplacement facilities, but are not directly involved in any waste handling or emplacement operations or activities. Therefore, there are no initiating events, HAZOP nodes, PFDs, MLDs, ESDs or event trees for BOP facilities or systems.

The operational summary of Intra-Site Operations and LLW management continues in Sections 6.1.2.1 through 6.1.2.13 and is organized according to the nodes, which are indicated in the PFD (Figure 14). The summary is primarily based on the Aging Facility mechanical handling system block flow diagrams (Ref. 2.2.15), (Ref. 2.2.16), (Ref. 2.2.17), (Ref. 2.2.18), (Ref. 2.2.24), and (Ref. 2.2.38), as well as waste stream descriptions, operational needs, and facility descriptions (Ref. 2.2.6), *Basis of Design for the TAD Canister-Based Repository Design Concept* (Ref. 2.2.24), and (Ref. 2.2.42).

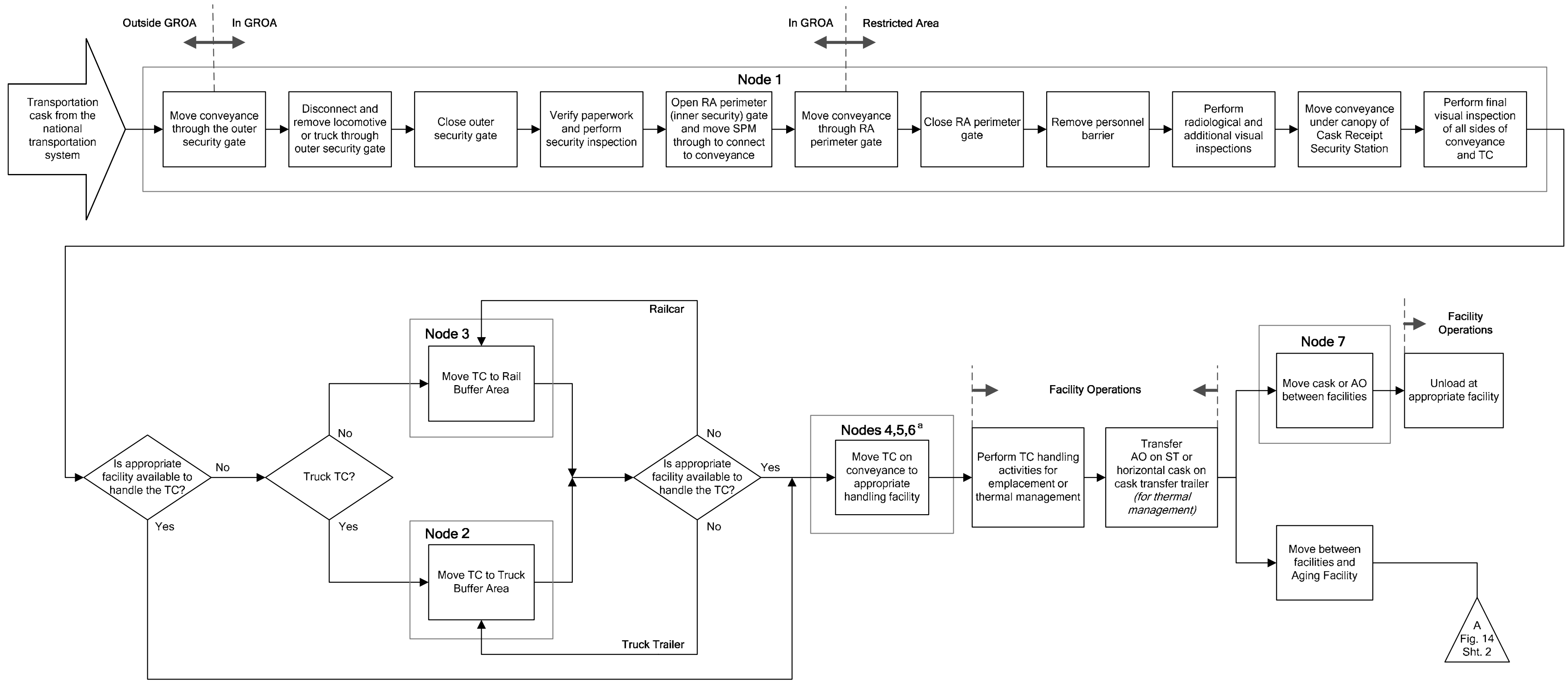
Table 8 and Figure 15 are provided as reference aids to support the descriptions and discussions in Sections 6.1 and 6.2. Table 8 consolidates general waste form information, and Figure 15 shows operational movements of waste forms in the GROA.

Attachment B provides more details on Intra-Site Operations and LLW management activities.

6.1.2.1 Node 1: Receipt of a Transportation Cask

The national transportation system delivers transportation casks containing the various waste forms to the site via either rail or truck. Each transportation cask is moved past the outer security gate and is disconnected from the locomotive or truck. The locomotive or truck exits the first security gate and the gate is closed. After paperwork is verified and a security inspection is performed, the restricted area perimeter (inner security) gate is opened, and the SPM comes through the inner security gate to be connected to the conveyance. The SPM is a multi-wheel, tractor tired and rail-guided vehicle that is used to tow or push railcars, trailers, and other heavy load conveyances. The SPM moves the transportation casks through the restricted area perimeter gate, and the gate is closed. The personnel barrier is removed, if appropriate for the cask type, and radiological and visual inspections are performed. Assuming satisfactory results from these inspections, the conveyance is moved to a position under the canopy of the Cask Receipt Security Station, where final visual inspections of all sides of the conveyance and transportation cask are performed.

This node is based on "Cask Receipt Security Station, Building 30B, General Shipment Arrival" (Ref. 2.2.46).

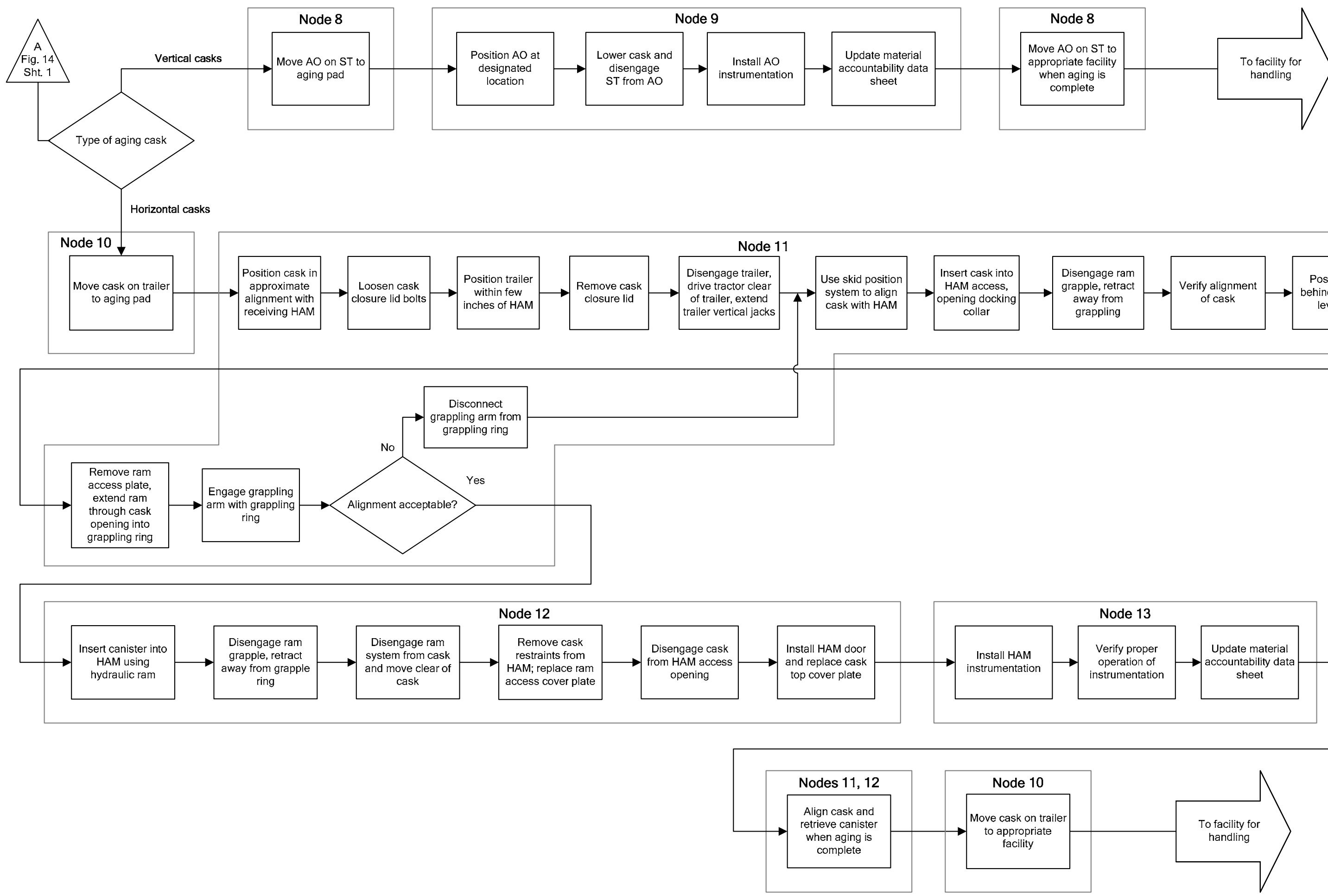


NOTE: [a] Nodes 4, 5, and 6 were initially organized by transportation mode and waste form type; however, the HAZOP revealed that these activities were very similar and could be analyzed and quantified collectively. Therefore, the PFD was modified to group these three nodes into one operational activity.

AO = aging overpack ; GROA = geological repository operations area; RA = restricted area; SPM = site prime mover; ST = site transporter; TC = transportation cask.

Source: Original

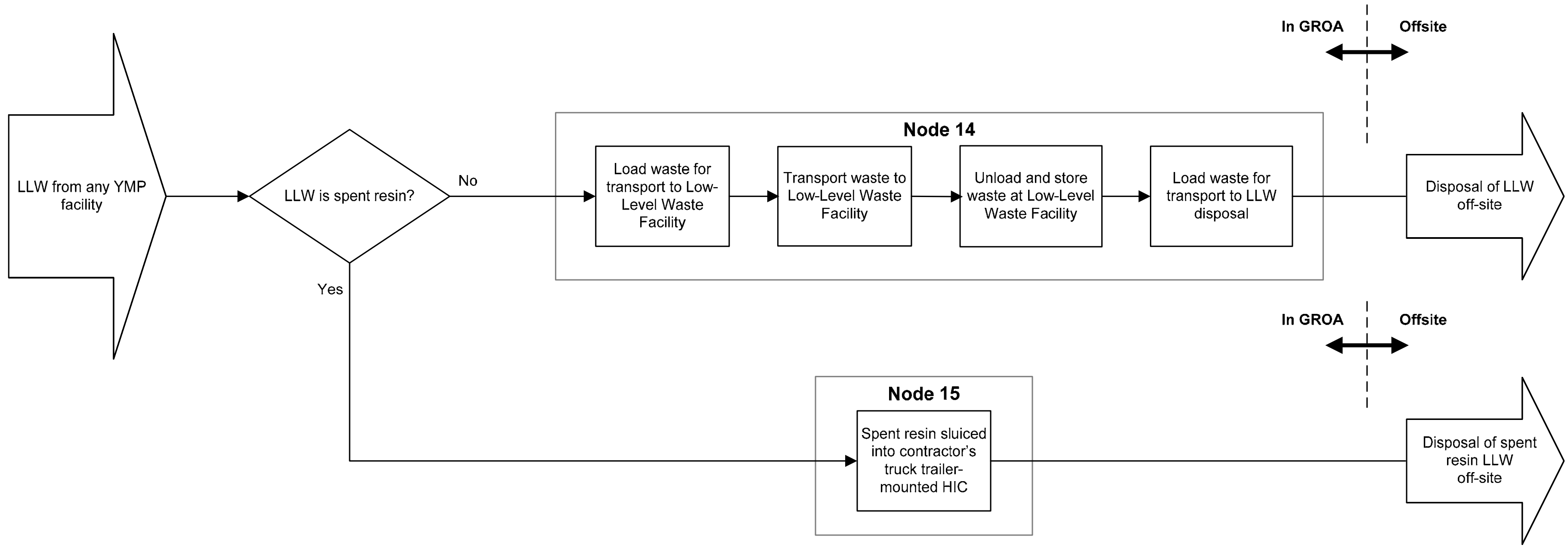
Figure 14. Intra-Site Operations Process Flow Diagram (Sheet 1 of 3)



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
AO = aging overpack; HAM = horizontal aging module; ST = site transporter.

Source: Original

Figure 14. Intra-Site Operations Process Flow Diagram (Sheet 2 of 3)



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
GROA = geological repository operations area; HIC = high-integrity container; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; YMP = Yucca Mountain Project.

Source: Original

Figure 14. Intra-Site Operations Process Flow Diagram (Sheet 3 of 3)

Table 8. Waste Form General Information

Waste Form (Canister)	Typical Contents	Source	Conveyance
MCO	(DOE) SNF	DOE weapons complex and nuclear processing/research facilities (e.g., Savannah River Site and West Valley Demonstration Project)	Railcar or truck trailer
DOE Standardized Canister	(DOE) SNF	Same as above	Railcar or truck trailer
Naval	SNF	U.S. Navy	Railcar
HLW+	Glass logs (vitrified radioactive waste)	DOE (e.g., Hanford)	Railcar
HLW1	Glass logs (vitrified radioactive waste)	DOE (e.g., Hanford)	Truck trailer
TAD	BWR/PWR CSNF (assemblies)	Utilities	Railcar or truck trailer
DPC	BWR/PWR CSNF (assemblies)	Utilities	Railcar
HDPC	BWR/PWR CSNF (assemblies)	Utilities	Railcar
Uncanistered commercial SNF (UCSNF)	CSNF	Utilities	Railcar or truck trailer

NOTE: BWR = boiling water reactor; CSNF = commercial spent nuclear fuel; DOE = U.S. Department of Energy; DPC = dual-purpose canister; HLW = high-level radioactive waste; MCO = multicanister overpack; PWR = pressurized water reactor; SNF = spent nuclear fuel; TAD = transportation, aging, and disposal; UCSNF = uncanistered commercial spent nuclear fuel.

Source: Original

6.1.2.2 Node 2: Movement of a Transportation Cask to Truck Buffer Area

Transportation casks received by truck are moved to the Truck Buffer Area if the appropriate handling facility is not ready to receive it. For example, the necessary handling facility could be performing unloading and loading operations on another waste shipment. The transportation cask is moved to the Truck Buffer Area using the SPM.

This node is based on "Cask Receipt Security Station, Building 30B, General Shipment Arrival" (Ref. 2.2.46).

6.1.2.3 Node 3: Movement of a Transportation Cask to Railcar Buffer Area

Transportation casks received by rail are moved to the Railcar Buffer Area if the appropriate facility is not ready to receive it. The transportation cask is moved to the buffer area by the SPM.

This node is based on "Cask Receipt Security Station, Building 30B, General Shipment Arrival" (Ref. 2.2.46).

ABBREVIATIONS:

WASTE FORMS (CASKS AND/OR CANISTERS)

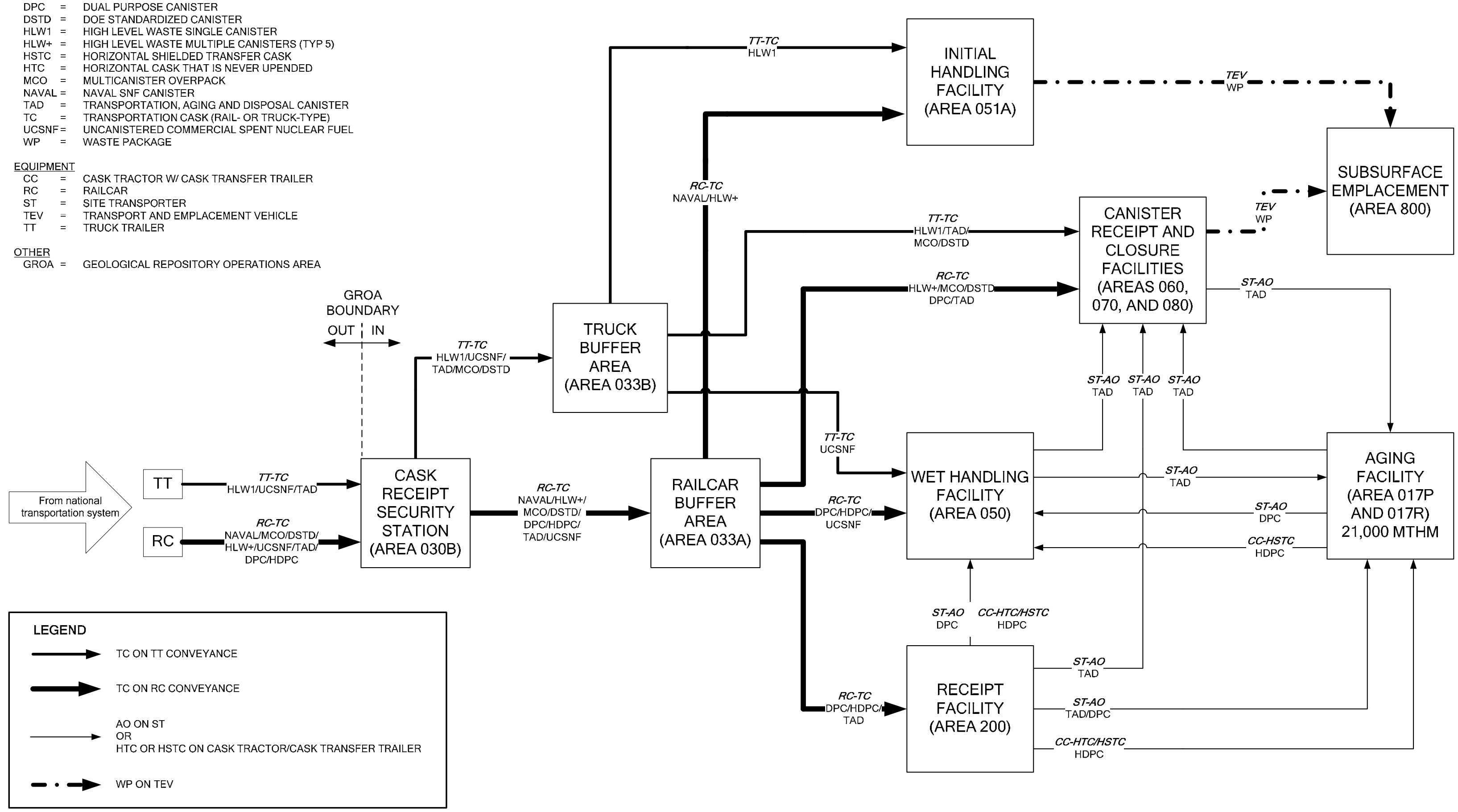
AO = AGING OVERPACK
DPC = DUAL PURPOSE CANISTER
DSTD = DOE STANDARDIZED CANISTER
HLW1 = HIGH LEVEL WASTE SINGLE CANISTER
HLW+ = HIGH LEVEL WASTE MULTIPLE CANISTERS (TYP 5)
HSTC = HORIZONTAL SHIELDED TRANSFER CASK
HTC = HORIZONTAL CASK THAT IS NEVER UPENDED
MCO = MULTICANISTER OVERPACK
NAVAL = NAVAL SNF CANISTER
TAD = TRANSPORTATION, AGING AND DISPOSAL CANISTER
TC = TRANSPORTATION CASK (RAIL- OR TRUCK-TYPE)
UCSNF = UNCANISTERED COMMERCIAL SPENT NUCLEAR FUEL
WP = WASTE PACKAGE

EQUIPMENT

CC = CASK TRACTOR W/ CASK TRANSFER TRAILER
RC = RAILCAR
ST = SITE TRANSPORTER
TEV = TRANSPORT AND EMPLACEMENT VEHICLE
TT = TRUCK TRAILER

OTHER

GROA = GEOLOGICAL REPOSITORY OPERATIONS AREA



Source: Original

Figure 15. Intra-Site Operations Waste Form Flow Diagram

6.1.2.4 Nodes 4, 5, and 6: Movement of a Transportation Cask to the Appropriate Handling Facility

The SPM moves the transportation cask on its conveyance (i.e., truck trailer or railcar) from the Cask Receipt Security Station (Area 030B) or buffer area into the RF, IHF, WHF, or CRCF entrance vestibule, as appropriate. The waste form type governs which waste handling facility is eligible to receive the transportation cask. The surface facility removes the transportation cask from the conveyance and initiates repackaging either into a waste package for emplacement or into an aging cask for transfer between facilities (Section 6.1.2.5, Node 7) or to the Aging Facility (Sections 6.1.2.6 through 6.1.2.11 for descriptions of Nodes 8 through 13).

This node is based on "Cask Receipt Security Station, Building 30B, General Shipment Arrival." (Ref. 2.2.46). Note that waste handling facilities and the related operations are not part of the Intra-Site Operations. For information on waste handling facility operations, refer to the other PCSA analyses for the CRCF, RF, WHF, IHF, and Subsurface Operations.

6.1.2.5 Node 7: Movement of an Aging Overpack or Horizontal Cask between Facilities

Movements between facilities are accomplished with site transporters and cask tractors/cask transfer trailers. The site transporter moves aging overpacks containing TAD canisters or vertical DPCs. The cask tractor towing a cask transfer trailer moves an HDPC in either an HTC or an HSTC. Refer to Attachment A for details on the site transporter, aging overpack, cask tractor/cask transfer trailer, HTC, and HSTC.

6.1.2.6 Node 8: Movement of an Aging Overpack to or from an Aging Pad

Movement of an aging overpack to or from an aging pad in the Aging Facility is accomplished with a site transporter. The site transporter moves aging overpacks containing TAD canisters or vertical DPCs to one of the concrete aging pads for thermal management. Once aging is complete, the site transporter is again used to transport the loaded aging overpack to the appropriate facility for repackaging and emplacement.

This node is described in Block 1.9 in (Ref. 2.2.14); and Blocks 1.8.1 and 1.9.1 in (Ref. 2.2.17). In addition, Node 8 represents the interface between all of the Aging Facility mechanical handling system block flow diagrams (Ref. 2.2.15), (Ref. 2.2.16), (Ref. 2.2.17), (Ref. 2.2.18) and the mechanical handling system block flow diagrams for the surface facilities.

6.1.2.7 Node 9: Position and Age an Aging Overpack on the Aging Pad

The Aging Facility is located north of the North Portal surface facilities and consists of two concrete pads to provide an area for the safe cooling of TAD canisters and DPCs. Encased in an aging overpack, each TAD canister or DPC that requires cooling is positioned on one of the two aging pads. The site transporter is used to move the aging overpack to an assigned location, where it then lowers the aging overpack into place and disengages. Material accountability data sheets are updated to track and manage the waste forms. The loaded aging overpack remains in the Aging Facility until the thermal heat load or waste content has decayed to a level low enough to be accepted by a waste package. When aging is complete, a site transporter moves the aging overpack containing the waste form to the appropriate facility for waste handling.

This node is described in Blocks 1.8 and 2.3 in (Ref. 2.2.15); and Blocks 1.8.2, 2.3.1, and 2.3.2 in (Ref. 2.2.18).

6.1.2.8 Node 10: Movement of a Horizontal Cask to or from the Aging Pad (HAM)

HDPCs that require aging must be cooled in HAMs. Movements to and from the HAM on the aging pad are accomplished using a cask transfer trailer (towed by a cask tractor). If an HDPC arrives at the site requiring aging (i.e., thermal management) before repackaging and emplacement into the repository, a cask transfer trailer is used to transport the loaded HTC to a HAM at the Aging Facility for HDPC insertion. After aging (Section 6.1.2.11, Node 13) the HDPC is retrieved from the HAM into an HSTC (Section 6.1.2.10, Node 12), and the cask transfer trailer transports the loaded HSTC to the WHF.

The HTCs are the property of the shipper; therefore, after the HDPC is removed either for aging in a HAM or for repackaging/emplacement, the HTC is returned to its owner. For the case in which an HDPC is sent to the Aging Facility, the retrieval movement activities are essentially repeated in reverse using a site-owned HSTC on the cask transfer trailer. This is depicted in Figure 14 as two different boxes labeled as Node 10. The loaded HSTC is then transported via cask tractor/cask transfer trailer to the WHF for repackaging and emplacement operations.

This node is described in Block 1.3 in (Ref. 2.2.15), and Block 1.3.1 in (Ref. 2.2.16). In addition, Node 10 represents the interface between the Aging Facility mechanical handling system block flow diagrams (Ref. 2.2.15), (Ref. 2.2.16), (Ref. 2.2.17), and (Ref. 2.2.18) and the mechanical handling system block flow diagrams for the surface facilities.

6.1.2.9 Node 11: Alignment of a Horizontal Cask with HAM

Prior to positioning a cask at the HAM, a portable crane removes the HAM door and places it in a staging rack, and personnel inspect the cavity of the HAM. The cask tractor then positions the cask transfer trailer within a few feet of the HAM, aligning the centerlines of the cask and HAM. The cask lid bolts and lid are removed at the pad, and the cask is aligned to the HAM and stabilized using a hydraulic suspension (hydraulic leveling cask jacks), adjustable trailer bearing plates, and, if needed, assistance from the mobile crane. The cask is inserted into the docking collar, and the hydraulic ram is positioned. The reverse operation is depicted in Figure 14 as the box at the bottom of the page labeled “Nodes 11, 12”.

This node is described in Blocks 1.4 and 1.5 in (Ref. 2.2.15); Block 1.3.2 in (Ref. 2.2.16); and Blocks 1.4.2 through 1.4.5, Blocks 1.5.1 through 1.5.5, and Block 1.5.9 in (Ref. 2.2.17).

6.1.2.10 Node 12: Transfer Canister to or from HAM

After the cask is securely docked to the HAM, the cask transfer trailer’s hydraulic ram is used to push the HDPC out of the cask, inserting it into the HAM. Hydraulic leveling cask jacks (and the mobile crane, if necessary) are used to stabilize the cask and trailer during transfer of the HDPC.

A hydraulic ram and hydraulic power unit are set up behind the cask and aligned to engage the hydraulic ram to the HDPC ram grapple rings. The hydraulic ram cylinder is actuated to insert the HDPC, and after insertion the HAM shield door is placed. The transfer is facilitated using the support guide rails inside the HAM.

After insertion, the HAM is sealed, and the contents, the module used, and the minimum time for aging are logged. Serial numbers are recorded, and checklists are completed to ensure that each horizontal module complies with the loading parameter and limits.

The casks are the property of the shipper; therefore, after the HDPC is removed and placed in the HAM for aging (or, if aging was not required, removed for repackaging/emplacement), the cask is returned to its owner.

Retrieving an HDPC from a HAM is essentially repeating the insertion procedures except for extracting the canister instead of inserting it, and the process uses the same or equivalent equipment. The alignment and positioning activities are essentially repeated (in reverse) using a site-owned HSTC instead of the shipper's cask. After the HDPC has been drawn into the HSTC on the cask transfer trailer, the cask lid is replaced. The cask tractor then pulls the trailer and the loaded HSTC to the WHF for repackaging and emplacement operations. The retrieval operation is depicted in Figure 14 as the box at the bottom of the page labeled "Nodes 11, 12".

This node is described in Blocks 1.4.6 through 1.4.9 and Blocks 1.5.6 through 1.5.8 in (Ref. 2.2.17).

6.1.2.11 Node 13: Age Horizontal Canister in HAM

The Aging Facility includes HAMs whose purpose is to provide an area for the cooling of HDPCs. The HDPCs requiring cooling are placed into HAMs at the Aging Facility (Sections 6.1.2.9, Node 11; and 6.1.2.10, Node 12) and aged until the thermal heat load has decayed to a level low enough to be accepted by a waste package for underground emplacement in the GROA. The HAMs are located in the Aging Facility located north of the North Portal Pad.

Inside the HAM, the HDPC rests on rails. The heavily reinforced concrete sidewalls and top provide shielding as well as protection against natural phenomena. The HAMs are configured with vents and flow paths to permit natural circulation airflow to transfer heat from the waste package to the atmosphere. Instrumentation connected to the HAMs allow workers to monitor the condition of each HDPC so that, once the thermal heat output decays to an acceptable level, the HDPC can be retrieved and transferred to the WHF for packaging and emplacement operations.

This node is described in Block 2.1 in (Ref. 2.2.15) and Block 2.1.1 in (Ref. 2.2.17).

6.1.2.12 Node 14: Management of Other LLW (i.e., Dry Active LLW, Liquid LLW, or Non-Resin Wet-Solid LLW)

The LLWF receives and stores LLW generated during the handling of HLW or SNF at the YMP. Management of LLW includes loading/unloading, onsite transportation and storage. After a LLW stream is characterized, it is loaded onto a transportation vehicle and transported to the

LLWF. The waste stream is unloaded at the LLWF, stored and monitored. The LLWF also provides any necessary capability for LLW transfer to a vendor for disposal.

Other LLW includes: dry solid LLW, also referred to as dry active waste (e.g., HEPA filters, gaskets or seal material, and protective clothing.); liquid LLW (e.g., spent fuel pool treatment system effluents and decontamination system effluents); and non-resin wet-solid LLW (e.g., pool filters and mop heads).

The LLWF includes the capability for short-term storage of LLW contained in drums, metal containers, and HICs. The LLWF also has the capability to receive liquid LLW and contain it in holding tanks external to the building until it can be transferred for disposal.

The LLWF (Building 160) is designed as a steel structure with an exterior steel skin. The overall dimensions are 205 ft × 130 ft. Four separate, partial-height-walls, shielded storage bays are located inside the building on the side of the facility opposite the truck bay. The storage bay exterior concrete walls are 3 ft thick and 20 ft high. Partition walls separating the bays are 2 ft thick. These four bays provide for interim storage of boxes, drums, HICs, filters, and other waste containers.

A pull-through truck bay is located on one end of the building. This area has hatches through which waste containers are moved. An open area is located adjacent to the Receipt Area, which contains a scale and areas for the storage of supplies and tools.

The activities identified in this node are derived from (Ref. 2.2.6) and *Basis of Design for the TAD Canister-Based Repository Design Concept*(Ref. 2.2.24, Section 30).

6.1.2.13 Node 15: Management of Resin Wet-Solid LLW

LLW in the form of spent resin is generated from the WHF pool water treatment system. The water is expected to be contaminated from contamination plated on the commercial spent nuclear fuel (CSNF) assemblies. This node covers the actions associated with the removal and disposal of the spent resin. An offsite vendor uses a truck with a trailer-mounted HIC and associated LLW processing equipment to remove the resin directly from the ion exchangers. The technique used is one of sluicing the resin from its location directly into the HIC, where the spent resin is de-watered. Once the transfer operation is complete, the contractor removes the resin for shipping to a suitable disposal site.

The activities identified in this node are derived from (Ref. 2.2.6) and *Basis of Design for the TAD Canister-Based Repository Design Concept*(Ref. 2.2.24, Section 30).

6.1.3 Identification of Initiating Events

The identification of initiating events is completed by constructing the MLD and supplementing it with a HAZOP. The methodologies for the MLD and HAZOP are described in Sections 4.3.1.2 and 4.3.1.3, respectively. The MLD diagram and HAZOP deviations for the Intra-Site Operations are provided in Attachments D and E, respectively.

To facilitate ESD development, a unique identification number has been assigned to each initiating event. The numbers consist of "ISO-" to identify the facility, followed by a three- or four-digit number. The last two digits of the identification numbers uniquely identify events on each page of the MLD. The first one or two digits specify the MLD page number. For example, "ISO-503" means "initiating event 03 on the page 5 of the MLD" and "ISO-1001" means "initiating event 01 on page 10 of the MLD." A slightly different convention has been used for external events: a prefix "E" has been inserted before the page number. Thus, "ISO-E202" means "external initiating event 02 on page 2 of the MLD." For internal events relating to fire, an "I" has been inserted before the page number. Thus, "ISO-I402" means "internal fire initiating event 02 and page 4 of the MLD."

A comprehensive list of initiating events identified by the MLD and HAZOP is provided in Table 9 for external events and Table 10 for internal events.

Table 9. List of External Initiating Events

Initiating Event Identifier	Initiating Event Description
ISO-E201	Exposure due to seismic events
ISO-E202	Non-seismic geologic activity (including landslides, avalanches)
ISO-E203	Volcanic activity
ISO-E204	Extreme winds/tornadoes (including wind effects from hurricanes)
ISO-E205	External floods
ISO-E206	Lightning
ISO-E207	Loss of power events
ISO-E208	Loss of cooling capability events (non-power cause, including biological events)
ISO-E209	Aircraft crash
ISO-E210	Nearby industrial/military facility events (including transportation events)
ISO-E211	Onsite hazardous materials release
ISO-E212	External fires (including forest fires, grass fires)
ISO-E213	Extraterrestrial activity (including meteorites, falling satellites)

Source: Original

Table 10. List of Internal Initiating Events

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
ISO-I401	Fire at Aging Facility	D-4		F-9
ISO-I402	Fire affects TC during movement between GROA boundary and either buffer area or handling facility	D-4	E-3, E-4, E-5, E-6, E-7	F-9
ISO-I403	Fire affects TC during staging in buffer area	D-4		F-9
ISO-I404	Fire affects AO, HTC, or HSTC during movement among facilities or to/from Aging Facility	D-4	E-8, E-9, E-11	F-9
ISO-501	RC collision leads to TC impact	D-5	E-3, E-4, E-5, E-6	F-1

Table 10. List of Internal Initiating Events (Continued)

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
ISO-502	TT collision leads to TC impact	D-5	E-3, E-7	F-1
ISO-503	RC derailment leads to TC rollover	D-5	E-4, E-5, E-6	F-1
ISO-504	Drop of object onto TC	D-5	E-2	F-1
ISO-601	Impact to HTC or HSTC during movement via cask tractor and CT trailer	D-6	E-11	F-3
ISO-602	Cast tractor/CT trailer drops an HTC or HSTC	D-6	E-11	F-3
ISO-701	ST collision causes impact to AO	D-7	E-8, E-9, E-10	F-2
ISO-702	ST drops AO	D-7	E-8, E-9, E-10	F-2
ISO-801	Collision during loading/unloading operations of LLW container	D-8		F-8
ISO-802	Drop during loading/unloading operations of LLW container	D-8		F-8
ISO-803	Collision during loading/unloading operations of LLW container or transfer pipe/equipment	D-8		F-8
ISO-804	Failure of transfer equipment during loading/unloading of LLW	D-8		F-8
ISO-805	Collision during transport of LLW container	D-8		F-8
ISO-806	Drop during transport of LLW container	D-8		F-8
ISO-807	Collision during transport of LLW container	D-8		F-8
ISO-808	Failure of equipment during transport of LLW	D-8		F-8
ISO-809	Loss of containment boundary	D-8		F-8
ISO-901	Impact to cask (HTC or HSTC) or canister or HAM during insertion and retrieval activities at HAM	D-9		F-4
ISO-1001	Impact to HAM involving auxiliary equipment	D-10		F-4
ISO-1002	Impact with HTC or HSTC involving auxiliary equipment at HAM location	D-10		F-3
ISO-1101	Impact to a single LLW container at the LLWF	D-11		F-5
ISO-1102	Non-fire event involving all LLW containers	D-11		F-6
ISO-1103	Fire event involving all combustible LLW in the LLWF	D-11		F-7

NOTE: [a] Screened from consideration. Refer to *Intra-Site Operations and BOP Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1, Section 6.0).

AO = aging overpack; CT = cask transfer; ESD = event sequence diagram; HAM = horizontal aging module; HSTC = horizontal shielded transfer cask; ISO = Intra-Site Operations; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; MLD = master logic diagram; RC = railcar; SPM = site prime mover; ST = site transporter; TC = transportation cask; TT = truck trailer; WHF = Wet Handling Facility.

Source: Original

6.2 DEVELOPMENT OF INTERNAL EVENT SEQUENCES

6.2.1 Introduction

The ESD technique, as described in Section 4.3.2.1, is used to develop event sequences associated with initiating events identified in the MLD. The resulting ESDs are presented in Attachment F. Sections 6.2.2 through 6.2.10 describe the logical flow of each ESD, from the initiating event, through the pivotal events, to the end state. In order to clearly understand the ESD logic, the text and the ESD should be considered together. The descriptions for each ESD provide the following information:

- Internal events addressed by the ESD
- Pivotal event descriptions and the associated decision logic
- A summary description of each event sequence embodied in the ESD.

6.2.2 ISO-ESD-01: Event Sequences for Activities Associated with Movement of a Transportation Cask during Site Transportation

6.2.2.1 Overall Description

This ESD delineates the event sequences that arise after a railcar derailment or after a railcar or truck trailer collision that occurs while a transportation cask is moved onsite, or after an object is dropped onto a cask during receipt activities. (Figure F-1 and Section 6.1.2.1, Node 1; Section 6.1.2.2, Node 2; Section 6.1.2.3, Node 3; and Section 6.1.2.4, Nodes 4, 5, and 6). This ESD applies to the following waste forms:

- Naval canisters in transportation casks
- DOE multi-canister overpacks (MCO) (containing SNF) in transportation casks
- DOE standardized canisters (containing SNF) in transportation casks
- DOE HLW (multicanister) in transportation casks
- Uncanistered CSNF in transportation casks
- TAD canisters in transportation casks
- DPCs in transportation casks
- HDPCs in HTCs.

6.2.2.2 Initiating Events

The individual initiating events that are identified in the MLD are indicated on the ESD by their initiating event identifiers and, for quantification purposes, are collected into one of four groups (represented as small circles), as follows:

1. Railcar collision leads to transportation cask impact
2. Railcar derailment leads to transportation cask rollover
3. Truck trailer collision leads to transportation cask impact and subsequent rollover
4. Drop of object onto transportation cask.

A collision could result, for example, from a loss of control of the conveyance that leads to an overturn and impact to the transportation cask. A derailment could occur due to a distortion in the rail system. An impact could arise from a crane failure that leads to a drop of a load onto the transportation cask. These groups are summarized by an aggregated initiating event, which is represented by the big circle in the ESD. The big circle represents a derailment, collision, or drop event that occurs during transit of the transportation cask outside of a waste handling facility but within the boundaries of the GROA.

6.2.2.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the containment boundary of the transportation cask remains intact. Determining whether or not the containment boundary of the transportation cask remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the cask and the strength of the cask. If the containment boundary remains intact, no radioactive release occurs. However, the question remains whether or not the transportation cask shielding remains intact, as posed by the next pivotal event. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is OK. Otherwise, the shielding is degraded and the event sequence terminates in a direct exposure to radiation.

If the containment boundary of the transportation cask does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), whether or not a radionuclide release occurs depends on whether or not the canister containment boundary remains intact. (This pivotal event is not applied to uncanistered CSNF.) Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the canister containment remains intact, radionuclide release is avoided, but a direct exposure occurs due to an implied loss of shielding caused by the cask breach. Otherwise, the containment boundaries of both the cask and the canister have been breached and a radionuclide release is inevitable. The subsequent and final pivotal event characterizes the potential for moderator intrusion. This pivotal event asks whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator (for example, from fire suppression water from a fire truck) enters the breached canister, the corresponding event sequence terminates in an unfiltered radionuclide release that must be further evaluated with respect to criticality (indicated as Also Important to Criticality). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals as the means of criticality prevention (Ref. 2.2.39). Note that Also Important to Criticality means that event sequences tagged as such that are found to be Category 1 or Category 2, must be demonstrated to be subcritical in the subsequent categorization analysis. Demonstration of subcriticality is not required for event sequences that are Beyond Category 2.

In summary, for each waste form (except UCSNF as noted) and each initiating event group (small circle), the ESD delineates five event sequences:

1. Cask containment and shielding remain intact (no radiation exposure)

2. Cask containment remains intact, but deformation of cask shielding causes direct exposure

3. Cask containment fails, canister containment remains intact, but implied loss of cask shielding causes direct exposure (note that canister containment is not applied to UCSNF)

4. Cask containment fails, canister containment fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release (note that canister containment is not applied to UCSNF)

5. Cask containment fails, canister containment fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality (note that canister containment is not applied to UCSNF).

6.2.3 ISO-ESD-02: Event Sequences for Activities Associated with Aging Overpack Transit, Placement, and Retrieval

6.2.3.1 Overall Description

This ESD delineates the event sequences that arise after an impact to or drop of an aging overpack during transit, placement and retrieval activities (Figure F-2 and Section 6.1.2.5, Node 7; Section 6.1.2.6, Node 8; and Section 6.1.2.7, Node 9). This ESD applies to the following waste forms:

- TAD canisters in aging overpacks
- DPCs in aging overpacks.

6.2.3.2 Initiating Events

The individual initiating events that are identified in the MLD are indicated on the ESD by their initiating event identifiers and, for quantification purposes, are collected into one of two groups (represented as small circles), as follows:

1. Site transporter collision causes impact to aging overpack
2. Site transporter drops aging overpack.

The groups are summarized by an aggregated initiating event, the big circle in the ESD. The big circle represents an impact to or drop of an aging overpack that occurs during transit, and placement or retrieval activities.

6.2.3.3 System Response

After the structural challenge occurs, the first pivotal event asks whether the containment boundary of the canister remains intact. Determining whether or not the containment boundary of the canister remains intact may be probabilistic, in that the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the aging overpack shielding remains intact, as posed by the next pivotal event. Loss of shielding in an aging overpack could occur from an impact, but only if the aging overpack is fractured such that a direct pathway is formed. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is OK. Otherwise, the event sequence terminates in a direct exposure to radiation.

If the containment boundary of the canister does not remain intact, a radionuclide release is inevitable. The next pivotal event asks if moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator enters the breached canister, the corresponding event sequences terminate in an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as Also Important to Criticality). Moderator intrusion is selected for the pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals as the means of criticality prevention (Ref. 2.2.39). Note that Also Important to Criticality means that event sequences tagged as such that are found to be Category 1 or Category 2, must be demonstrated to be subcritical in the subsequent categorization analysis. Demonstration of subcriticality is not required for event sequences that are Beyond Category 2.

In summary, for each waste form and each initiating event group (small circle), the ESD delineates four event sequences:

1. Canister containment and shielding remain intact (no radiation exposure)
2. Canister containment remains intact, but loss of aging overpack shielding causes direct exposure
3. Canister containment fails but moderator intrusion is prevented, resulting in an unfiltered radionuclide release
4. Canister containment fails and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.4 ISO-ESD-03: Event Sequences for Activities Associated with the Transporting and Positioning of an HTC or an HSTC

6.2.4.1 Overall Description

This ESD delineates the event sequences that arise after an impact to or drop of a loaded HTC or HSTC during transport and positioning operations (Figure F-3 and Section 6.1.2.5, Node 7; Section 6.1.2.8, Node 10; and Section 6.1.2.9, Node 11). This ESD applies to the following waste forms:

- HDPCs in HTC or HSTCs.

6.2.4.2 Initiating Events

The individual initiating events that were identified in the MLD are indicated on the ESD by their initiating event identifiers and, for quantification purposes, are collected into one of two groups (represented as small circles), as follows:

1. Cask tractor/cask transfer trailer drops an HTC or HSTC (e.g., after collision or jack knife)

2. Impact to an HTC or HSTC (e.g., during positioning).

The groups are summarized by an aggregated initiating event, the big circle in the ESD. The big circle represents an impact to or drop of a loaded HTC or HSTC resulting from transit and positioning activities.

6.2.4.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the containment boundary of the HTC or HSTC remains intact. Determining whether or not the containment boundary of the cask remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the cask and the strength of the cask. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the cask shielding remains intact, as posed by the next pivotal event. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is OK. Otherwise, the shielding is degraded and the event sequence terminates in a direct exposure to radiation.

If the containment boundary of the cask does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), whether or not a radionuclide release occurs depends on whether or not the canister containment boundary remains intact. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the canister containment remains intact, radionuclide release is avoided, but a direct exposure occurs due to an implied loss of shielding caused by cask breach. Otherwise, the containment boundaries of both the cask and the canister have been breached and a radionuclide release is inevitable. The subsequent and final pivotal event characterizes the potential for moderator intrusion. This event provides further delineation of the event sequences by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator (for example, from fire suppression water from a fire truck) enters the breached canister, the corresponding event sequences terminate in an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as Also Important to Criticality). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals as the means of criticality prevention (Ref. 2.2.39). Note that Also Important to Criticality means that event sequences tagged as such that are found to be Category 1 or Category 2, must be demonstrated to be subcritical in the subsequent categorization analysis. Demonstration of subcriticality is not required for event sequences that are Beyond Category 2.

In summary, for each waste form and each initiating event group (small circle), the ESD delineates five event sequences:

1. Cask containment and shielding remain intact (no radiation exposure)

2. Cask containment remains intact, but deformation of cask shielding causes direct exposure

3. Cask containment fails, canister containment remains intact, but implied loss of cask shielding causes direct exposure

4. Cask containment and canister containment fail, but moderator intrusion is prevented, resulting in an unfiltered radionuclide release

5. Cask containment and canister containment fail, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.5 ISO-ESD-04: Event Sequences Associated with Impacts during Canister Operations at a Horizontal Aging Module

6.2.5.1 Overall Description

This ESD delineates the event sequences that arise after an impact occurs to a cask, canister, or a HAM during canister insertion or retrieval on the aging pad (Figure F-4 and Section 6.1.2.10, Node 12 and Section 6.1.2.11, Node 13). This ESD applies to the following waste forms:

- HDPCs in open HTCs, HSTCs, or HAMs.

6.2.5.2 Initiating Events

The individual initiating events that are identified in the MLD are presented on the ESD by their initiating event identifiers and, for quantification purposes, are collected into one of two groups (represented as small circles), as follows:

1. Impact to cask (HTC or HSTC) or canister or HAM during insertion and retrieval activities at HAM

2. Impact to HAM involving auxiliary equipment.

A canister could be impacted from an inadvertent movement of the cask transfer trailer that pinches or shears a partially inserted canister. An impact to a HAM or cask while the two are docked for transfer operations could occur from a vehicle collision or crane drop. The groups are summarized by an aggregated initiating event, which is represented by the big circle in the ESD. The big circle represents impacts that occur during canister operations at a HAM.

6.2.5.3 System Response

After an impact event has occurred, the first pivotal event asks whether or not the containment boundary of the canister remains intact. Determining whether or not the canister remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the cask or HAM shielding remains intact, as posed by the next pivotal event. Because the HAM is vented, it does not provide containment and, because the cask is docked to the HAM for these operations, the cask also does not provide containment. If the cask or HAM shielding remains intact, there is no exposure of personnel to radiation beyond that of normal operations, and the end state is OK. Otherwise, the shielding is degraded and the event sequence terminates in a direct exposure to radiation.

If the containment boundary of the canister does not remain intact, a radionuclide release is inevitable. The remaining pivotal event asks whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator enters the breached canister, the corresponding event sequences terminate in an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as Also Important to Criticality). Moderator intrusion is selected for the pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals as the means of criticality prevention (Ref. 2.2.39). Note that Also Important to Criticality means that event sequences tagged as such that are found to be Category 1 or Category 2, must be demonstrated to be subcritical in the subsequent categorization analysis. Demonstration of subcriticality is not required for event sequences that are Beyond Category 2.

In summary, for each waste form and the initiating event group, the ESD delineates four event sequences:

1. Canister containment and shielding remain intact (no radiation exposure)

2. Canister containment remains intact, but deformation of shielding causes direct exposure

3. Canister containment fails and moderator intrusion is prevented, resulting in an unfiltered radionuclide release

4. Canister containment fails, but moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.6 ISO-ESD-05: Event Sequences for Activities Associated with a Single Low-Level Waste Container at the Low-Level Waste Facility

6.2.6.1 Overall Description

This ESD delineates the event sequences that arise after an impact to a single LLW container occurs at the LLWF (Figure F-5 and Section 6.1.2.12, Node 14; and Section 6.1.2.13, Node 15). This ESD applies to the following LLW forms:

- Dry active LLW
- Wet-solid LLW
- Liquid LLW.

6.2.6.2 Initiating Events

The initiating event that is identified in the MLD is presented on the ESD as an event involving a single LLW container at the LLWF, which could include an impact resulting from various standard industrial operations within the facility. This initiating event is represented by the big circle on the ESD.

6.2.6.3 System Response

After the initiating event has occurred, the lone pivotal event asks whether the containment boundary of the LLW container remains intact. Determining whether or not the containment boundaries remain intact may be probabilistic in that the event involves uncertainties in both the load imposed on the container and the strength of the container. If the container remains intact, radionuclide release is avoided, and the end state is OK. Otherwise, the containment boundary of the container has been breached and a radionuclide release is inevitable.

In summary, for each LLW form and the initiating event, the ESD delineates two event sequences:

1. Containment boundary of the LLW container remains intact (no radiation exposure)

2. Containment boundary does not remain intact, resulting in an unfiltered radionuclide release.

6.2.7 ISO-ESD-06: Event Sequences Associated with Non-Fire Events Causing Release from all Low-Level Waste Containers at the Low-Level Waste Facility

6.2.7.1 Overall Description

This ESD delineates the event sequences that arise after a non-fire event, such as an earthquake, that results in a release from all of the LLW containers at the LLWF (Figure F-6). There are no direct node associations between this event sequence and the PFD. This ESD applies to the following LLW forms:

- Dry active LLW
- Wet-solid LLW
- Liquid LLW.

6.2.7.2 Initiating Events

The initiating event that is identified in the MLD is presented on the ESD as a non-fire event involving all of the LLW containers at the LLWF. This event could result from, for example, an earthquake. This initiating event is represented by the big circle on the ESD.

6.2.7.3 System Response

After the initiating event has occurred, the lone pivotal event asks whether the containment boundaries of the containers remain in place. Determining whether or not the containment boundaries remain intact may be probabilistic in that the event involves uncertainties in both the load imposed on the containers and the strength of the containers. If the containers remain intact, radionuclide release is avoided, and the end state is OK. Otherwise, the containment boundary of one or more containers has been breached and a radionuclide release is inevitable.

In summary, for each LLW form and the initiating event, the ESD delineates two event sequences:

1. Containment boundaries of the LLW containers remain intact (no radiation exposure)

2. Containment boundaries do not remain intact, resulting in an unfiltered radionuclide release.

6.2.8 ISO-ESD-07: Event Sequences Associated with Fire Events for All Combustible Low-Level Radioactive Waste in the Low-Level Waste Facility

6.2.8.1 Overall Description

This ESD delineates the event sequences that occur when a fire threatens the entire inventory of combustible LLW at the LLWF. This includes event sequences associated with a fire that affects the entire facility (Figure F-7). There are no direct node associations between this event sequence and the PFD. This ESD applies to the full inventory of combustible LLW, which is contained in sorting bags, HICs, boxes, or 55-gallon drums. The other waste forms, liquid and wet-solid LLW are either noncombustible (e.g., DPCs, liquid waste, and fiberglass HEPA filters), or they are in sealed containers (e.g., pool filter drums) (Ref. 2.2.24, Sections 13.1 and 30; and Ref. 2.2.6).

6.2.8.2 Initiating Events

The initiating event that is identified in the MLD is presented on the ESD as a fire event involving all of the combustible LLW at the LLWF. This event results from fire that affects the entire LLWF. The initiating event is represented by the big circle on the ESD.

6.2.8.3 System Response

After the fire event has occurred (thermally challenging the LLW containers), the lone pivotal event asks whether the containment boundaries of these containers remain intact. Determining whether or not the containment boundaries remain intact may be probabilistic in that the event involves uncertainties in both the heat load imposed on the container and the ability of the container to resist thermal failure. If the LLW containers remain intact, radionuclide release is avoided, and the end state is OK. Otherwise, the containment boundaries have been breached and a radionuclide release is inevitable.

In summary, for LLW and the initiating event, the ESD delineates two event sequences:

1. Containment boundaries of the LLW containers remain intact (no radiation exposure)

2. Containment boundaries do not remain intact, resulting in an unfiltered radionuclide release.

6.2.9 ISO-ESD-08: Event Sequences for Activities Associated with Waste Transfers to the Low-Level Waste Facility

6.2.9.1 Overall Description

This ESD delineates the event sequences that arise after an impact, equipment failure, or inadequate maintenance/monitoring affects one or more LLW containers or LLW transfer pipes/equipment during LLW loading and unloading activities or during transport between the waste handling facilities and the LLWF (Figure F-8 and Section 6.1.2.12, Node 14 and Section 6.1.2.13, Node 15). This ESD applies to the following waste forms:

- Dry active LLW
- Wet-solid LLW
- Liquid LLW.

6.2.9.2 Initiating Events

The individual initiating events that were identified in the MLD are indicated on the ESD by their initiating event identifiers and, for quantification purposes, are collected into one of four groups (represented as small circles), as follows:

1. Impacts involving dry active LLW or liquid LLW

2. Loss of containment boundary (e.g., pipe break or valve failure)

3. Equipment failure or collision involving wet-solid LLW (e.g., resin or filters)

4. Equipment failure involving liquid LLW (non-WHF-generated) and non-resin wet-solid LLW.

The groups are summarized by an aggregated initiating event, the big circle in the ESD. This big circle represents collectively the events that result from LLW loading/unloading and transport processes and activities.

6.2.9.3 System Response

After the structural challenge has occurred, the lone pivotal event asks whether the containment boundaries of the LLW containers remain in place. Determining whether or not the containment boundaries remain intact may be probabilistic in that the event involves uncertainties in both the load imposed on a container and the strength of a container. If the LLW containers remain intact, radionuclide release is avoided, and the end state is OK. Otherwise, the containment boundary of one or more containers has been breached and a radionuclide release is inevitable.

In summary, for each LLW form and each initiating event group (small circle), the ESD delineates two event sequences:

1. Containment boundaries of the LLW containers remain intact (no radiation exposure)
2. Containment boundaries do not remain intact, resulting in a radionuclide release.

6.2.10 ISO-ESD-09: Event Sequences for Fire Occurring during Site Transportation Activities or at the Aging Facility

6.2.10.1 Overall Description

This ESD delineates the event sequences that occur when a fire threatens one or more waste forms during site transportation activities or at the Aging Facility (Figure F-9). There are no specific node associations between this event sequence and the PFD because a fire is possible wherever and whenever in the process that combustible materials are present. This ESD applies to the following waste forms:

- Naval canisters in transportation casks
- DOE MCOs (containing SNF) in transportation casks
- DOE standardized canisters (containing SNF) in transportation casks
- DOE HLW (multicanister or single canister) in transportation casks
- Uncanistered CSNF in transportation casks
- TAD canisters in transportation casks or aging overpacks
- DPCs in transportation casks or aging overpacks
- HDPCs in HAMs, HTCs, or HSTCs.

6.2.10.2 Initiating Events

The individual initiating events that are identified in the MLD are indicated on the ESD by their initiating event identifiers and, for quantification purposes, are collected into one of four groups (represented as small circles), as follows:

1. Fire affects transportation cask during staging in buffer area

2. Fire affects transportation cask during movement between GROA boundary and either buffer area or a handling facility

3. Fire affects aging overpack, HTC, or HSTC during movement among facilities or to or from the Aging Facility

4. Fire at Aging Facility.

The groups are summarized by an aggregated initiating event, the big circle in the ESD. This big circle represents the events that result from fire that affects one or more waste forms during site transportation activities or at the Aging Facility.

6.2.10.3 System Response

After the fire has occurred (thermally challenging a waste form), the first pivotal event asks whether the containment boundary remains intact. Determining whether or not the containment boundary remains intact may be probabilistic in that the event involves uncertainties in both the heat load imposed and the ability of the containment to resist thermal failure. For each waste form considered, the thermal analysis may consider the configuration of that waste form. For example, if a canister is in a transportation cask, the ability of the cask to resist thermal failure and protect the canister contained within may be considered in the analysis. The same method may be used to determine a thermal failure of a canister that is contained within an aging overpack or HAM. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not shielding remains intact, as posed by the next pivotal event. If the shielding remains intact, there is no exposure of personnel to radiation, and the end state is OK. Otherwise, the shielding is degraded and the event sequence terminates in a direct exposure to radiation.

If the containment boundary does not remain intact, a radionuclide release is inevitable. The subsequent pivotal event provides further characterization of each potential event sequence regarding whether moderator is prevented from entering the breached canister. In the case of a fire, the analysis of this pivotal event is subject to the expectation that fire-suppression water from open hydrants and/or fire trucks would be in abundant supply. In the affirmative case, that is, the absence of moderator intrusion, the unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator enters a breached canister, the corresponding event sequences terminate in an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as Also Important to Criticality). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals as the means of criticality prevention (Ref. 2.2.39). Note that Also Important to Criticality means that event sequences tagged as such that are found to be Category 1 or Category 2, must be demonstrated to be subcritical in the subsequent categorization analysis. Demonstration of subcriticality is not required for event sequences that are Beyond Category 2.

In summary, for each waste form and each initiating event group (small circle), the ESD delineates three event sequences:

1. Containment remains intact and no radiation exposure results

2. Containment fails, but moderator intrusion is prevented, resulting in an unfiltered radionuclide release

3. Containment fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.3 EVENT TREES

Event trees are developed for the ESDs discussed above, with a differentiation for the type of waste forms involved in the process. The structure of the ESDs allows for a straightforward transposition of ESDs into event trees, as described in Section 4.3.2.2. For ESDs that have more than one initiating event (small circle), there is a pair of corresponding event trees, one for the initiating events and the other for the corresponding system response. Although all initiating events in a given initiator event tree transfer to the same system response event tree, the pivotal event conditional probabilities may depend on the initiating event. For ESDs with only one initiating event, a single event tree (incorporating the initiating event and the system response), suffices. In cases for which the initiating event or events apply to more than one waste form, a corresponding initiator event tree (or combined initiator and response event tree) is constructed for each waste form. This is necessary because the frequency of occurrence of an end state is proportional to the number of waste forms, and the pivotal event probabilities may be different for different waste forms. Attachment G presents the event trees. Table G-1 shows the correlation between the event trees in Attachment G and the ESDs in Attachment F.

7. RESULTS AND CONCLUSIONS

This analysis constitutes a systematic examination of the operations of the Intra-Site Operations and identifies and develops potential event sequences that could occur in the Intra-Site Operations during the preclosure period. The results of this analysis are:

- An MLD for Intra-Site Operations (Attachment D) that identifies potential initiating events for event sequences
- A set of ESDs for Intra-Site Operations (Attachment F) that graphically depict the event sequences that may be initiated by the initiating events identified in the MLD
- A set of event trees (Attachment G) that translate the ESDs into a convenient form for event sequence quantification and categorization.

ATTACHMENT A
INTRA-SITE OPERATIONS LAYOUT AND EQUIPMENT SUMMARY

A1 PURPOSE OF THIS ATTACHMENT

This attachment supplements the facility overview that is provided in Section 6.1.2. Details about the layout of the facility and important pieces of equipment are provided here. The intent is primarily to present information that is needed for the identification of initiating events and the development of event sequences. Additional information is provided simply to give an idea of the scale of the facility and the sizes of important pieces of equipment. Because the results of this analysis only weakly depend on the dimensions, weights, and weight capacities given, they may change without affecting the results.

A2 FACILITY OVERVIEW

Intra-Site Operations include those activities that occur in outdoor areas of the GROA (e.g., inter-facility site transportation or the Aging Facility) or in facilities that are not utilized for waste packaging and emplacement operations (e.g., the LLWF, the balance of plant (non-nuclear) facilities, and the EDGF).

Intra-Site activities occur in the GROA, located in Midway Valley at the eastern margin of Yucca Mountain. Elevations range from about 3,510 ft (1,070 m) on the east side of Midway Valley to about 4,003 ft (1,220 m) in the northwestern side. The initial surface facilities site layout is shown in Figure C-1 of Attachment C. Section 6.1.2 of this analysis provides an operational overview of the Intra-Site activities that are involved with nuclear materials. In particular, Figure 15 in Section 6.1.2 provides a conceptual schematic representation of Intra-Site Operations, and Figure 14 provides a PFD, which emphasizes the operational aspects important to event sequence development.

A3 INTRA-SITE OPERATIONS FACILITY AND EQUIPMENT DESCRIPTIONS

Descriptions for Intra-Site Operational areas that are important for event-sequence development are provided in this section roughly in the order experienced by a waste form traveling through the GROA, followed by descriptions of other areas and facilities relevant to Intra-Site Operations. Important pieces of equipment are covered in the description of the operational area or facility in which the equipment is predominantly located or first encountered by a waste form in transit. The descriptions are synthesized, in part, from general arrangement drawings for the Aging Facility (Ref. 2.2.11); (Ref. 2.2.9); (Ref. 2.2.10); and (Ref. 2.2.12) and the LLWF (Ref. 2.2.32); (Ref. 2.2.31); (Ref. 2.2.34); (Ref. 2.2.33); and (Ref. 2.2.35).

The Aging Facility mechanical handling block flow diagram, which occupies several sheets as follows, was also used to synthesize the facility and equipment descriptions.

- *Aging Facility Mechanical Handling System Block Flow Diagram-Level 2* (Ref. 2.2.15)

- *Aging Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 1 of 4* (Ref. 2.2.16)

- *Aging Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.17)
- *Aging Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 4* (Ref. 2.2.18)

A3.1 SITE TRANSPORTATION

Site transportation activities involve movement of waste forms through outdoor non-facility areas of the GROA, including arrival on a railcar or truck trailer, security and radiological inspection activities, movement to and staging in buffer areas if needed, movement to or among facilities, and transport to or from the Aging Facility. For purposes of the analysis, emplacement transportation (i.e., movement using the TEV) is evaluated as part of Subsurface Operations and is excluded from analysis of site transportation activities.

Upon arrival at the GROA, the rail or truck conveyance is disconnected from the commercial transporter. Security inspections are performed, and then a SPM is connected to transport the transportation cask on the conveyance through the inner security gate. The SPM is the primary mode of transport for railcars and truck trailers through the GROA. If appropriate for the type of transportation cask received, a diesel-powered portable crane is used to remove the cask personnel barrier.

After passing radiological inspections, the SPM moves the conveyance either directly to the appropriate facility or, if the facility is unavailable, to one of the two buffer areas: Railcar Buffer Area (Area 33A) or Truck Buffer Area (Area 33B).

The transportation cask is removed from the conveyance in one of the surface facilities. No further site transportation activities are required for the waste form if it is ready for emplacement. If the waste form requires aging or if it requires movement to another facility for additional handling activities, the waste form, which is no longer on the original conveyance, is transported either by a site transporter (for vertical casks/overpacks) or by a cask tractor/cask transfer trailer (for horizontal casks/overpacks).

Buffer Areas: The GROA buffer railyard includes multiple rail spurs for queuing and staging incoming loaded casks and staging outbound emptied casks and other commercial vehicles. Rail spurs are accessed through positioning of various switches controlled by operators. Casks in queuing and storage have impact limiters attached that meet the transportation safety requirements in 10 CFR Part 71 (Ref. 2.3.2). To the greatest practical extent, loaded casks are positioned away from normally occupied work areas in an effort to lower worker doses.

A Truck Buffer Area (Area 033B) provides a staging location inside the GROA for truck trailers carrying transportation casks. The transportation casks have impact limiters that meet the requirements of 10 CFR Part 71 (Ref. 2.3.2). The function of this buffer area is to provide a holding area away from other work areas for when the appropriate handling facility is temporarily unavailable to accept the waste form.

The buffer areas are a defined requirement in *Project Operational and Performance Requirements* (Ref. 2.2.41, Section 2.1.5)[1] and are identified in *Geologic Repository Operations Area North Portal Site Plan* (Ref. 2.2.43).

The equipment used for site transportation operations is described below. Note that site transporters and cask tractors/cask transfer trailers are also used for site transportation activities between facilities, but these are the primary modes of transportation associated with Aging Facility operations and are therefore described in Section A3.2.

Diesel-Powered Portable Crane

An industry standard portable 80-ton crane is available for removal of personnel barriers and general, non-nuclear heavy lifting operations.

Site Prime Mover

The SPM is a multi-wheel, tractor-tired and rail-guided vehicle used to tow or push railcars, truck trailers, and other heavy load conveyances as needed. For site transportation activities, the SPM is the principal equipment used to move loaded and empty railcar and truck trailer conveyances throughout the GROA and in and out of the handling facilities entrance vestibules.

A3.2 AGING FACILITY

The Aging Facility is located north of the North Portal. The facility consists of two adjacent aging areas: Area 17P and Area 17R. Each is composed of a series of ground-level reinforced concrete slabs. Area 17P, the northern most aging pad, comprises one concrete slab 114 ft × 640 ft, two concrete slabs 114 ft × 718 ft each, and four concrete slabs 114 ft × 1,030 ft each, providing a combined capacity of 1,248 aging positions for aging overpacks (Ref. 2.2.9). Area 17R, the southern most aging pad, comprises eight concrete slabs 114 ft × 718 ft each, providing 1,152 positions for vertical aging overpacks, and two concrete slabs 63 ft × 431 ft, providing 100 positions for HDPCs in HAMs (Ref. 2.2.10).

The function of the Aging Facility is to provide an area for the cooling of TAD canisters and vertical or horizontal dual-purpose canisters that contain CSNF.

The TAD canisters and DPCs that require cooling are placed into aging overpacks. The aging overpacks are moved between facilities and positioned on an aging pad using site transporters. The HDPCs that require cooling are housed in the stationary HAMs. A cask tractor with a cask transfer trailer is used to move an HDPC between facilities and to or from the Aging Facility. HDPCs are transported either in the HTC (pre-aging) or the site-use-only HSTC (post-aging). The canisters are aged and monitored until the thermal heat load has decayed to a level low enough to be accepted by a waste package for underground emplacement in the repository (Ref. 2.2.38).

The following equipment is used in Aging Facility operations.

[1] This reference was revised February 6, 2008. The revision did not affect the information cited, and the reference was not changed or reordered in Section 2.2.

Aging Overpack

The function of an aging overpack is to hold TAD canisters and DPCs for cooling on the aging pad. An aging overpack is a movable, robust structural component constructed of an outer steel shell, a thick layer of reinforced concrete, and an inner steel liner. The thermal vents on the aging overpack are designed to cool the contents using natural circulation. The design and operation are similar to NRC-certified CSNF storage overpacks and modules. Aging overpacks are for onsite use only.

The aging overpack has the following design features:

- Maximum overall dimensions are 12 ft in diameter by 22 ft tall (dimensions provide low center of gravity to prevent tip over during beyond-design-basis-ground-motion)
- Maximum empty weight is 205 tons
- Maximum fully loaded weight is 250 tons
- Passive cooling vents to maintain air flow through the unit (designed to hold and age canisters with high thermal output until output decreases to at least 11.8 kW)
- The combined neutron and gamma dose rate is limited by design to less than 40 mrem/hr at contact with any exterior surface of the overpack.

The physical characteristics of the aging overpack are shown and described in the mechanical equipment envelope drawings (Ref. 2.2.23); (Ref. 2.2.21); and (Ref. 2.2.22); (Ref. 2.2.38); and (Ref. 2.2.48). Additional descriptions and requirements are in *Basis of Design for the TAD Canister-Based Repository Design Concept* (Ref. 2.2.24).

Site Transporter

Site transporters are used to securely move aging overpacks between handling facilities and to and from the Aging Facility. The site transporter is similar to transporters supplied to existing dry storage facilities. It is a diesel/electric self-propelled tracked (crawler-type) vehicle with a maximum speed of 2.5 mph. The site transporter is designed to lift and transport vertically an aging overpack. It employs an electromechanical screw lift mechanism (four ACME-type screws that turn to raise or lower an ACME nut) to raise or lower the forks. It has a built-in cask restraint system to stabilize the load during movement (*Site Transporter Mechanical Equipment Envelope and Mechanical Handling Design Report - Site Transporter* (Refs. 2.2.52; 2.2.36)).

The site transporter has the following design features (*Site Transporter Mechanical Equipment Envelope and Mechanical Handling Design Report Site Transporter* (Refs. 2.2.52; 2.2.36)):

- It can carry an aging overpack or STC
- Diesel fuel tank size is less than 100 gallons
- It can negotiate roadways with a 5% grade and up to a 2% cross-slope

- The maximum speed is 9 mph (controlled by a governor on the diesel generator and by the physical limitations of the drive system)
- The maximum lifting height for an aging overpack is 12 in.

The site transporter is shown in *Site Transporter Mechanical Equipment Envelope* (Ref. 2.2.52).

Horizontal Aging Module

The function of a HAM is to hold an HDPC for cooling in the Aging Facility. The internal design configuration of the HAM accommodates the dimensions and characteristics of the existing HDPCs stored at reactor sites. Each HAM is a stationary structural component that is box-like and constructed of thick-walled steel-reinforced concrete, similar to the advanced horizontal storage unit approved by the NRC for use at the nuclear power plants. Inside the HAM, the HDPC rests on rails. Thermal vents on the HAM are designed to cool the contents using natural circulation, and the heavily reinforced concrete sidewalls and top provide shielding and protection. HAMs are installed and secured on the aging pad side-by-side and in series, and the end modules in a row include a secured 3-ft thick shield wall.

Each HAM has the following design features:

- Maximum overall dimensions are 26 ft 4 in long by 8.5 ft wide by 21 ft tall (dimensions and side-by-side grouping configuration provide stability and prevent tip over during beyond-design-basis-ground movement)
- Passive cooling vents to maintain air flow through the unit (designed to hold and age canisters with high thermal output until output decreases to at least 11.8 kW)
- The combined neutron and gamma dose rate is limited by design to less than 40 mrem/hr at contact with any exterior surface of the module.

The physical characteristics of a HAM are shown in *Aging Facility Horizontal Aging Module Mechanical Equipment Envelope* (Ref. 2.2.13) and described in *Mechanical Handling Design Report for Surface Aging Equipment* (Ref. 2.2.38). In addition, the planned layout for these stationary units is depicted in *Aging Facility General Arrangement Aging Pad Area Plan* (Ref. 2.2.11). Additional description and requirements are in *Basis of Design for the TAD Canister-Based Repository Design Concept* (Ref. 2.2.24).

HTC

A typical HTC is fabricated mostly of stainless steel and includes two concentric shells with a neutron shield of cast lead situated between the shells. Overall dimensions and maximum weight (loaded and unloaded) are in accordance with HDPC and HAM requirements.

An HTC is shipped and owned by the sender, to whom it is returned after the HDPC is removed.

This equipment description is based on *Basis of Design for the TAD Canister-Based Repository Design Concept* (Ref. 2.2.24) and *Certificate of Compliance for Radioactive Material Packages, Transnuclear Inc., Application Dated August 30, 2007*. (Ref. 2.2.56).

Horizontal Shielded Transfer Cask

An HSTC is used to retrieve an HDPC from a HAM in the Aging Facility. Loaded HSTCs are moved from the Aging Facility to the WHF on the cask transfer trailer pulled by the cask tractor.

An HSTC is designed to provide protection and capability equivalent to a typical HTC. The HSTC has a cylindrical 68-in.-diameter cavity and length sufficient for either boiling water reactor or pressurized water reactor DPCs, but spacers are used in the cask to fill the cavity length for the shorter pressurized water reactor DPCs. The cask is capable of rotating between the vertical and horizontal positions on the support skid. The cask has a top cover plate fitted with a lifting eye to allow removal when the cask is oriented horizontally.

Each HSTC has the following design features:

- Maximum overall dimensions are 94 in. in diameter by 217 in. long
- Maximum loaded weight is 125 tons
- Maximum dimensions for HAM interface is 82 in. in diameter by 12 in. deep
- The combined neutron and gamma dose rate is limited by design to less than 100 mrem/hr at contact with any exterior surface of the module.

The HSTC is shown in *Aging Facility Horizontal STC Mechanical Equipment Envelope* (Ref. 2.2.14) and is described in *Mechanical Handling Design Report for Shielded Transfer Casks* (Ref. 2.2.37) and *Basis of Design for the TAD Canister-Based Repository Design Concept* (Ref. 2.2.24).

Cask Tractor (see also Cask Transfer Trailer)

The cask tractor is an over-the-road diesel-powered tow tractor used to haul the cask transfer trailer. It has multiple wheels for stability. The cask tractor's coupler elevation matches the cask transfer trailer's coupler. The trailer design requires the height to be as low as possible to minimize cask lift height and HAM portal height. In addition, the wheel base (of both) is sufficiently wide to preclude tip over during a seismic event. This means the tractor has a low center of gravity. The cask tractor has the following design features:

- Maximum loaded trailer weight is 165 tons.
- Dimensions are 26 ft long and 12 ft high.
- Maximum speed is 2.5 mph, due to designed limiters.

The cask tractor is shown in (Ref. 2.2.7), and a description for the cask tractor and its operation are included in (Ref. 2.2.38).

Cask Transfer Trailer (with Hydraulic Ram)

The function of the cask transfer trailer is to convey HDPCs in either HTCs (pre-aging) or HSTCs (post-aging) between facilities. The cask transfer trailer is towed by the cask tractor. It consists of a heavy industrial trailer with multiple wheels with a wide wheel base, and includes a transfer support skid, a hydraulic ram, and alignment instruments. The cask transfer trailer is designed to safely insert HDPCs carried by HTCs into the HAM (using the hydraulic ram) and then, after sufficient cooling, to safely retrieve the canister from the HAM into an HSTC for transfer to the appropriate waste handling facility for packaging and emplacement.

The cask transfer trailer hydraulic ram system is used to insert an HDPC into a HAM. The ram consists of a hydraulic cylinder with a capacity and a reach sufficient for HDPC insertion and, after aging, retrieval from the HAM. The design of the ram support system provides a direct load path for the hydraulic ram reaction forces during HDPC transfer to and from the HAM. The system uses an adjustable rear ram support for alignment at the rear of the ram and a fixed set of trunnion towers as a front support.

The cask transfer trailer has the following design features:

- The trailer and skid have a payload capacity of approximately 125 tons

- The trailer is designed to ride as low to the ground as possible to minimize the cask height and the necessary HAM portal height. This also provides for a low-center of gravity.

- Hydraulic leveling jacks allow vertical alignment with the HAM

- The nominal trailer bed height during canister transfer to the HAM is such that the HTCs or HSTC is not elevated more than 5 ft 6 in. above grade, as measured from the lowest point on the cask

- The hydraulic ram is designed to ensure it does not puncture, scratch, or deform a canister.

The cask transfer trailer is shown in (Ref. 2.2.8) and (Ref. 2.2.13), and a description for the cask transfer trailer and its operation are included in (Ref. 2.2.38).

Mobile Crane (30-ton)

A diesel-powered commercial mobile crane is used to support HDPC insertion and retrieval operations to and from a HAM on an aging pad. The 30-ton crane is capable of lifting HAM concrete closure ports and the end cover lids of HTCs and HSTCs (Ref. 2.2.10). It may also be used to remove the cask transfer trailer hydraulic ram from unloaded cask transfer trailers.

The mobile crane has the following design features:

- The maximum road grade is 5%
- The crane boom angle is between -3 degrees and +76 degrees

- Height of lifting hook is approximately 65 ft at a 45-degree boom angle.

The mobile crane is shown in *Aging Facility Mobile Crane Mechanical Equipment Envelope* (Ref. 2.2.19).

Aging Facility Mobile Platform

The Aging Facility mobile platform is a battery-powered, self-propelled scissor lift platform used to provide personnel full vertical access to an aging overpack. The primary purpose of this equipment is ventilation maintenance and connection of resistance thermometers to the external monitoring system. Design features include:

- Extended height is approximately 19 ft from the ground to the platform working surface (i.e., not including safety rails)

- Maximum lift capacity is 600 lbs.

The mobile platform is shown in *Aging Facility Mobile Platform Mechanical Equipment Envelope* (Ref. 2.2.20).

A3.3 LOW-LEVEL WASTE FACILITY

The purpose of the LLWF is to characterize and store site-generated LLW waste prior to offsite disposal. The LLW results from repository operations and comprises dry active LLW, wet-solid LLW, and liquid LLW.

The facility includes truck shipping and receiving docks and has shielded high-bay rooms to provide for storage of dry active LLW and wet-solid LLW, including but not limited to, used HEPA filters (Room 1009), drums (Room 1008), loaded high-integrity containers, and empty DPCs. These rooms (or cells) are physically separated from adjacent rooms or cells by shielding walls, allowing for storage and related operations to continue while keeping to as low as reasonably achievable standards.

Liquid LLW generated at the WHF is transferred via buried double-walled pipes to the three 25,000 gal liquid LLW collection tanks at the LLWF. WHF liquid LLW consists primarily of potentially contaminated pool water. The relatively small quantities of liquid LLW produced by facilities other than the WHF are accumulated in small satellite collection tanks to be shipped via truck to the LLWF as needed.

DPC shells can be received at the LLWF via shielded transfer casks dedicated to that purpose and moved between the WHF and the LLWF on a site transporter.

The LLWF has two truck docks for receipt and shipping of dry active LLW and wet-solid LLW. A truck entrance bay (Room 1001) is also available to perform truck loading/unloading in an enclosure. A sloped access ramp provides truck access to the tank farm on the north side of the facility (Room 1016), where liquid LLW is processed by offsite vendors using privately owned equipment (Ref. 2.2.31).

After characterizing and packaging, the LLW is cleared for offsite disposal. All LLW is shipped offsite by vendor-supplied transportation.

The facility equipment used for moving and handling LLW in NRC and U.S. Department of Transportation compliant containers includes an overhead 50-ton crane, onsite trailers, forklifts, and (for emptied DPCs in dedicated shielded transfer casks) site transporters.

This equipment is shown and described in *Basis of Design for the TAD Canister-Based Repository Design Concept*(Ref. 2.2.24), (Ref. 2.2.31), (Ref. 2.2.32), (Ref. 2.2.33), (Ref. 2.2.34), and (Ref. 2.2.35).

A3.4 EMERGENCY DIESEL GENERATOR FACILITY

The EDGF encloses the emergency diesel generators and related structures, systems, and components. The facility is a single-story structure with a footprint measuring approximately 174 ft long × 98 ft wide, and a height of approximately 23 ft (not including equipment located on or extending above the roof). The facility's exterior walls are constructed of reinforced concrete. Two 90,000-gallon underground storage tanks are located approximately to the north of the building and store diesel fuel oil for the generators. The emergency diesel generators provide emergency power to pre-selected loads (i.e., those loads critical to nuclear safety or equipment ITS) in the event that offsite electrical power is lost.

The EDGF (Area 260) is located within the protected area of the GROA, North Portal Site, between the WHF (Area 050) and CRCF 1 (Area 060). The EDGF provides enclosed space for the systems and components that provide redundant emergency electrical power for ITS electrical circuits in the CRCF 1 (Area 060), CRCF 2 (Area 070), CRCF 3 (Area 080), WHF (Area 050), and RF (Area 200), upon loss of offsite electrical power. The EDGF provides a suitable environment for personnel and equipment; protects the systems operating within the building from natural and induced environments and provides space and layout for maintenance and testing, operational control and monitoring, safeguards and security systems, fire protection systems, ventilation systems, and utility systems.

The facility and equipment descriptions are based on the following documents: (Ref. 2.2.26), (Ref. 2.2.27), (Ref. 2.2.28), (Ref. 2.2.29), (Ref. 2.2.30), and (Ref. 2.2.24).

A3.5 BALANCE OF PLANT

The diesel fuel oil storage tank (Area 70A) stores the fuel necessary for operations equipment (e.g., site transporters and cask tractors). It is a balance of plant facility located within the GROA boundary outside of the security fencing that surrounds the handling facilities (*Geologic Repository Operations Area North Portal Site Plan* (Ref. 2.2.43). The tank is 30 ft in diameter and 23 ft high and designed to hold 120,000 gal of diesel fuel oil (Ref. 2.2.25). Mobile tanker trucks with portable pumps supply fuel oil to the tanks.

The remaining areas identified as BOP, a partial list of which is provided below, have no nuclear operations. Therefore, these areas are not described further.

- Standby Diesel Generator Facility

- Central Control Center Facility
- Site Roadways
- Site Railways
- Helicopter Pad
- Batch Plant
- Utility Support Facilities
- Offsite Facility
- BOP Infrastructure
- Craft Shop and Equipment Yard

ATTACHMENT B
INTRA-SITE OPERATIONAL SUMMARY

B1 INTRODUCTION

The description of operations in Section 6.1 and this attachment emerged from a cooperative effort involving PCSA personnel (facility leads, human reliability analysts, and equipment reliability analysts), nuclear operations personnel, and other engineering personnel. The PFD was developed while preparing for the HAZOP study because this is a precondition for conducting the HAZOP study. Furthermore, the specific processes described in Section 6.1 and this attachment emerged during the HAZOP meetings and subsequent discussions among the above parties. This multidisciplinary effort was led by the Preclosure Safety Analysis group and is documented herein.

A summary of Intra-Site Operations is presented to provide the context within which the event sequences were developed. Intra-Site Operations comprise a number of functional entities, including:

- Site transportation processes to move waste forms within the GROA and to and from facilities
- Aging Facility, where TAD canisters, DPCs, and HDPCs are aged if needed until the decay heat reaches a level acceptable for a waste package to permit emplacement in the repository
- LLWF, where LLW is stored pending offsite disposal
- Emergency Diesel Generator Facility.

For purposes of the preclosure safety analysis, emplacement activities using the TEV are not included as part of Intra-Site Operations. TEV operations are analyzed as part of Subsurface Operations. PCSA analyses regarding the TEV are in the *Subsurface Operations Event Sequence Development Analysis*.

B2 FACILITY OVERVIEW

This attachment describes the various operations within the GROA covering onsite transportation (excluding TEV movements); canister aging activities at the Aging Facility; and loading, unloading, transportation and storage of LLW, and the EDGF. BOP facilities and activities are non-nuclear, and are not described in this document. The operations are presented according to the nodes of the Intra-Site PFD, Figure 14. The major pieces of equipment, such as the SPM, site transporter, cask tractor with a cask transfer trailer, are summarized in Attachment A.

Site transportation includes the movement of waste forms within the GROA using varying casks or overpacks and varying conveyance modes. Loaded transportation casks arrive at the site on either truck trailers or railcars. After initial receipt activities, these conveyances are either moved into the appropriate facility, or they are staged in the Truck or Railcar Buffer Areas until the necessary facility is available to handle the cask and its contents. Site transportation also includes any inter-facility transfers that are required (e.g., the Receipt Facility cannot load waste packages for emplacement, so all waste forms received there are transferred to another facility for handling).

The Aging Facility provides a location (i.e., two aging pads) where received TAD canisters, DPCs, or HDPCs can be aged safely. If one of these canisters requires thermal management, it is and aged and monitored at the designated aging pad location in either an aging overpack (for a TAD canister or DPC) or a HAM (for an HDPC). Each canister remains in the Aging Facility, where it is monitored and maintained, until the decay heat drops to an acceptable level for insertion into a waste package.

LLWF activities include the loading and unloading, transportation, and storage of site-generated LLW (i.e., dry active LLW, wet-solid LLW, and liquid LLW). Offsite vendors sort and process these wastes as needed for transport, and then they remove them for final disposal at an approved offsite LLW repository.

The Emergency Diesel Generator Facility houses two separate and independent emergency diesel generator units with associated subsystems. The emergency diesel generators automatically initiate to provide power to ITS HVAC confinement systems in the RF, CRCF, and WHF in the event that offsite power is lost. There are no waste handling operations associated with this facility, and it is not further described herein.

The operations and facilities considered collectively as BOP are non-nuclear. Review of the BOP operations within the GROA did not identify any initiating events and, thus, no event sequences were developed involving these facilities or their operations. A partial list of the facilities included as BOP is provided below for information.

- Standby Diesel Generator Facility
- Central Control Center Facility
- Site Roadways
- Site Railways
- Helicopter Pad
- Batch Plant
- Utility Support Facilities
- Offsite Facility
- BOP Infrastructure
- Craft Shop and Equipment Yard.

B3 NODE 1: RECEIPT OF A TRANSPORTATION CASK

Move Conveyance through the Outer Security Gate

- Crew members are available to guide and facilitate movement as the conveyance is moved by the commercial carrier into a predesignated area for receiving.

Disconnect and Remove Locomotive or Truck through Outer Security Gate

- The conveyance is placed in a predesignated area
- Crew members disconnect the commercial transporter (locomotive or truck)
- The commercial transporter exits through the outer gate.

Close Outer Security Gate

- Crew members close the outer security gate to preclude or limit other vehicles or conveyances from the area until initial receipt activities are completed.

Verify Paperwork and Perform Security Inspection

Once the casks pass through the gate, they are inspected to confirm that casks are correctly described and number coded. The coded values are transmitted to the National Control Center for the control of radioactive materials.

- Security personnel verify the transportation and accountability paperwork
- Security personnel perform an initial security inspection of the cask and conveyance.

Open Restricted Area Perimeter (Inner Security) Gate and Move SPM through to Connect to Conveyance

- Crew members open the Restricted Area perimeter gate.

- Crew members move the SPM into the area and position it near the conveyance.

- The SPM is connected to the conveyance. The SPM can move on either rails or site roadways.

Move Conveyance with SPM through Restricted Area Perimeter Gate

- The SPM is driven by crew members to pull the conveyance on a rail for railcars (crew controls speed, but does not steer) or on a roadway for a truck trailer (crew controls speed and steering).

- Crew members can control the speed, including stopping and starting, and a speed limiter (approximately 9 mph) is on the conveyance.

- When parking, crew members must set the brakes and chock the wheels of the railcar or set the brakes and turn off the truck trailer.

- When in the rail or truck yard, the crew members can switch the railcars – this involves engaging/disengaging the connector and air hoses for the braking system to the conveyance.

- There is an interlock that, if the air hoses for the braking system fail, sever, or disconnect, then the mechanical brakes will automatically engage. So, if the conveyance separates from the SPM, then the railcar or trailer will automatically stop.

- Construction activities will not be in the vicinity of normal operations and are expected to have an independent road system.

Close Restricted Area Perimeter Gate

- Crew members close the outer security gate to prohibit or limit unmonitored movement of vehicles in the area.

Remove Personnel Barrier

The personnel barrier is removed and stored using the mobile crane with a personnel barrier lifting device, common tools, and a mobile access platform. In order to remove the personnel barrier from the cask conveyance, crew members must first unbolt the barrier from the cask. After the crew members are positioned a safe distance away from the cask conveyance, the crane operator maneuvers the crane and removes the personnel barriers as follows:

- Crane operator aligns crane to personnel barrier, and the crew attaches the rigging

- Crane operator lifts the personnel barrier vertically

- Crane operator moves the personnel barrier laterally to a position above the barrier staging location

- Crane operator lowers the personnel barrier, and the crew detaches the rigging.

Perform Radiological and Additional Visual Inspections

- Radiation crew member checks radiation levels of the transportation cask

- Security personnel perform a ground visual check of the conveyance and the transportation cask.

Move Conveyance under Canopy of Cask Receipt Security Station

- The SPM is driven by crew members that pull the conveyance to the designated area under the canopy of the Cask Receipt Security Station on a rail for railcars and on a roadway for a truck trailer. For a truck trailer, crew members can control both the speed and direction of movement; however, for a railcar, crew members can control the speed, but only forwards and backwards movement of the conveyance.

Perform Final Visual Inspection of All Sides of Conveyance and Transportation Cask

Cask Receipt Security Station equipment and building design provide personnel full visual access to the transportation cask and conveyance, allowing a more thorough inspection than from ground level.

- Security personnel perform a final visual check of all sides of the conveyance and the transportation cask.

With the paperwork (information on shipper, contents, etc.) and the condition of the cask approved, the cask can be moved to the appropriate facility (refer to Nodes 4, 5, and 6). If the facility is not available, the cask is moved into a buffer area: Area 033A for railcars or Area 033B for truck trailers (refer to Nodes 2 and 3).

B4 NODES 2 AND 3: MOVEMENT OF A TRANSPORTATION CASK TO (TRUCK OR RAILCAR) BUFFER AREA

If the appropriate handling facility is not prepared to receive the transportation cask or if the facility is engaged in handling operations for another cask or canister, the transportation cask is sent to the appropriate buffer area until the required facility becomes available. Transportation casks are positioned in the buffer areas to minimize potential personnel exposure.

B5 NODES 4, 5, AND 6: MOVEMENT OF A TRANSPORTATION CASK TO THE APPROPRIATE HANDLING FACILITY

These nodes are analyzed as a single operational node. Nodes 4, 5, and 6 cover the movement of transportation casks to handling facilities. The handling facilities, including RF, CRCF, IHF, and WHF, prepare the contents of transportation casks (i.e., canistered or uncanistered radioactive waste forms) for packaging and emplacement in the repository or, if needed, for thermal aging at the Aging Facility prior to emplacement.

The following operations are typical for turnover to the RF, CRCF, or IHF.

- A crew is at the entrance to the handling facility to guide and assist movement of the transportation cask. The transportation cask, whether on a railcar or truck, is conveyed to the facility by the SPM. (The SPM runs on either rail or road.)

- Once the conveyance reaches the facility, the crew opens the outer overhead door and directs it through.

- The outer door is closed, and the SPM moves the conveyance into and through the Entrance Vestibule. The movement is halted temporarily to allow the facility's crew to verify that the waste form received matches their pre-job plan.

- If the waste form matches the pre-job plan, the outer shield door is opened and the conveyance is moved into the preparation area. At this point, the facility assumes control of the conveyance and transportation cask.

The following operations are typical for turnover to the WHF.

- A crew is at the entrance to the WHF to guide and assist movement of the transportation cask. The transportation cask, whether on a railcar or truck, is conveyed to the facility by the SPM. (The SPM runs on either rail or road.)

- Once the conveyance reaches the WHF, the crew opens the outer reinforced shield door and directs it through.

- The outer reinforced shield door is closed. Movement is halted to allow the WHF facility's crew to verify that the waste form received matches their pre-job plan.

- If the waste form matches the pre-job plan, the facility assumes control of the conveyance and transportation cask.

B6 NODE 7: MOVEMENT OF AN AGING OVERPACK OR HORIZONTAL CASK BETWEEN FACILITIES

Only two facility designs allow for loading of waste packages for emplacement: IHF and CRCF. As a result, inter-facility movements will be necessary. The following inter-facility movements are permitted (refer also to Figure 15). This does not include movements to or from the Aging Facility, which are reviewed as Node 8 for aging overpacks and Node 10 for HTCs and HSTCs.

1. RF to WHF or CRCF.
2. WHF to CRCF.

IHF does not receive waste forms from any other handling facility, nor does it manage any type of waste form that requires thermal aging or special handling by WHF. As a result, Node 7 does not apply to IHF.

The RF cannot prepare waste forms for emplacement, so transportation casks arriving at the RF that do not require thermal management are prepared for transfer to WHF or CRCF. The waste form type determines the overpack and transfer equipment used, as follows:

- A vertical DPC is transferred to the WHF in an aging overpack using a site transporter.

- A TAD canister is transferred to the CRCF in an aging overpack using a site transporter.

- An HDPC is transferred to the WHF in the HTC. RF crew members shift the HTC from the original conveyance (i.e., the railcar) onto a cask transfer trailer. A cask tractor pulls the cask transfer trailer to the WHF.

The WHF cannot load waste packages for emplacement, so transportation casks or aging overpacks arriving at the WHF that do not require thermal management are prepared for transfer to the CRCF.

- The contents of vertical DPCs and HDPCs are transferred into TAD canisters. The TAD canisters are placed into aging overpacks. The loaded aging overpacks are moved to the CRCF using a site transporter.

- The WHF also receives transportation casks containing uncanistered SNF. WHF crew members transfer this waste form into a TAD canister, and then place the TAD canister into an aging overpack. Loaded aging overpacks are moved to the CRCF using a site transporter.

B7 NODE 8: MOVEMENT OF AN AGING OVERPACK TO OR FROM AN AGING PAD

The RF, WHF, and CRCF can transfer DPCs and TAD canisters in aging overpacks to the Aging Facility, if thermal management of the waste form is required. Node 8 activities do not apply to the IHF, because it does not receive waste forms that require aging.

Aging overpacks are moved onsite via site transporter on approved site roadways, which are either paved or compacted aggregate. The maximum speed of the site transporter is limited to 2.5 mph by design.

The facility releasing the aging overpack (containing a DPC or TAD canister) for relocation to the Aging Facility is responsible for properly securing the aging overpack on the site transporter. Handling facility crew move the loaded site transporter into the facility's Entrance Vestibule, where control is relinquished to site transportation personnel (except for WHF, which relinquishes control at the outer facility door).

- Site transportation crew members use a remote control to move and steer the loaded site transporter, which can be controlled from a separate, speed-limited site vehicle if necessary.

- Crew members maneuver the site transporter from the handling facility to the Aging Facility on approved site roadways.

B8 NODE 9: POSITION AND AGE AN AGING OVERPACK ON THE AGING PAD

The site transporter is the primary equipment used to position the aging overpacks on one of two aging pads. Positions for the aging overpacks are allocated on the pads, and the site transporter moves down lanes to place an aging overpack in its designated location. The lines of aging overpacks form a regular array, with equidistant spacing. The aging overpack is not bolted or tied down at the location. The aging overpacks are designed to possibly slide laterally during an earthquake, but cannot tip over and damage either the aging overpack or the canisters contained within.

Position Aging Overpack at Designated Location

- Crew members use the remote control to move the loaded site transporter to a position near the assigned location on the aging pad.
- Crew members use the remote control to maneuver the loaded site transporter into the specific designated location.

Lower Cask and Disengage Site Transporter from Aging Overpack

- Crew members use the remote control to lower the aging overpack until it is no longer supported by the site transporter's forks.
- Aging Facility crew members remove the restraints.
- Crew members use the remote control to retract the forks and move the site transporter.

Install Aging Overpack Instrumentation

- Crew members use common tools and a scissor lift platform to install the monitoring instrumentation on the aging overpack.
- Crew members use common tools and test equipment to verify that the instrumentation is properly connected and functional.

Update Material Accountability Data Sheet

- Crew members update the material accountability data sheet to ensure accurate accounting of the material in the Aging Facility.

B9 NODE 10: MOVEMENT OF A HORIZONTAL CASK TO OR FROM THE AGING PAD (HAM)

The RF and WHF can transfer HDPCs in HTCs (or in HSTCs, if necessary) to the Aging Facility, if thermal management is required. Node 10 activities do not apply to the IHF, because it does not receive waste forms that require aging.

Horizontal casks (i.e., HTCs and HSTCs) are moved via cask transfer trailer pulled by a cask tractor traveling on approved site roadways. Crew members drive the cask tractor, pulling the cask on the cask transfer trailer to the Aging Facility. The maximum speed by design is 2.5 mph.

The facility releasing the cask (containing an HDPC) for relocation to the Aging Facility is responsible for properly securing the cask onto the cask transfer trailer and for securely connecting the cask transfer trailer to the cask tractor. Handling facility crew move the cask tractor and cask transfer trailer into the facility's Entrance Vestibule.

- Site transportation crew members drive the cask tractor pulling the cask transfer trailer out of the facility's Entrance Vestibule.

- Crew members maneuver the cask tractor/cask transfer trailer from the handling facility to the Aging Facility on approved site roadways.

B10 NODE 11: ALIGNMENT OF A HORIZONTAL CASK WITH HAM

This node deals with the cask transfer activities at a HAM. The cask tractor maneuvers the cask transfer trailer so that the cask is approximately aligned with the HAM opening. The purpose of the ram is to transfer the HDPC between a transportation cask and a HAM. Each HAM is designed to hold and age one HDPC.

Position Cask in Approximate Alignment with HAM

- Crew members remove the HAM door
- After ground crew members are moved a safe distance from the crane operation, the crane operator lifts the cover, and places it in a staging area.
- For HDPC insertions only, crew members perform a cavity inspection to ensure that the HAM is fit to receive a canister.
- Aging Facility crew members use the cask tractor to maneuver the cask transfer trailer into alignment with the HAM opening.

Loosen Cask Closure Lid Bolts

Position Trailer within Few Inches of HAM

- Crew members manipulate the cask tractor and cask tractor trailer to refine the alignment between the cask and the HAM opening and to move the trailer close to the HAM.

Remove Cask Closure Lid

- The cask closure lid is unbolted and the crane operator lists the lid after ground crew members are moved to a safe distance.
- The crane operator moves the cask lid laterally to its designated staging area.

Disengage Trailer, Drive Tractor Clear of Trailer, Extend Trailer Vertical Jacks

Use Skid Position System to Align Cask with HAM

- Crew members engage the cask transfer trailer’s skid to align the cask with the HAM opening.

Insert Cask into HAM Access Port, Opening Docking Collar

- Crew members engage the cask transfer trailer's skid to move the cask forward into the HAM access port. Proper alignment opens the docking collar.

Disengage Ram Grapple, Retract Away From Grappling, Position Ram behind Cask and Level Ram, Remove Ram Access Plate, Extend Ram through Cask Opening into Grappling Ring, Engage Grappling Arm with Grappling Ring

- Crew members initiate and then monitor the cask transfer trailer's automated ram operation and then visually verify them.

- If alignment is not acceptable, crew members disconnect the grappling arm from the grappling ring, reset, and then repeat the previous steps, starting with using the skid position system to align the cask with the HAM opening.

- If alignment is not acceptable, crew members disconnect the grappling arm from the grappling ring, reset, and then repeat the previous steps, starting with using the skid position system to align the cask with the HAM opening.

- If alignment is acceptable, crew members continue by disconnecting the grappling arm from the grappling ring.

B11 NODE 12: TRANSFER CANISTER TO OR FROM HAM

The cask transfer trailer is designed to smoothly move the canister into or out of the HAM.

To move an HDPC out of the HAM, Node 11 operations above are essentially reversed. The cask transfer trailer must be aligned in the same way as when inserting the canister.

Insert (or Remove) Canister at HAM using Hydraulic Ram Equipment

- Personnel initiate and then monitor the cask transfer trailer's automated ram operations.

- To insert the canister, the ram pushes the canister into the HAM.

- To remove the canister, the ram has a clamping device on its end to engage the DPC.

Disengage Ram Grapple, Retract Away from Grapple Ring

- Personnel initiate and then monitor the cask transfer trailer's automated ram operations.

Disengage Ram System from Cask and Move Clear of Cask

- Personnel disengage the ram system from the cask
- Personnel move away from the cask and cask transfer trailer.

Remove Cask Restraints from HAM and Replace Ram Access Cover Plate

- Personnel use common tools to remove the cask restraints from the HAM.
- Personnel replace the ram access cover plate.

Disengage Cask from HAM Access Opening

- Personnel disengage the cask from the HAM access port.

Install HAM Door and Replace Cask Cover Plate

- Personnel install the HAM cover using a mobile crane and common tools.
- Personnel attach crane rigging to the cover.
- Ground personnel are moved a safe distance from the crane operation.
- The crane operator lifts the cover.
- The crane operator moves the cover laterally to the appropriate position.
- The crane operator lowers the cover to the appropriate position.
- The crane is shut down.
- Personnel disengage the rigging from the cover.

B12 NODE 13: AGE HORIZONTAL CANISTER IN HAM

Instrumentation is provided to monitor the "health" and aging progress of the HDPC. A clear indicator of the state of the HDPC is provided by temperature measurement. Data from the instrumentation is logged locally.

B13 NODE 14: MANAGEMENT OF OTHER LLW (I.E., DRY ACTIVE LLW, LIQUID LLW, OR NON-RESIN WET-SOLID LLW)

This node involves the management of the various forms of LLW produced by the Yucca Mountain Project. LLW waste streams are described in the *Low-Level Waste Management Plan* (Ref. 2.2.6).

The waste is collected from each of the facilities, sorted according to its type and placed into appropriate containers, such as 55-gallon drums and high integrity containers (HICs). The LLWF provides shielded areas for storage pending offsite disposal.

Load Waste and Transport to LLWF

- Crew members use a site-approved vehicle to collect LLW from each facility's satellite collection area.

- For WHF only: Liquid LLW from the pool is transported to the LLWF through a buried pipe system. The underground piping is double-walled and monitored for leakage. If liquid LLW leaks from the inner to outer pipe, it accumulates in a collection box situated downstream in the pipe system. Two gauges that monitor humidity and radioactivity levels relay a signal back to the control room to alert personnel of a leak.

Unload and Store Waste at LLWF

- Crew members use standard industrial equipment, such as forklifts and an overhead crane, to unload and properly locate the LLW.

Load Waste for Transport to LLW Disposal

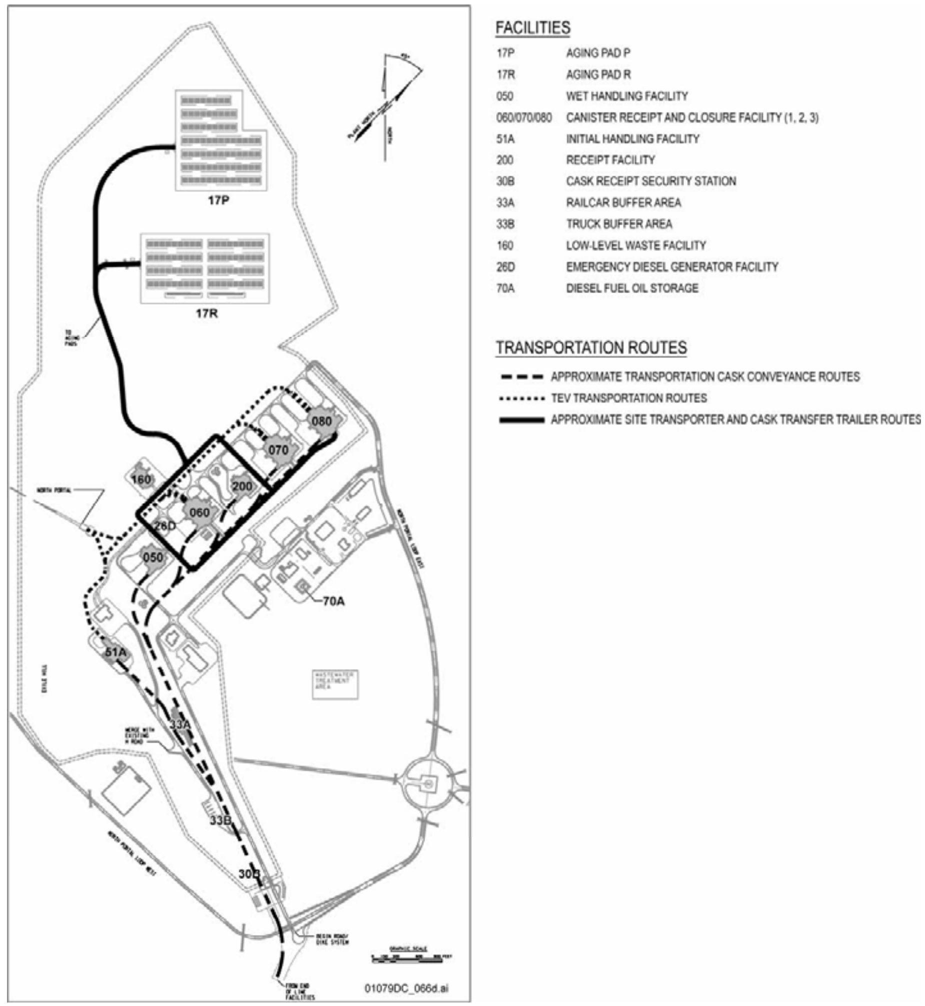
- Offsite vendors collect and process the LLW as needed for offsite disposal.

B14 NODE 15: MANAGEMENT OF RESIN WET-SOLID LLW

This node covers the actions associated with the removal and disposal of the spent resin. An offsite vendor uses a truck with a trailer-mounted HIC and associated LLW processing equipment to remove the resin directly from the ion exchangers. The technique used is one of sluicing the resin from its location directly into the HIC, where the spent resin is de-watered. Once the transfer operation is complete, the contractor removes the resin for shipping to a suitable disposal site.

ATTACHMENT C
OVERVIEW OF INTRA-SITE OPERATIONS WITHIN THE GEOLOGIC REPOSITORY OPERATIONS AREA

Intra-Site Operations and BOP facilities include site transportation, the Aging Facility, the Low-Level Waste Facility and related activities, and non-nuclear facilities. Figure C-1 is the site plan for the GROA and provides a generic view of the site transportation routes (particularly those used for waste form movement), and relational layout of the waste handling facilities, the Aging Facility, and the Low-Level Waste Facility (*Geologic Repository Operations Area North Portal Site Plan* (Ref. 2.2.43) and *Geologic Repository Operations Area Overall Site Plan* (Ref. 2.2.44)).



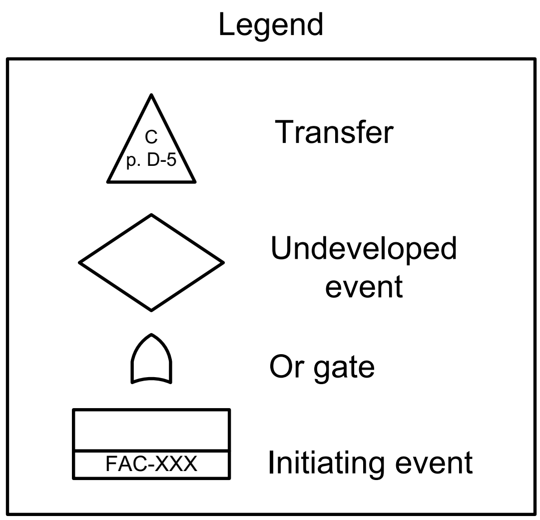
NOTE: TEV = transport and emplacement vehicle.

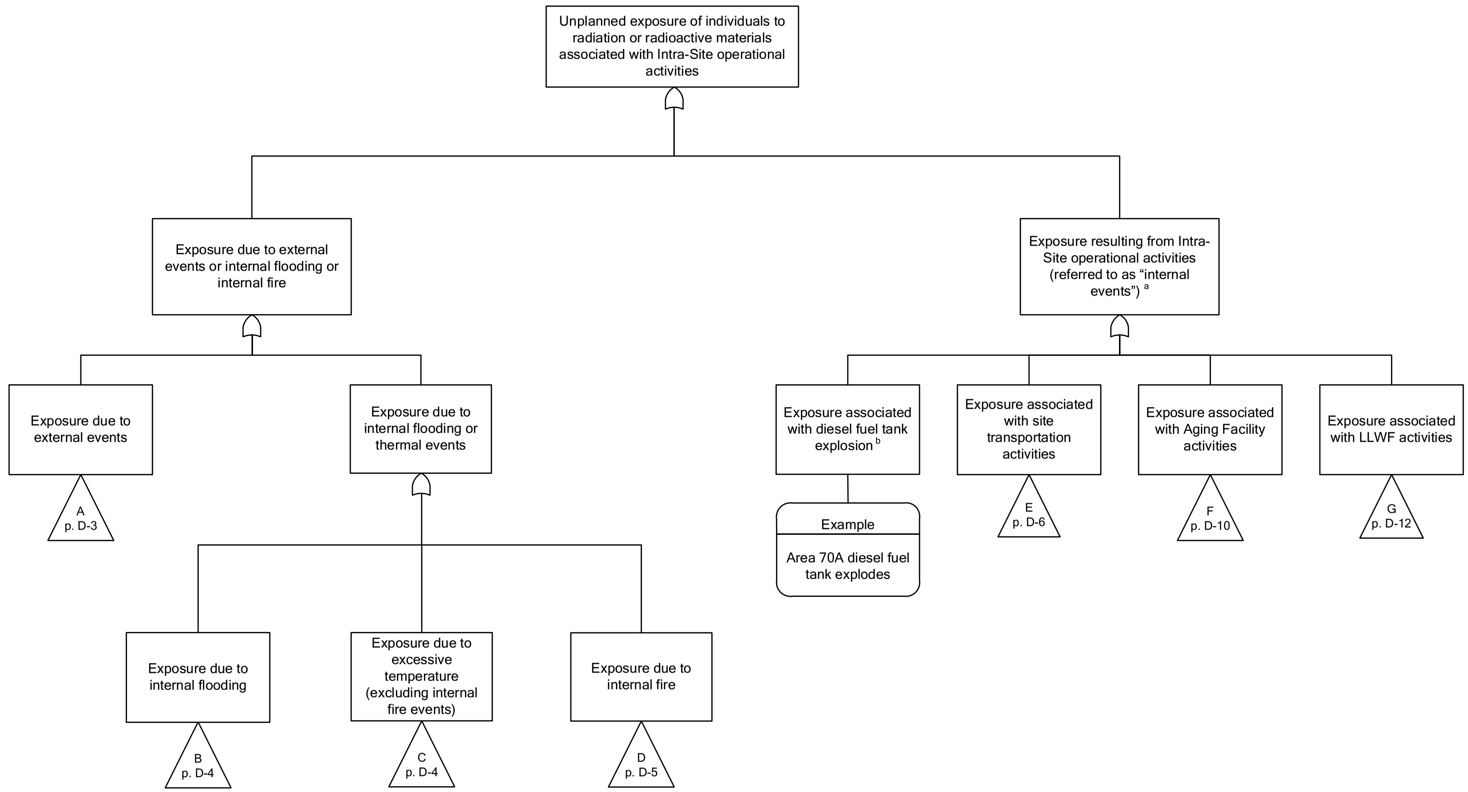
Source: Modified from (Ref. 2.2.43) and (Ref. 2.2.44).

Figure C-1 Geologic Repository Operations Area Overall Site Plan

ATTACHMENT D
INTRA-SITE OPERATIONS MASTER LOGIC DIAGRAM

The MLD for the Intra-Site Operations is presented in Figures D-1 through D-11.



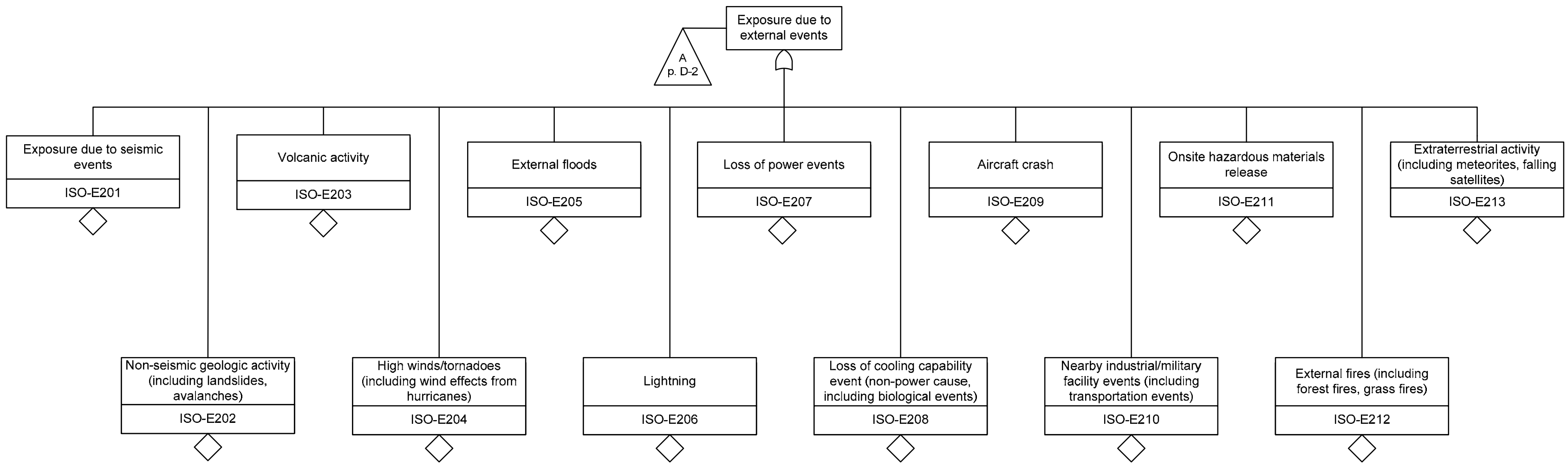


NOTE: [a] Balance of Plant activities and facilities are not included in the MLD because they are non-nuclear and are not analyzed further in regard to nuclear safety.
The potential for exposure due to diesel fuel tank explosion is addressed in the *Intra-Site Operations and BOP Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1), and is not developed further in this analysis.

[b] Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
LLWF = Low-Level Waste Facility

Source: Original

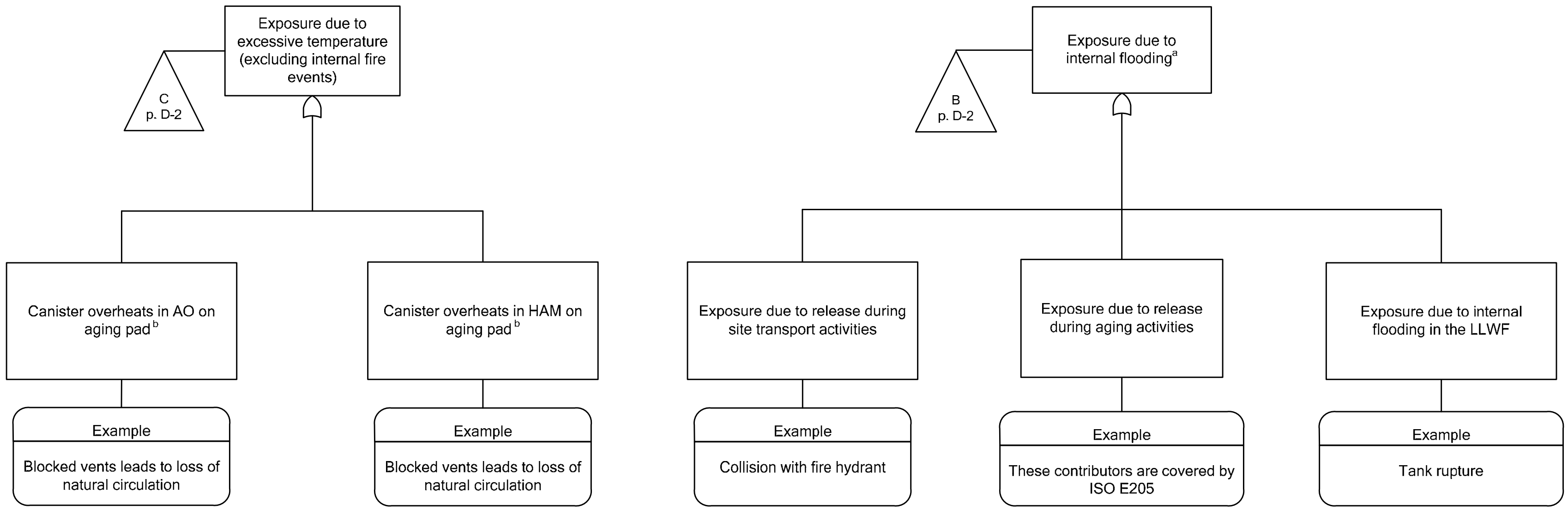
Figure D-1. Unplanned Exposure of Individuals to Radiation or Radioactive Materials Associated with Intra-Site Operational Activities



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
Analyses for these events are performed and documented separately ((Ref. 2.2.5)).
ISO = Intra-Site Operations.

Source: Original

Figure D-2. Exposure Due to External Events



NOTE: [a] The potential for internal flooding is covered in the *Intra-Site Operations and BOP Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1), and is not developed further in this analysis.

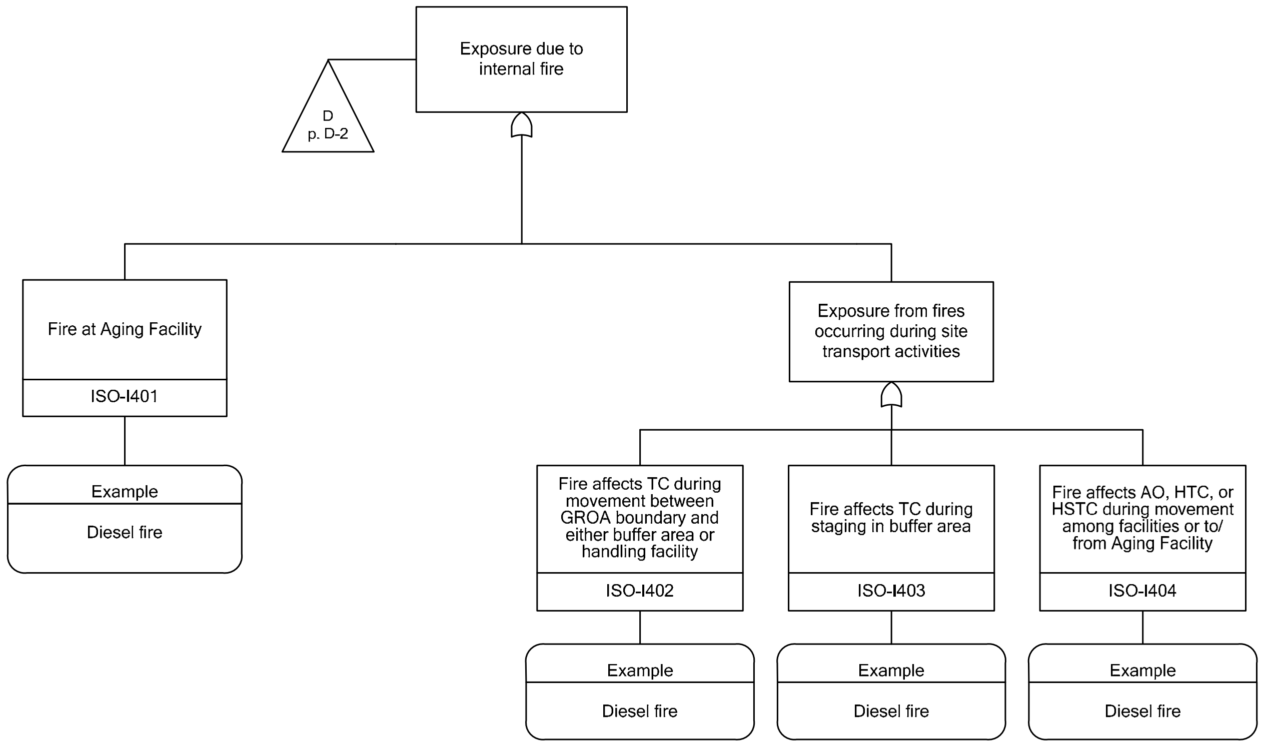
The potential for exposure due to canister overheating in an AO or HAM (i.e., a non-fire thermal event) is addressed in the *Intra-Site Operations and BOP Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1), and is not developed further in this analysis.

[b] Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."

AO= aging overpack; BOP = balance of plant; HAM = horizontal aging module; ISO = Intra-Site Operations; LLWF = Low-Level Waste Facility.

Source: Original

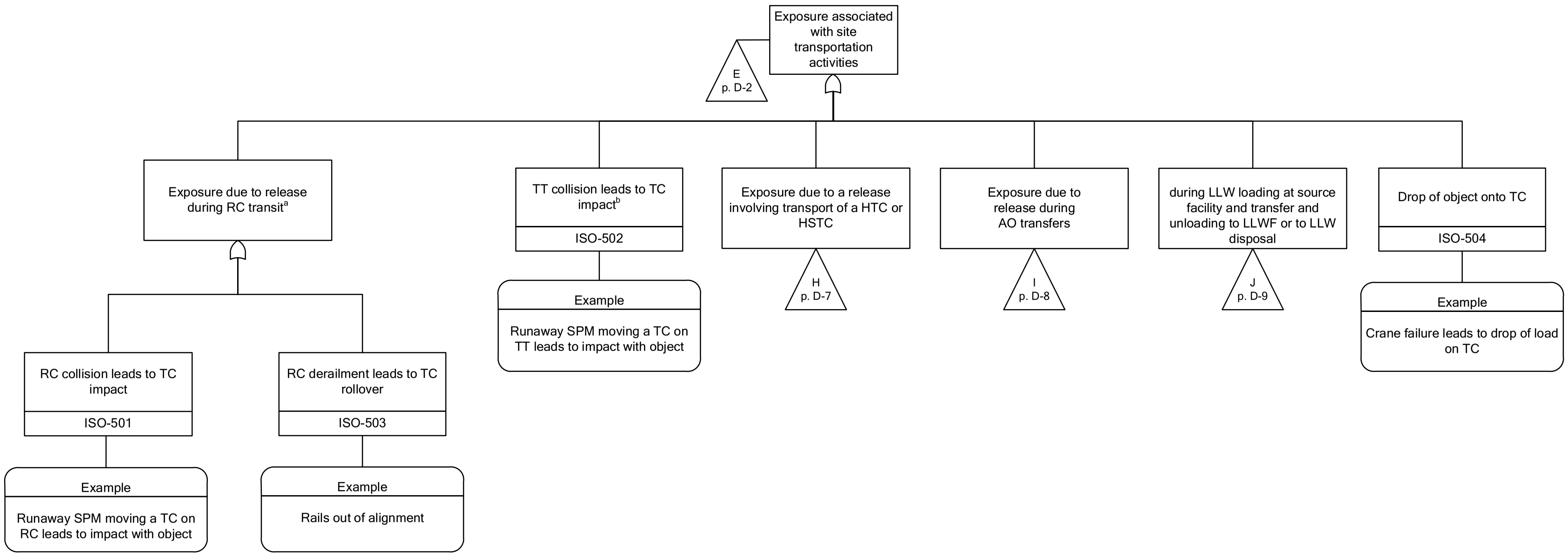
Figure D-3. Exposure Due to Excessive Temperature (Excluding Internal Fire Events) and Exposure Due to Internal Flooding



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
AO = aging overpack; GROA = geologic repository operations area; HAM = horizontal aging module; HSTC = horizontal shielded transfer cask; HTC = transportation cask that is never upended; ISO = Intra-Site Operations; SPM = site prime mover; ST = site transporter; TC = transportation cask.

Source: Original

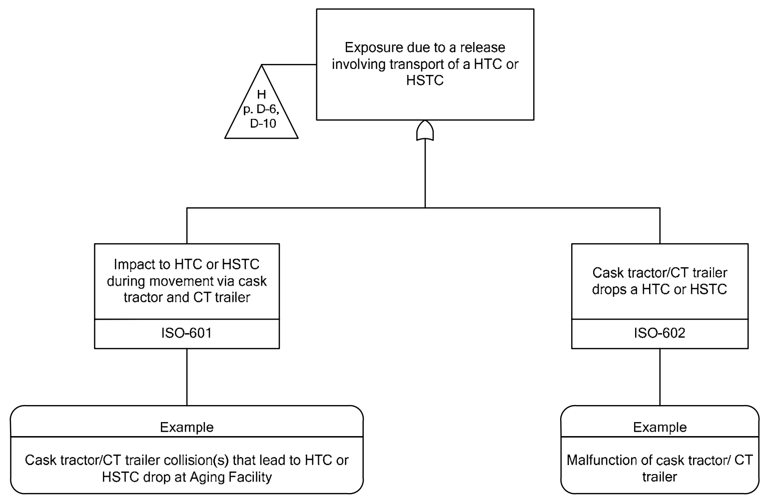
Figure D-4. Exposure Due to Internal Fire



NOTE: [a] Affected waste forms include (in TCs): MCOs, DOE standardized canisters, Naval, HLW (5 canisters), TAD canisters, DPCs, HDPCs, and uncanistered SNF.
[b] Affected waste forms include (in TCs): MCOs, DOE standardized canisters, HLW (only 1 canister), TAD canisters, and uncanistered SNF.
Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
AO = aging overpack; CSNF = commercial spent nuclear fuel; DPC = dual-purpose canister; HLW = high-level waste; HSTC = horizontal shielded transportation cask; HTC = transportation cask that is never upended; ISO = Intra-Site Operations; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; RC = railcar; SPM = site primer mover; TAD = transportation, aging, and disposal; TC = transportation cask; TT = truck trailer.

Source: Original

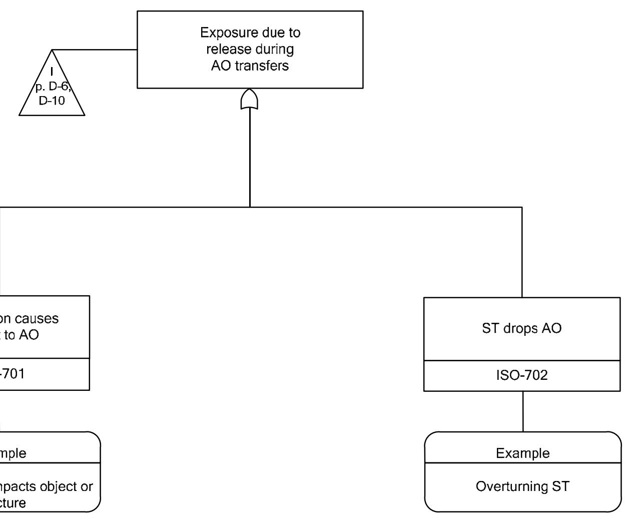
Figure D-5. Exposure Associated with Site Transportation Activities



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
CT = cask transfer; HSTC = horizontal shielded transfer cask; HTC = transportation cask that is never upended; ISO = Intra-Site Operations; ST = site transporter.

Source: Original

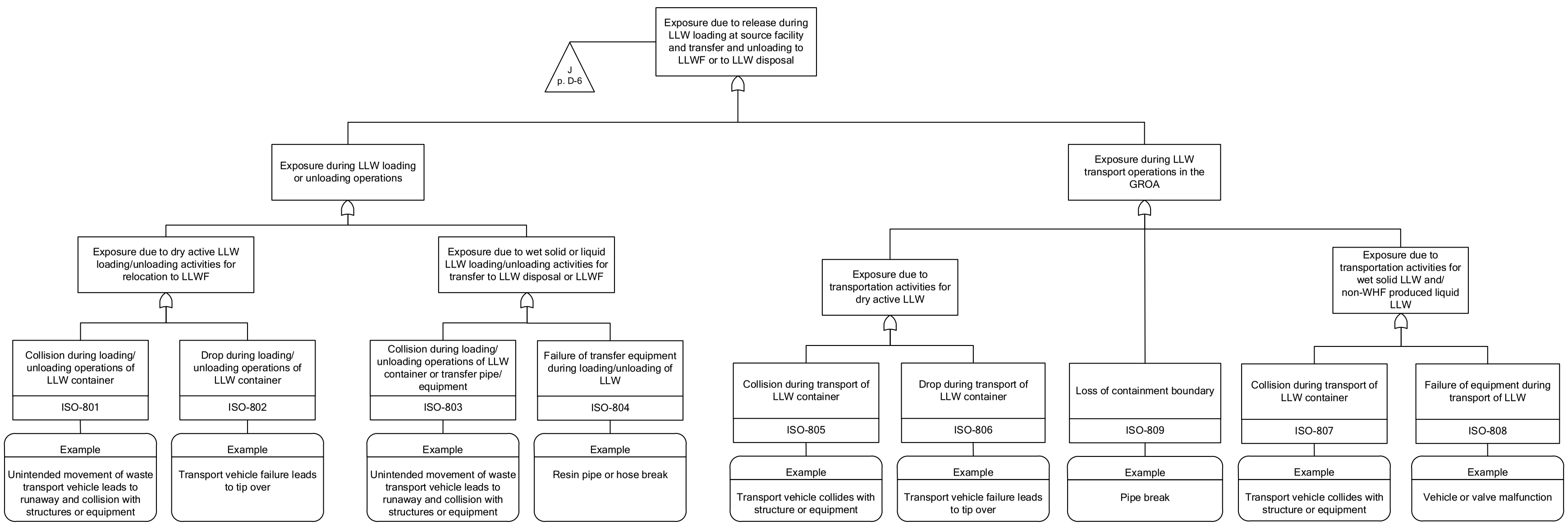
Figure D-6. Exposure Due to a Release Involving Transport of a HTC or HSTC within Aging Facility or between Facilities



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
AO = aging overpack; ISO = Intra-Site Operations; ST = site transporter.

Source: Original

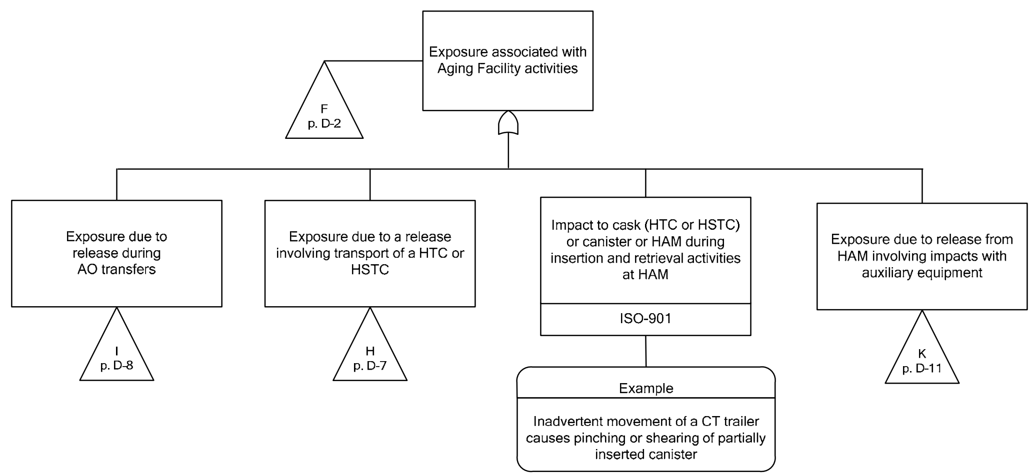
Figure D-7. Exposure Due to Release during AO Transfers within Aging Facility or between Facilities



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
GROA = geologic repository operations area; ISO = Intra-Site Operations; LLW = low-level waste; LLWF = Low-Level Waste Facility; WHF = Wet Handling Facility.

Source: Original

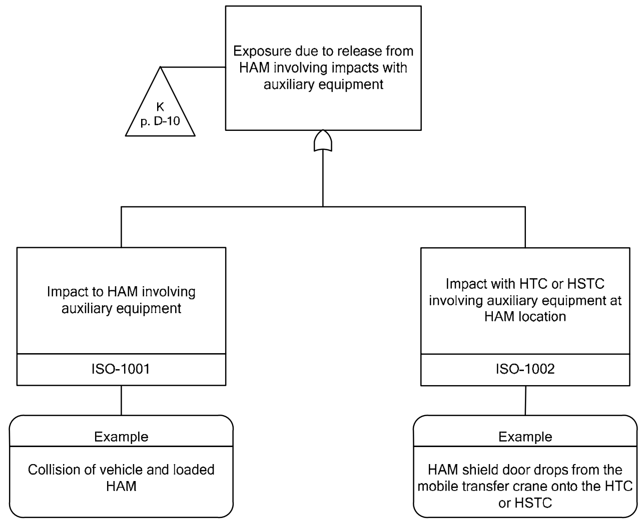
Figure D-8. Exposure Due to Release During LLW Loading at Source Facility and Transfer and Unloading to Low-Level Waste Facility or to LLW Disposal



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
AO = aging overpack; CT = cask transfer; HAM = horizontal aging module; HSTC = horizontal shielded transfer cask; HTC = transportation cask that is never upended;
ISO = Intra-Site Operations.

Source: Original

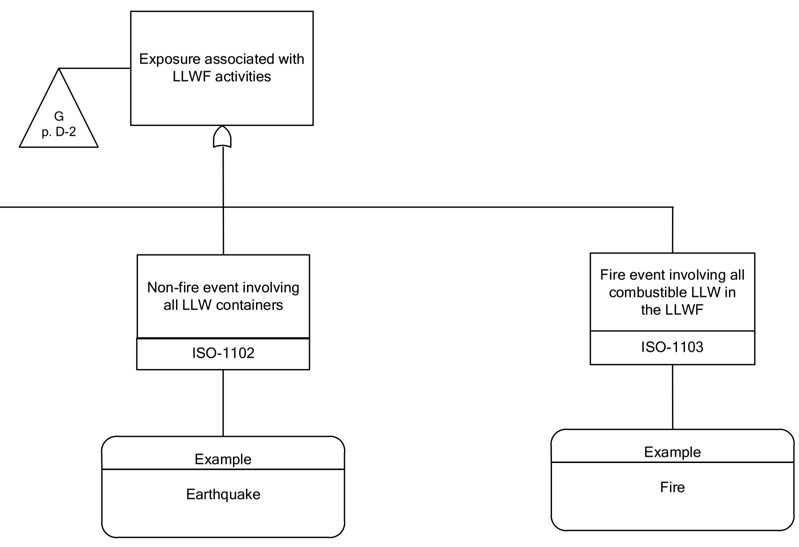
Figure D-9. Exposure Associated with Aging Facility Activities



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
HAM = horizontal aging module; HSTC = horizontal shielded transportation cask; HTC = transportation cask that is never upended; ISO = Intra-Site Operations.

Source: Original

Figure D-10. Exposure Due to Release from HAM Involving Impacts with Auxiliary Equipment



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
ISO = Intra-Site Operations; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility.

Source: Original

Figure D-11. Exposure Associated with Low-Level Waste Facility Activities

ATTACHMENT E
HAZARD AND OPERABILITY EVALUATION (HAZOP)

A HAZOP for Intra-Site Operations is provided in this attachment. The HAZOP was conducted in accordance with the process described in Section 4.3.1.3, and included a series of meetings that lasted from 4 to 8 hours for each facility. A list of attendees and a biography of each team member is also provided in this attachment.

HAZOP MEETINGS

LIST OF SUBJECT MATTER EXPERT ATTENDEES AND BIOGRAPHIES

Table E-1 contains the HAZOP meeting dates and the names of the subject matter experts who attended the meetings.

Table E-1. HAZOP Meeting Dates and List of Attendees

HAZOP Meetings		
Name	**Telephone Number**	**Organization**
Meeting Date: March 26, 2007		
Erin Collins	702-821-7913	SAIC
Robert Garrett	702-821-8239	B&A
Norm Graves	702-821-7012	BSC
Phuoc Le	702-821-7468	SAIC
Kelvin Montague	702-821-7847	B&A
Doug Orvis	702-821-7914	BSC
Clarence Smith	702-821-7126	BSC
Meeting Date: March 27, 2007		
Erin Collins	702-821-7913	SAIC
Robert Garrett	702-821-8239	B&A
Phuoc Le	702-821-7468	SAIC
Doug Orvis	702-821-7914	BSC
Kelvin Montague	702-821-7847	B&A
Clarence Smith	702-821-7126	BSC
Meeting Date: March 28, 2007		
Erin Collins	702-821-7913	SAIC
Norm Graves	702-821-7012	BSC
Daryl Keppler	505-272-7102	ARES
Phuoc Le	702-821-7468	SAIC
Kelvin Montague	702-821-7847	B&A
Doug Orvis	702-821-7914	BSC
Mary Presley	505-272-7102	ARES
Guy Ragan	702-821-7637	BSC
Daniel Reny	505-272-7102	ARES
Meeting Date: March 29, 2007		
Erin Collins	702-821-7913	SAIC
Norm Graves	702-821-7012	BSC
Daryl Keppler	505-272-7102	ARES
Phuoc Le	702-821-7468	SAIC
Suzanne Loyd	702-821-7350	SAIC
Jeff Marr	505-272-7102	ARES
Kelvin Montague	702-821-7847	B&A
Doug Orvis	702-821-7914	BSC
Mary Presley	505-272-7102	ARES
Guy Ragan	702-821-7637	BSC
Daniel Reny	505-272-7102	ARES
Clarence Smith	702-821-7126	BSC

Table E-1. HAZOP Meeting Dates and List of Attendees (Continued)

HAZOP Meetings		
Name	**Telephone Number**	**Organization**
Meeting Date: April 2, 2007		
Erin Collins	702-821-7913	SAIC
Norm Graves	702-821-7012	BSC
Daryl Keppler	505-272-7102	ARES
Phuoc Le	702-821-7468	SAIC
Kelvin Montague	702-821-7847	B&A
Doug Orvis	702-821-7914	BSC
Mary Presley	505-272-7102	ARES
Guy Ragan	702-821-7637	BSC
Clarence Smith	702-821-7126	BSC
Meeting Date: April 3, 2007		
Paul Amico	702-821-7911	SAIC
Erin Collins	702-821-7913	SAIC
Robert Garrett	702-821-8239	B&A
Norm Graves	702-821-7012	BSC
Daryl Keppler	505-272-7102	ARES
Phuoc Le	702-821-7468	SAIC
Kelvin Montague	702-821-7847	B&A
Doug Orvis	702-821-7914	BSC
Mary Presley	505-272-7102	ARES
Guy Ragan	702-821-7637	BSC
Clarence Smith	702-821-7126	BSC
Meeting Date: April 4, 2007		
Paul Amico	702-821-7911	SAIC
Erin Collins	702-821-7913	SAIC
Norm Graves	702-821-7012	BSC
Daryl Keppler	505-272-7102	ARES
Phuoc Le	702-821-7468	SAIC
Kelvin Montague	702-821-7847	B&A
Doug Orvis	702-821-7914	BSC
Mary Presley	505-272-7102	ARES
Guy Ragan	702-821-7637	BSC
Clarence Smith	702-821-7126	BSC
Meeting Date: April 5, 2007		
Paul Amico	702-821-7911	SAIC
Erin Collins	702-821-7913	SAIC
Norm Graves	702-821-7012	BSC
Daryl Keppler	505-272-7102	ARES
Phuoc Le	702-821-7468	SAIC
Ernest Lindner	702-821-7713	BSC
Suzanne Loyd	702-821-7350	SAIC
Doug Orvis	702-821-7914	BSC
Mary Presley	505-272-7102	ARES
Clarence Smith	702-821-7126	BSC

Table E-1. HAZOP Meeting Dates and List of Attendees (Continued)

HAZOP Meetings		
Name	**Telephone Number**	**Organization**
Meeting Date: April 6, 2007		
Paul Amico	702-821-7911	SAIC
Norm Graves	702-821-7012	BSC
Daryl Keppler	505-272-7102	ARES
Phuoc Le	702-821-7468	SAIC
Dale Pendry	702-821-8380	BSC
Mary Presley	505-272-7102	ARES

Source: Original

Biographies of subject matter experts attending the HAZOP meetings:

Paul J. Amico: Mr. Amico is a nuclear engineer with 30 years of experience in risk, safety, regulation, and operation of nuclear power plants, nuclear material production reactors, nuclear weapons research, production, and storage facilities, nuclear fuel cycle facilities, chemical demilitarization facilities, and industrial chemical plants.

Erin P. Collins: Ms. Collins is a risk analyst with over 20 years of experience in safety, reliability and risk analysis for the U.S. Army chemical weapons destruction program, National Aeronautics and Space Administration, Federal Aviation Administration, nuclear power plants, and the chemical process industry. Her specialties are equipment reliability database development and human reliability analysis. She has participated in two prior HAZOPs as part of the U.S. Army and chemical process work.

Robert J. Garrett: Mr. Garrett is a safety analyst with over 17 years of experience in risk analysis and hazards analysis at DOE non-reactor nuclear facilities. He has participated in several HAZOPs for facilities at the Savannah River Site and the Yucca Mountain Project. For this study, Mr. Garrett served as a representative in the Intra-Site Operations areas for the HAZOP sessions.

Norman L. Graves: Mr. Graves is an engineer with over 40 years of experience in the nuclear industry including operations, construction, risk analysis, and waste disposal. For this study, Mr. Graves served as the Preclosure Safety Analysis Lead for the HAZOP sessions.

Daryl C. Keppler: Mr. Keppler is an electrical engineer with over 35 years experience in all phases of weapon and space system development, deployment, and disposal. For 5 years Mr. Keppler served as the technical advisor to the Chairman of the Nuclear Weapons System Safety Group and was the U.S. Air Force certification authority for all software programs developed for ground launched missile systems. Mr. Keppler participated in numerous safety assessments for the Department of Defense, the DOE, and the National Aeronautics and Space Administration. Mr. Keppler served as a participant/observer during the HAZOP sessions.

Phuoc T. Le: Mr. Phuoc Le is an engineer with over 27 years of experience in risk analysis for nuclear power plants, chemical processing and petroleum refining industry. Mr. Le has led many HAZOPs ranging from nuclear to chemical processing and food industries. For this study, Mr. Le served as co-leader of the HAZOP sessions.

Ernest N. Lindner, Ph.D. (Mining): Dr. Lindner is a member of Preclosure Safety Analysis Department with over 3 years direct experience on evaluating repository hazards, and has over 30 years experience in civil and geotechnical engineering. Dr. Lindner has a Ph.D. in Mining with a major of geomechanics, together with a Master of Science (specializing in soil and rock mechanics), and a Bachelor of Engineering in Civil Engineering. Dr. Lindner also has a Professional Engineering License, and his experience includes work on nuclear facilities and other nuclear waste programs together with commercial engineering experience on subsurface projects. He is designated as the Lead Analyst for subsurface operations.

Suzanne M. Loyd: Ms. Loyd is a risk analyst with over 7 years of experience in risk analysis for chemical weapons demilitarization. Ms. Loyd has participated in HAZOPs for various processes, including incineration and hazardous materials handling. For this study, Ms. Loyd served as a participant for subsurface-related HAZOP sessions.

Jeffrey W. Marr: Mr. Marr is a senior safety analyst with over 20 years of experience in the reliability and safety analysis fields providing services to the DOE and Department of Defense. Mr. Marr has participated in several hazard studies and hazard analyses in the support and development of Safety Analysis Reports and Documented Safety Analyses. For this study, Mr. Marr served as a participant for the purpose of using the HAZOP results for development of the Canister Receipt and Closure Facility Master Logic Diagram, Event Sequence Diagrams, and Event Trees.

Kelvin J. Montague: Mr. Montague is an engineer with over 16 years of experience in safety analysis. Mr. Montague has led numerous HAZOPs in nuclear industries. For this study, Mr. Montague served as co-leader of the HAZOP sessions and Lead Analyst for Intra-Site Operations.

Douglas D. Orvis, Ph.D. (Nuclear): Dr. Orvis is a registered professional engineer (California, Nuclear No. 0925) with over 35 years of experience in nuclear engineering, regulation, and risk analysis of nuclear power plants, alternative concepts for interim storage of spent nuclear fuel, and aerospace applications. Dr. Orvis has performed numerous qualitative and quantitative safety assessments, to include participation in HAZOP sessions. Dr. Orvis has participated in the development of human reliability analysis techniques (e.g., SHARP) and conducted measurements of, and analyzed data for, nuclear power plant control room operators during simulated accidents. Dr. Orvis has performed event tree and fault tree analyses of hazardous systems for both internal events and seismic initiators. Dr. Orvis is a former Supervisor of the BSC Preclosure Safety Analysis group.

Dale L. Pendry: Currently the YMP Nuclear Operations Manager, Mr. Pendry's credentials include a civil engineering degree and a Senior Reactor Operator license. Mr. Pendry was a U.S. Navy nuclear submarine officer and has 25 years of experience encompassing nuclear operations, maintenance, licensing, engineering, chemistry, radiological controls, and waste disposal. He has managed commercial nuclear and DOE/National Nuclear Security Administration facilities, including experimental facilities tasked with nuclear stockpile stewardship. Mr. Pendry was an operations representative for this study.

Mary R. Presley: Ms. Presley is an engineer with 3 years of experience in risk analysis for nuclear power plants, specializing in human reliability. Ms. Presley graduated in 2006 from the Massachusetts Institute of Technology with her M.S. in nuclear engineering.

Guy E. Ragan, Ph.D.: Dr. Ragan is an engineer with over 17 years of experience related to nuclear technology. For this study, Dr. Ragan served as lead preclosure safety analyst for the events associated with the IHF.

Daniel A. Reny: Mr. Reny is a nuclear safety analyst with over 27 years of experience in risk analysis for nuclear power plants and DOE nuclear facilities. Mr. Reny has participated in several HAZOPs on nuclear facilities. For this study, Mr. Reny served as a representative for the Canister Receipt and Closure Facility for the HAZOP sessions.

Clarence L. Smith: Mr. Smith has approximately 45 years of extensive management and supervisory experience within the engineering field and nuclear facilities that includes 27 years of nuclear operational and maintenance experience. Mr. Smith has participated in the decommissioning and decontamination of various nuclear reactors at the Hanford site in Richland, Washington. He has served as liaison in the design development of various processing facilities to coordinate and ensure that operability and maintainability features such as reliability, maintainability, accountability and inspectability are incorporated. Mr. Smith has negotiated and managed contract work that included safeguards in the erection of support facilities.

Table E-2. HAZOP Worksheet for Node 1

Facility/Operation: Intra-Site Operations — Process: Cask Receipt

Node 1: Cask Receipt Security Station — Process/Equipment: Bridge or Portable Crane

Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of — Consequence Categories: Radioactive Release, Direct Exposure, Criticality

Node Item Number	Parameter	Deviation Considered	Postulated Cause	Consequence(s)	Potential Prevention/Mitigation Design of Operational Feature	Notes	MLD Index Number
1.1	Load	(More) Lifted load heavier than expected	Failure to remove personnel barrier bolts	1 – Potential crane tip-over leading to radioactive release 2 – Potential damage to personnel barrier	1 – Procedures and training 2 – Load cell 3 – TC in 10 CFR Part 71 configuration	Mobile crane	ISO-504
1.2	Load	(Less) Lifted load lighter than expected	N/A	No safety consequences	N/A	N/A	N/A
1.3	Load	(Other Than) Riggings (below-the-hook-lifting devices) do not function properly	Improper rigging	Potential drop of load onto cask leading to radioactive release	1 – Procedures and training 2 – Specific rigging design 3 – TC in 10 CFR Part 71 configuration	Improper selections for rigging, center of gravity location, and load connection	ISO-504
1.4	Hoist	(More) Hoist line extended faster than specified prior to lifting personnel barrier off conveyance	1 – Operator allows rapid rundown 2 – Mechanical control system failure	Potential drop of hook/rigging on personnel barrier/cask leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	Hoist is block-and-hook type	ISO-504
1.5	Hoist	(Less) Hoist line extended while lifting personnel barrier prior to clearing conveyance footprint	1 – Operator allows rapid rundown 2 – Mechanical control system failure	Potential drop of personnel barrier onto cask leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	Ground crew guides set-down of personnel barrier – Scenario involves drop of personnel barrier while being lifted off conveyance	ISO-504
1.6	Technique (Inspection)	(Other Than) Radiation protection personnel fail to detect contamination on TC	1 – Inadequate sampling techniques used by radiation protection personnel 2 – Laboratory equipment failure	Potential direct exposure of personnel	Procedures and training	The assumptions for this analysis are that TCs arrive in pristine condition. The identified deviation is considered an off-normal event and outside of the scope.	N/A
1.7	Technique (Inspection)	(Other Than) Security personnel fail to detect contraband	Inadequate detection techniques used by security personnel	Potential release of radioactive material	Procedures and training	The assumptions for this analysis are that TCs arrive in pristine condition. The identified deviation is considered an off-normal event and outside of the scope.	N/A

NOTE: Guidewords not used in this node: No, Reverse, As Well As, and Part Of.
ISO = Intra-Site Operations; MLD = master logic diagram; TC = transportation cask.

Source: Original; 10 CFR Part 71 (Ref. 2.3.2).

Table E-3. HAZOP Worksheet for Node 2

Facility/Operation: Intra-Site Operations — Process: Truck TC Transit

Node 2: TC (HLW/CSNF) Movement from Cask Receipt Security Station to Truck Buffer Area — Process/Equipment: SPM/Truck Trailer

Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of — Consequence Categories: Radioactive Release, Direct Exposure, Criticality

Node Item Number	Parameter	Deviation Considered	Postulated Cause	Consequence(s)	Potential Prevention/Mitigation Design of Operational Feature	Notes	MLD Index Number
2.1	Speed	(More) SPM moves at faster than desired speed	Driver drives SPM faster than desired speed	Potential loss of control or collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Speed control feature on SPM engine 3 – Procedures and training	Safe speed of 5 mph or less expected	ISO-502
2.2	Speed	(More) SPM moves at faster than desired speed	Mechanical failure of SPM	Potential loss of control or collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	Safe speed of 5 mph or less expected	ISO-502
2.3	Speed	(Less) SPM moves at slower than desired speed	Mechanical failure of SPM	No safety consequences	N/A	N/A	N/A
2.4	Speed	(No) SPM does not move	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	N/A	N/A
2.5	Direction	(Reverse) SPM moves backward instead of going forward	1 – Human failure 2 – Mechanical failure of SPM	Potential loss of control or collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	N/A	ISO-501
2.6	Direction	(Other Than) SPM does not follow designated travel route	1 – Human failure 2 – Mechanical failure of SPM	Potential loss of control or collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	Steering system failure, etc.	ISO-502
2.7	Lift	(More) Truck trailer lifted too high when connecting to SPM	1 – Human failure 2 – Mechanical failure of SPM	Potential drop leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	N/A	ISO-502
2.8	Lift	(Less) Truck trailer not lifted high enough when connecting to SPM	1 – Human failure 2 – Mechanical failure of SPM	Potential collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	N/A	ISO-502
2.9	Lift	(No) Truck trailer front support legs collapse	1 – Human failure 2 – Mechanical failure of SPM	Potential drop leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	N/A	ISO-502
2.10	Temperature	(More) Temperature exceeds TC design basis	Fire caused by or involving SPM	1 – Potential radioactive release 2 – Potential criticality	1 – Procedures and training 2 – Combustible materials control	10 CFR Part 71 temperature design basis	ISO-I402
2.11	Temperature	(Less) Temperature does not exceed TC design basis temperature	Normal condition	No safety consequences	TC in 10 CFR Part 71 configuration	10 CFR Part 71 temperature design basis	N/A
2.12	Shielding	(Less) Displacement of TC shielding	Impact or fire	Potential direct exposure	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Combustible materials control	N/A	ISO-I402 ISO-502
2.13	Shielding	(No) Total displacement of TC shielding	No cause identified	N/A	N/A	N/A	N/A

NOTE: Guidewords were not used in this node: As Well As and Part Of.
CSNF = commercial spent nuclear fuel; HLW = high-level radioactive waste; ISO = Intra-Site Operations; MLD = master logic diagram; SPM = site prime mover; TC = transportation cask.

Source: Original; 10 CFR Part 71 (Ref. 2.3.2).

Table E-4. HAZOP Worksheet for Node 3

Facility/Operation: Intra-Site Operations — Process: Rail TC Transit

Node 3: TC (TAD Canister, DPC, DC) Movement from Cask Receipt Security Station to Railcar Buffer Area — Process/Equipment: SPM/Railcar

Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of — Consequence Categories: Radioactive Release, Direct Exposure, Criticality

Node Item Number	Parameter	Deviation Considered	Postulated Cause	Consequence(s)	Potential Prevention/Mitigation Design of Operational Feature	Notes	MLD Index Number
3.1	Speed	(More) SPM moves at faster than desired speed	Driver drives SPM faster than desired speed	Potential loss of control or collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Speed control feature on SPM engine 3 – Procedures and training	Safe speed of 5 mph or less expected	ISO-501
3.2	Speed	(More) SPM moves at faster than desired speed	Mechanical failure of SPM	Potential loss of control or collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	Safe speed of 5 mph or less expected	ISO-501
3.3	Speed	(Less) SPM moves at slower than desired speed	Mechanical failure of SPM	No safety consequences	N/A	N/A	N/A
3.4	Speed	(No) SPM does not move	1 – Human failure 2 – Mechanical failure of SPM	No safety consequences	N/A	N/A	N/A
3.5	Direction	(Reverse) SPM moves backward instead of going forward	1 – Human failure (chock, set brake) 2 – Failure of brake	Potential collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Brake design	N/A	ISO-501
3.6	Direction	(Other Than) Derailment of railcar	1 – Human failure 2 – Mechanical failure of railcar	Potential collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Brake design	N/A	ISO-503
3.7	Direction	(Other Than) Derailment of railcar	Rail distortion due to structural failure	Potential drop leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Rail design	N/A	ISO-503
3.8	Temperature	(More) Temperature exceeds TC design basis	Fire caused by or involving SPM	1 – Potential radioactive release 2 – Potential criticality	1 – Procedures and training 2 – Combustible materials control	10 CFR Part 71 temperature design basis	ISO-I402
3.9	Temperature	(Less) Temperature does not exceed design basis	Normal condition	No safety consequences	TC in 10 CFR Part 71 configuration	10 CFR Part 71 temperature design basis	N/A
3.10	Shielding	(Less) Displacement of TC shielding	Impact or fire	Potential direct exposure	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Combustible materials control	N/A	ISO-I402 and ISO-501
3.11	Shielding	(No) Total displacement of TC shielding	No cause identified	N/A	N/A	N/A	N/A

NOTE: Guidewords not used in this node: As Well As and Part Of.
DC = disposable canister; DPC = dual-purpose canister; ISO = Intra-Site Operations; MLD = master logic diagram; SPM = site prime mover; TAD = transportation, aging, and disposal; TC = transportation cask.

Source: Original; 10 CFR Part 71 (Ref. 2.3.2)

Table E-5. HAZOP Worksheet for Node 4

Facility/Operation: Intra-Site Operations — Process: Rail TC Transit

Node 4: TC (Naval) Movement from Cask Receipt Security Station to IHF — Process/Equipment: SPM/Railcar

Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of — Consequence Categories: Radioactive Release, Direct Exposure, Criticality

Node Item Number	Parameter	Deviation Considered	Postulated Cause	Consequence(s)	Potential Prevention/Mitigation Design of Operational Feature	Notes	MLD Index Number
4.1	Speed	(More) SPM moves at faster than desired speed	Driver drives SPM faster than desired speed	Potential loss of control or collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Speed control feature on SPM engine 3 – Procedures and training	Safe speed of 5 mph or less expected	ISO-501
4.2	Speed	(More) SPM moves at faster than desired speed	Mechanical failure of SPM	Potential loss of control or collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	Safe speed of 5 mph or less expected	ISO-501
4.3	Speed	(Less) SPM moves at slower than desired speed	Mechanical failure of SPM	No safety consequences	N/A	N/A	N/A
4.4	Speed	(No) SPM does not move	1 – Human failure 2 – Mechanical failure of SPM	No safety consequences	N/A	N/A	N/A
4.5	Direction	(Reverse) SPM moves backward instead of going forward	1 – Human failure (chock, set brake) 2 – Failure of brake	Potential collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Brake design	N/A	ISO-501
4.6	Direction	(Other Than) Derailment of railcar	1 – Human failure 2 – Mechanical failure of railcar	Potential collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Brake design	Includes collision due to road/railroad crossing	ISO-503
4.7	Direction	(Other Than) Derailment of railcar	Rail distortion due to structural failure	Potential drop leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Rail design	N/A	ISO-503
4.8	Temperature	(More) Temperature exceeds TC design basis	Fire caused by or involving SPM	1 – Potential radioactive release 2 – Potential criticality	1 – Procedures and training 2 – Combustible materials control	10 CFR Part 71 temperature design basis	ISO-I402
4.9	Temperature	(Less) Temperature does not exceed TC design basis	Normal condition	No safety consequences	TC in 10 CFR Part 71 configuration	10 CFR Part 71 temperature design basis	N/A
4.10	Shielding	(Less) Displacement of TC shielding	Impact or fire	Potential direct exposure	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Combustible materials control	N/A	ISO-I402 and ISO-501
4.11	Shielding	(No) Total displacement of TC shielding	No cause identified	N/A	N/A	N/A	N/A

NOTE: Guidewords not used in this node: As Well As and Part Of.
IHF = Initial Handling Facility; ISO = Intra-Site Operations; MLD = master logic diagram; SPM = site prime mover; TC = transportation cask.

Source: Original; 10 CFR Part 71 (Ref. 2.3.2)

Table E-6. HAZOP Worksheet for Node 5

Facility/Operation: Intra-Site Operations — Process: Rail TC Transit

Node 5 TC Movement from Railcar Buffer Area to RF (TAD Canister/DPC), WHF (DPC), CRCF (TAD Canister/DC) — Process/Equipment: SPM/Railcar

Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of — Consequence Categories: Radioactive Release, Direct Exposure, Criticality

Node Item Number	Parameter	Deviation Considered	Postulated Cause	Consequence(s)	Potential Prevention/Mitigation Design of Operational Feature	Notes	MLD Index Number
5.1	Speed	(More) SPM moves at faster than desired speed	Driver drives SPM faster than desired speed	Potential loss of control or collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Speed control feature on SPM engine 3 – Procedures and training	Safe speed of 5 mph or less expected	ISO-501
5.2	Speed	(More) SPM moves at faster than desired speed	Mechanical failure of SPM	Potential loss of control or collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	Safe speed of 5 mph or less expected	ISO-501
5.3	Speed	(Less) SPM moves at slower than desired speed	Mechanical failure of SPM	No safety consequences	N/A	N/A	N/A
5.4	Speed	(No) SPM does not move	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	N/A	N/A
5.5	Direction	(Reverse) SPM moves backward instead of going forward	1 – Human failure (chock, set brake) 2 – Failure of brake	Potential collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Brake design	N/A	ISO-501
5.6	Direction	(Other Than) Derailment of railcar	1 – Human failure 2 – Mechanical failure of railcar	Potential collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Brake design	Includes collision due to road/railroad crossing	ISO-503
5.7	Direction	(Other Than) Derailment of railcar	Rail distortion due to structural failure	Potential drop leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Rail design	N/A	ISO-503
5.8	Direction	(Other Than) Collision with structure	1 – Human failure 2 – Mechanical failure of railcar	Potential drop leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Rail design	Outer doors of the facilities	ISO-501
5.9	Temperature	(More) Temperature exceeds TC design basis	Fire caused by or involving SPM	1 – Potential radioactive release 2 – Potential criticality	1 – Procedures and training 2 – Combustible materials control	10 CFR Part 71 temperature design basis	ISO-I402
5.10	Temperature	(Less) Temperature does not exceed TC design basis	Normal condition	No safety consequences	TC in 10 CFR Part 71 configuration	10 CFR Part 71 temperature design basis	N/A
5.11	Shielding	(Less) Displacement of TC shielding	Impact or fire	Potential direct exposure	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Combustible materials control	N/A	ISO-I402 and ISO-501
5.12	Shielding	(No) Total displacement of TC shielding	No cause identified	N/A	N/A	N/A	N/A

NOTE: Guidewords not used in this node: As Well As and Part Of.
CRCF = Canister Receipt and Closure Facility; DC = disposable canister; DPC = dual-purpose canister; ISO = Intra-Site Operations; MLD = master logic diagram; RF = Receipt Facility; SPM = site prime mover; TAD = transportation, aging, and disposal; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original; 10 CFR Part 71 (Ref. 2.3.2).

Table E-7. HAZOP Worksheet for Node 6

Facility/Operation: Intra-Site Operations — Process: Truck TC Transit

Node 6: TC Movement from Truck Buffer Area to IHF (HLW) or WHF (CSNF) — Process/Equipment: SPM/Truck Trailer

Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of — Consequence Categories: Radioactive Release, Direct Exposure, Criticality

Node Item Number	Parameter	Deviation Considered	Postulated Cause	Consequence(s)	Potential Prevention/Mitigation Design of Operational Feature	Notes	MLD Index Number
6.1	Speed	(More) SPM moves at faster than desired speed	Driver drives SPM faster than desired speed	Potential loss of control or collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Speed control feature on SPM engine 3 – Procedures and training	Safe speed of 5 mph or less expected	ISO-502
6.2	Speed	(More) SPM moves at faster than desired speed	Mechanical failure of SPM	Potential loss of control or collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	Safe speed of 5 mph or less expected	ISO-502
6.3	Speed	(Less) SPM moves at slower than desired speed	Mechanical failure of SPM	No safety consequences	N/A	N/A	N/A
6.4	Speed	(No) SPM does not move	1 – Human failure 2 – Mechanical failure of SPM	No safety consequences	N/A	N/A	N/A
6.5	Direction	(Reverse) SPM moves backward instead of going forward	1 – Human failure 2 – Mechanical failure of SPM	Potential loss of control or collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	N/A	ISO-502
6.6	Direction	(Other Than) SPM does not follow designated travel route	1 – Human failure 2 – Mechanical failure of SPM	Potential loss of control or collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	Steering system failure, etc.	ISO-502
6.7	Lift	(More) Truck trailer lifted too high when connecting to SPM	1 – Human failure 2 – Mechanical failure of SPM	Potential drop leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	N/A	ISO-502
6.8	Lift	(Less) Truck trailer not lifted high enough when connecting to SPM	1 – Human failure 2 – Mechanical failure of SPM	Potential collision leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	N/A	ISO-502
6.9	Lift	(No) Truck trailer front support legs collapse	1 – Human failure 2 – Mechanical failure of SPM	Potential drop leading to radioactive release	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training	N/A	ISO-502
6.10	Temperature	(More) Temperature exceeds TC design basis	Fire caused by or involving SPM	1 – Potential radioactive release 2 – Potential criticality	1 – Procedures and training 2 – Combustible materials control	10 CFR Part 71 temperature design basis	ISO-I402
6.11	Temperature	(Less) Temperature does not exceed design basis	Normal condition	No safety consequences	TC in 10 CFR Part 71 configuration	10 CFR Part 71 temperature design basis	N/A
6.12	Shielding	(Less) Displacement of TC shielding	Impact or fire	Potential direct exposure	1 – TC in 10 CFR Part 71 configuration 2 – Procedures and training 3 – Combustible materials control	N/A	ISO-I402 and ISO-502
6.13	Shielding	(No) Total displacement of TC shielding	No cause identified	N/A	N/A	N/A	N/A

NOTE: Guidewords not used in this node: As Well As and Part Of.
CSNF = commercial spent nuclear fuel; HLW = high-level radioactive waste; IHF = Initial Handling Facility; ISO = Intra-Site Operations; MLD = master logic diagram; SPM = site prime mover; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original; 10 CFR Part 71 (Ref. 2.3.2).

Table E-8. HAZOP Worksheet for Node 7

Facility/Operation: Intra-Site Operations							Process: Cask (AO) Transit
Node 7: Cask (AO) Movement among RF (TAD Canister/DPC), WHF (TAD Canister/DPC), and CRCF							Process/Equipment: ST, Cask (AO)
Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Direct Exposure, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
7.1	Speed	(More) ST moves at faster than desired speed	No cause identified	N/A	N/A	Inherent design of ST limits maximum speed	N/A
7.2	Speed	(Less) ST moves at slower than desired speed	Mechanical failure of the ST	No safety consequences	N/A	Low normal speed (less than 5 mph) expected on ramp to aging pad	N/A
7.3	Speed	(No) ST does not move	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	N/A	N/A
7.4	Direction	(Reverse) ST moves backward instead of going forward	1 – Human failure 2 – Mechanical failure	Potential loss of control or collision leading to radioactive release	1 – TAD canister or DPC provides confinement 2 – Procedures and training 3 – Cask provides shielding 4 – ST design integrity	N/A	ISO-701
7.5	Direction	(Other Than) ST does not follow designated path	1 – Human failure 2 – Mechanical failure	Potential loss of control or collision leading to radioactive release	1 – TAD canister or DPC provides confinement 2 – Procedures and training 3 – Cask provides shielding 4 – ST design integrity	Steering failure	ISO-701
7.6	Lift	(More) ST lifts load higher than 1 ft	1 – Human failure 2 – Mechanical failure	Potential drop leading to radioactive release	1 – ST design limits lift height to 1 ft 2 – Procedures and training	N/A	ISO-702
7.7	Lift	(Less) ST does not lift to required transport height	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – ST design 2 – Procedures and training	N/A	ISO-701
7.8	Lift	(No) ST does not lift load	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	1 – No loss of shielding or radioactive release 2 – Expected damage to bottom plate only	N/A
7.9	Temperature	(More) Temperature exceeds canister design basis	Fire on ST (electrical, hydraulic, diesel)	1 – Potential radioactive release 2 – Potential criticality	1 – Procedures and training 2 – Combustible materials control 3 – Cask provides thermal barrier to direct exposure of canister	N/A	ISO-I404
7.10	Temperature	(Less) Temperature below canister design basis	Normal condition	No safety consequences	N/A	N/A	N/A
7.11	Shielding	(Less) Displacement of Cask shielding	Impact or fire	Potential direct exposure	1 – Cask design 2 – Procedures and training 3 – Combustible materials control	N/A	ISO-I404 and ISO-701
7.12	Shielding	(No) Total displacement of Cask shielding	No cause identified	N/A	N/A	N/A	N/A

NOTE: Guidewords not used in this node: As Well As and Part Of.

AO = aging overpack; CRCF = Canister Receipt and Closure Facility; DPC = dual-purpose canister; ISO = Intra-Site Operations; MLD = master logic diagram; RF = Receipt Facility; ST = site transporter; TAD = transportation, aging, and disposal; WHF = Wet Handling Facility; ft = foot.

Source: Original

Table E-9. HAZOP Worksheet for Node 8

Facility/Operation: Intra-Site Operations — Process: AO Transit

Node 8: AO Movement among RF (TAD Canister/DPC), WHF (TAD Canister/DPC), CRCF (TAD Canister) and Aging Pad — Process/Equipment: ST, AO

Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of — Consequence Categories: Radioactive Release, Direct Exposure, Criticality

Node Item Number	Parameter	Deviation Considered	Postulated Cause	Consequence(s)	Potential Prevention/Mitigation Design of Operational Feature	Notes	MLD Index Number
8.1	Speed	(More) ST moves at faster than desired speed	No cause identified	N/A	N/A	1 – Safe speed of 5 mph or less expected 2 – Inherent design of ST limits maximum speed	N/A
8.2	Speed	(Less) ST moves at slower than desired speed	Mechanical failure of ST	No safety consequences	N/A	Low normal speed (less than 5 mph) expected on ramp to aging pad	N/A
8.3	Speed	(No) ST does not move	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	N/A	N/A
8.4	Direction	(Reverse) ST moves backward instead of going forward	1 – Human failure 2 – Mechanical failure	Potential loss of control or collision leading to radioactive release	1 – TAD canister or DPC provides confinement 2 – Procedures and training 3 – AO provides shielding 4 – ST design integrity	N/A	ISO-701
8.5	Direction	(Other Than) ST does not follow designated path	1 – Human failure 2 – Mechanical failure	Potential loss of control or collision leading to radioactive release	1 – TAD canister or DPC provides confinement 2 – Procedures and training 3 – AO provides shielding 4 – ST design integrity	Steering failure	ISO-701
8.6	Lift	(More) ST lifts load higher than 1 ft	1 – Human failure 2 – Mechanical failure	Potential drop leading to radioactive release	1 – ST design limits lift height to 1 ft 2 – Procedures and training	Procurement requirement	ISO-702
8.7	Lift	(Less) ST does not lift to required transport height	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – ST design 2 – Procedures and training	N/A	ISO-701
8.8	Lift	(No) ST does not lift load	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	1 – No loss of shielding or radioactive release 2 – Expected damage to bottom plate only	N/A
8.9	Temperature	(More) Temperature exceeds canister design basis	Fire on ST (electrical, hydraulic, diesel)	1 – Potential radioactive release 2 – Potential criticality	1 – Procedures and training 2 – Combustible materials control 3 – AO provides thermal barrier to direct exposure of canister	Potential for AO vents to provide path for flame impingement	ISO-I404
8.10	Temperature	(Less) Temperature below canister design basis	Normal condition	No safety consequences	N/A	N/A	N/A
8.11	Shielding	(Less) Displacement of AO shielding	Impact or fire	Potential direct exposure	1 – AO design 2 – Procedures and training 3 – Combustible materials control	N/A	ISO-I404 and ISO-701
8.12	Shielding	(No) Total displacement of AO shielding	No cause identified	N/A	N/A	N/A	N/A

NOTE: Guidewords not used in this node: As Well As and Part Of.

AO = aging overpack; CRCF = Canister Receipt and Closure Facility; DPC = dual-purpose canister; ISO = Intra-Site Operations; MLD = master logic diagram; RF = Receipt Facility; ST = site transporter; TAD = transportation, aging, and disposal; WHF = Wet Handling Facility; ft = foot.

Source: Original

Table E-10. HAZOP Worksheet for Node 9

Facility/Operation: Intra-Site Operations							Process: AO Staging
Node 9: AO Placement on Aging Pad							Process/Equipment: ST, AO
Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Direct Exposure, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
9.1	Drop	(More) Drop load when placing AO on pad	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – Procedures and training 2 – ST design 3 – AO design	N/A	ISO-702
9.2	Direction	(Other Than) ST impacts object on pad	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – Procedures and training 2 – ST design speed 3 – AO design	N/A	ISO-701
9.3	Direction	(Other Than) AO placed in incorrect location	Human failure	No direct safety consequence	1 – Procedures and training 2 – Location markings	Governed by accountability requirements (manifests)	N/A

NOTE: Guidewords not used in this node: No, Less, Reverse, As Well As, and Part Of.
AO = aging overpack; ISO = Intra-Site Operations; MLD = master logic diagram; ST = site transporter.

Source: Original

Table E-11. HAZOP Worksheet for Node 10

Facility/Operation: Intra-Site Operations — Process: Horizontal DPC Transit

Node 10: Horizontal DPC Movement among WHF (TAD Canister/DPC), Aging Pad, and CRCF (TAD Canister) — Process/Equipment: Cask Transfer Trailer/Cask Tractor, Horizontal TC, and Site HSTC

Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of — Consequence Categories: Radioactive Release, Direct Exposure, Criticality

Node Item Number	Parameter	Deviation Considered	Postulated Cause	Consequence(s)	Potential Prevention/Mitigation Design of Operational Feature	Notes	MLD Index Number
10.1	Speed	(More) Cask tractor moves at faster than desired speed	Driver drives cask tractor faster than desired speed	Potential loss of control or collision leading to radioactive release	1 – TC design (without impact limiters) 2 – Speed limiting device on cask tractor engine 3 – Procedures and training	Safe speed of 5 mph or less expected	ISO-601
10.2	Speed	(More) Cask tractor moves at faster than desired speed	Mechanical failure of cask tractor	Potential loss of control or collision leading to radioactive release	1 – TC design (without impact limiters) 2 – Procedures and training	Safe speed of 5 mph or less expected	ISO-601/602
10.3	Speed	(More) Tractor trailer disengages from cask tractor	Mechanical failure of cask tractor	Potential loss of control or collision leading to radioactive release	1 – TC design (without impact limiters) 2 – Procedures and training 3 – Fail-safe brake on trailer 4 – Coupling design	Safe speed of 5 mph or less expected	ISO-601/602
10.4	Speed	(Less) Cask tractor moves at slower than desired speed	Mechanical failure of cask tractor or trailer	No safety consequences	N/A	N/A	N/A
10.5	Speed	(No) Cask tractor does not move	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	N/A	N/A
10.6	Direction	(Reverse) Cask tractor moves backward instead of going forward	1 – Human failure 2 – Mechanical failure	Potential loss of control or collision leading to radioactive release	1 – TC design (without impact limiters) 2 – Procedures and training	N/A	ISO-601/602
10.7	Direction	(Other Than) Cask tractor does not follow designated route	1 – Human failure 2 – Mechanical failure	Potential loss of control or collision leading to radioactive release	1 – TC design (without impact limiters) 2 – Procedures and training	1 – Steering failure 2 – Brake failure	ISO-601/602
10.8	Lift	(More) No lift associated with trailer	N/A	N/A	N/A	N/A	N/A
10.9	Temperature	(More) Temperature exceeds 10 CFR Part 71 design basis	Fire	1 – Potential radioactive release 2 – Potential criticality	1 – TC design (without impact limiters) 2 – Procedures and training 3 – Combustible materials control	10 CFR Part 71 temperature design basis	ISO-I404
10.10	Temperature	(More) Temperature exceeds canister design basis	Fire	1 – Potential radioactive release 2 – Potential criticality	1 – HSTC provides thermal barrier 2 – Procedures and training 3 – Combustible materials control	The HSTC is designed to be the same as the TC (i.e., a NUHOMS cask), so it should provide the same protection. Therefore, this is the same as 10.9, above (10 CFR Part 71 temperature design basis)	ISO-I404
10.11	Temperature	(Less) Temperature below 10 CFR Part 71 or canister design basis	Normal condition	No safety consequences	N/A	N/A	N/A
10.12	Shielding	(Less) Displacement of TC shielding	Impact or fire	Potential direct exposure	1 – TC design (without impact limiters) 2 – Procedures and training 3 – Combustible materials control	N/A	ISO-I404 and ISO-601
10.13	Shielding	(Less) Displacement of HSTC shielding	Impact or fire	Potential direct exposure	1 – HSTC provides shielding 2 – Procedures and training 3 – Combustible materials control	N/A	ISO-I404 and ISO-601
10.14	Shielding	(No) Total displacement of HSTC shielding	No cause identified	N/A	N/A	N/A	N/A

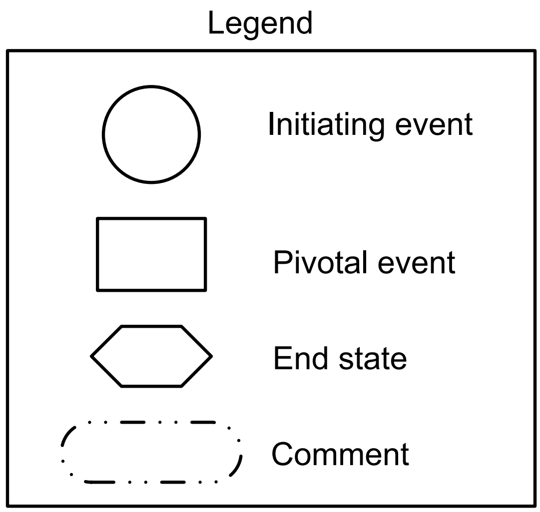
NOTE: Guidewords not used in this node: As Well As and Part Of.

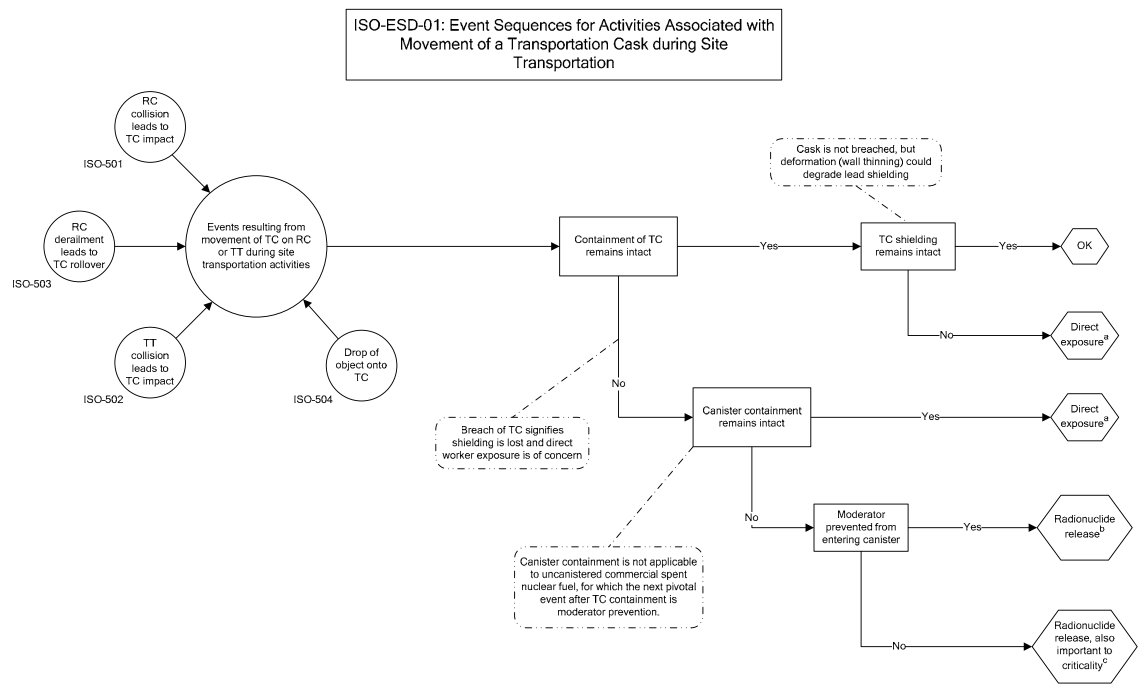
CRCF = Canister Receipt and Closure Facility; DPC = dual-purpose canister; HSTC = horizontal shielded transfer cask; ISO = Intra-Site Operations; MLD = master logic diagram; TAD = transportation, aging, and disposal; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original; 10 CFR Part 71 (Ref. 2.3.2)

ATTACHMENT F
INTRA-SITE OPERATIONS EVENT SEQUENCE DIAGRAMS

Event sequence diagrams for the Intra-Site Operations are presented in Figures F-1 through F-9.





NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a breach of a waste form container.

[b] Radionuclide release describes a condition where radioactive material has been released from the container creating a potential inhalation or ingestion hazard, accompanied by the potential for immersion in a radioactive plume and direct exposure, as described above.

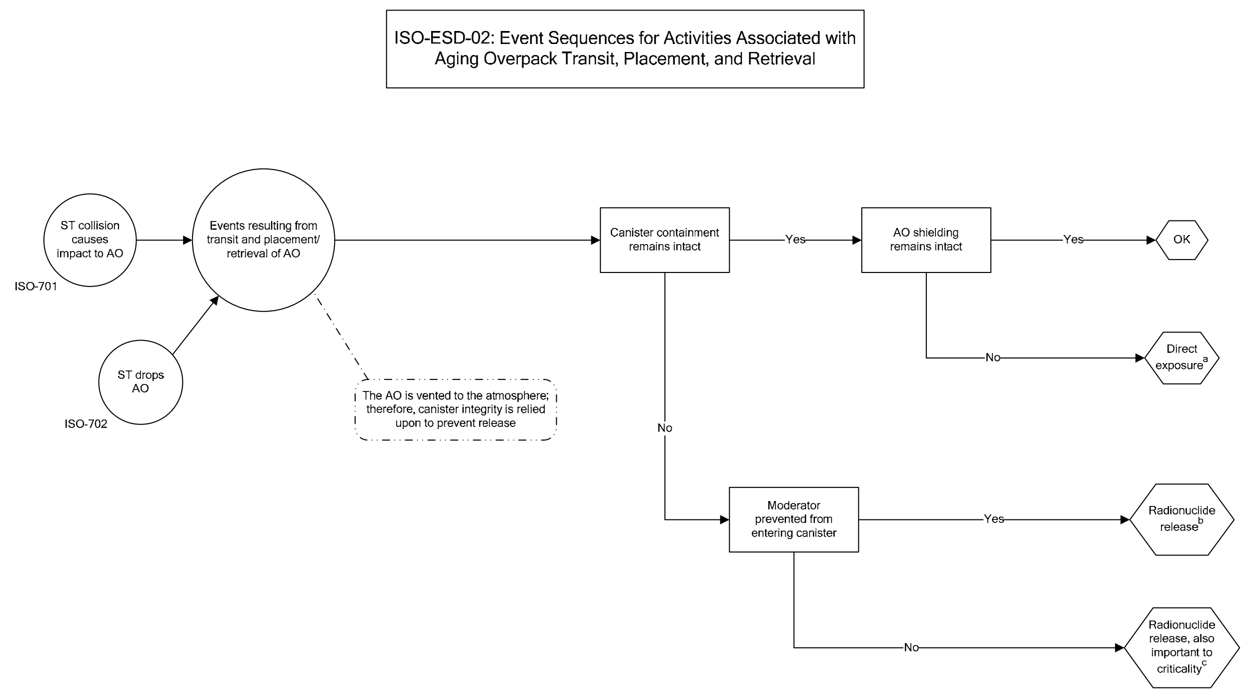
[c] Radionuclide release, also important to criticality, involves radionuclide release as described above, accompanied by the potential for nuclear criticality, which may arise when liquid moderator is available to enter a breached container.

This ESD applies to TCs containing Naval canisters; TCs containing MCOs; TCs containing DOE standardized canisters; TCs containing DOE HLW (multi-canister); TCs containing DOE HLW (single canister); TCs containing UCSNF (canister response is not applied); TCs containing TAD canisters; TCs containing DPCs; and HTCs containing HDPCs.

DOE = Department of Energy; DPC = dual-purpose canister; ESD = event sequence diagram; HDPC = horizontal dual-purpose canister; HLW = high-level radioactive waste; HTC = transportation cask that is never upended; ISO = Intra-Site Operations; MCO = multi-canister overpack; RC = railcar; SNF = spent nuclear fuel; TAD = transportation, aging, and disposal; TC = transportation cask; TT = truck trailer; UCSNF = uncanistered commercial spent nuclear fuel.

Source: Original

Figure F-1. ISO-ESD-01 Event Sequences for Activities Associated with Movement of Transportation Cask during Site Transportation



NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a breach of a waste form container.

[b] Radionuclide release describes a condition where radioactive material has been released from the container creating a potential inhalation or ingestion hazard, accompanied by the potential for immersion in a radioactive plume and direct exposure, as described above.

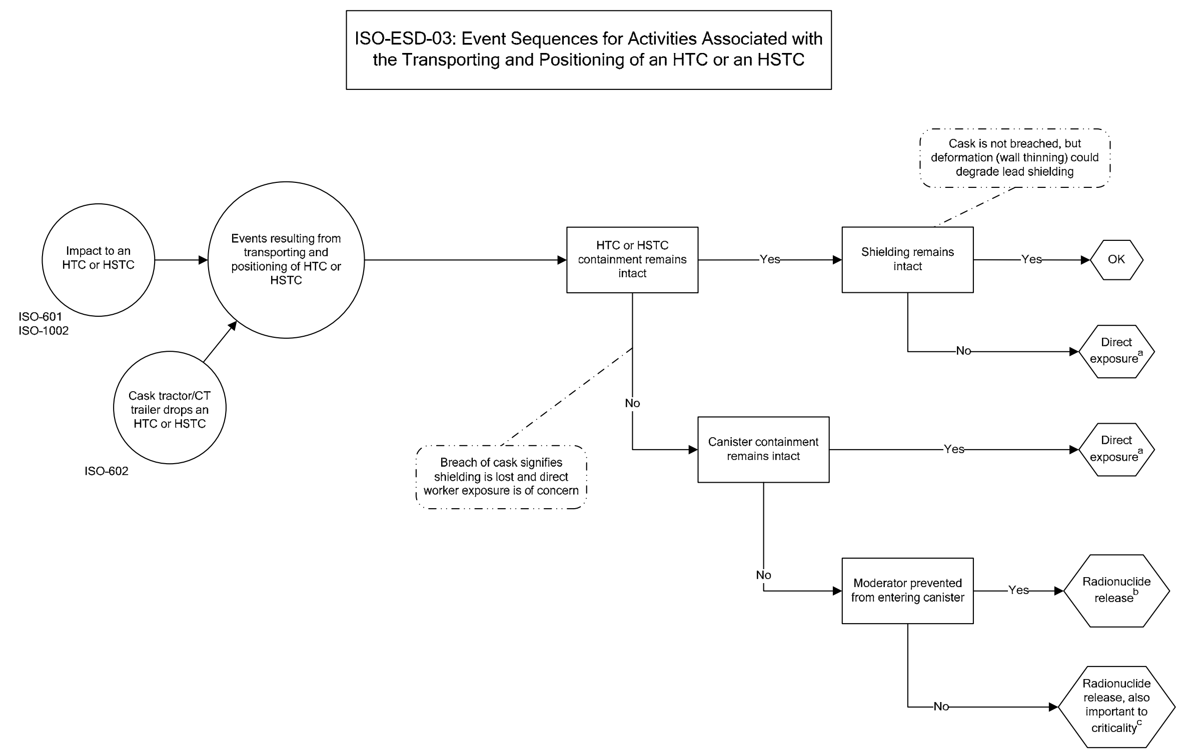
[c] Radionuclide release, also important to criticality, involves radionuclide release as described above, accompanied by the potential for nuclear criticality, which may arise when liquid moderator is available to enter a breached container.

This ESD applies to AOs containing TAD canisters and AOs containing DPCs.

AO = aging overpack; DPC = dual-purpose canister; ESD = event sequence diagram; ISO = Intra-Site Operations; ST = site transporter; TAD = transportation, aging, and disposal.

Source: Original

Figure F-2. ISO-ESD-02 Event Sequences for Activities Associated with Aging Overpack Transit, Placement, and Retrieval



NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a breach of a waste form container.

[b] Radionuclide release describes a condition where radioactive material has been released from the container creating a potential inhalation or ingestion hazard, accompanied by the potential for immersion in a radioactive plume and direct exposure, as described above.

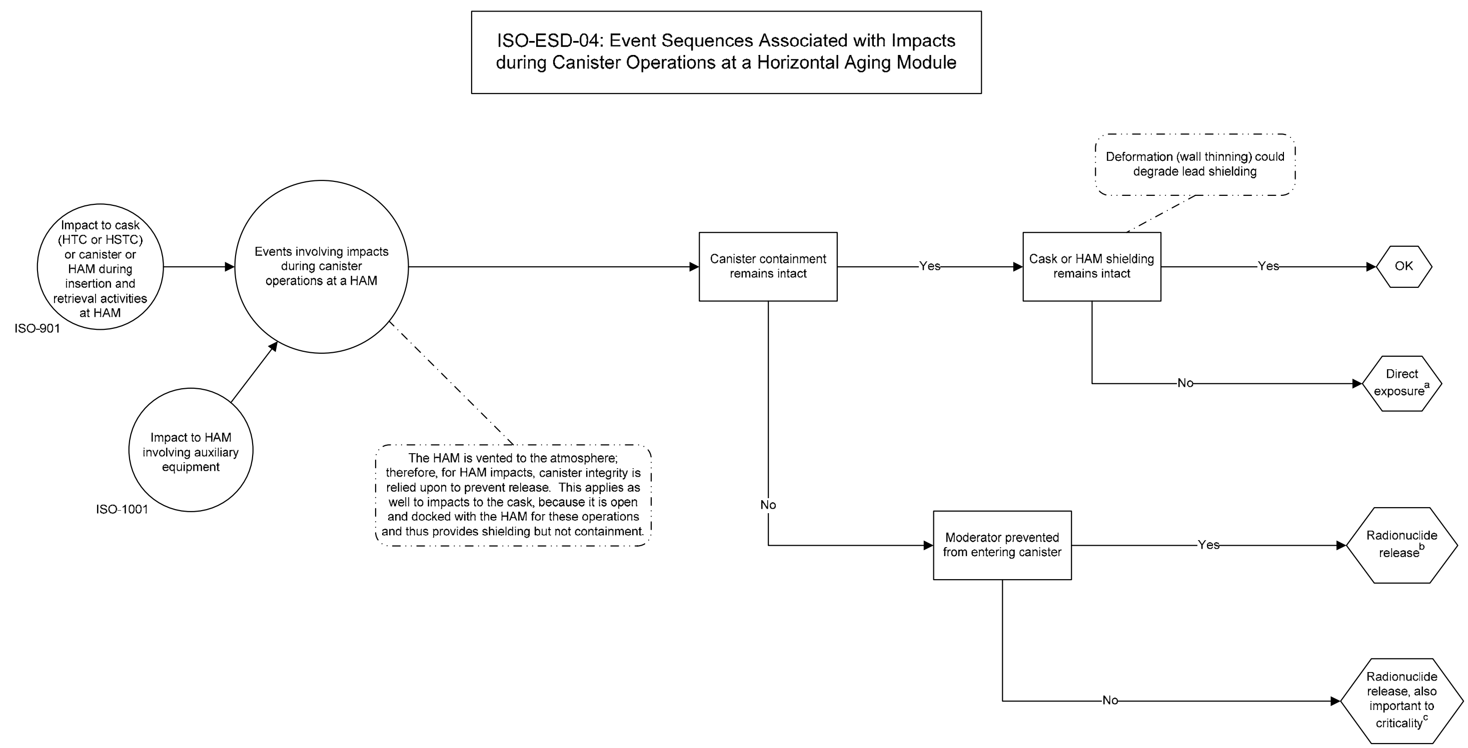
[c] Radionuclide release, also important to criticality, involves radionuclide release as described above, accompanied by the potential for nuclear criticality, which may arise when liquid moderator is available to enter a breached container.

This ESD applies to HTCs containing HDPCs and HSTCs containing HDPCs.

CT = cask transfer; ESD = event sequence diagram; HDPC = horizontal dual-purpose canister; HSTC = horizontal shielded transfer cask; HTC = transportation cask that is never upended; ISO = Intra-Site Operations.

Source: Original

Figure F-3. ISO-ESD-03 Event Sequences for Activities Associated with Transporting and Positioning of an HTC or an HSTC



NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a breach of a waste form container.

[b] Radionuclide release describes a condition where radioactive material has been released from the container creating a potential inhalation or ingestion hazard, accompanied by the potential for immersion in a radioactive plume and direct exposure, as described above.

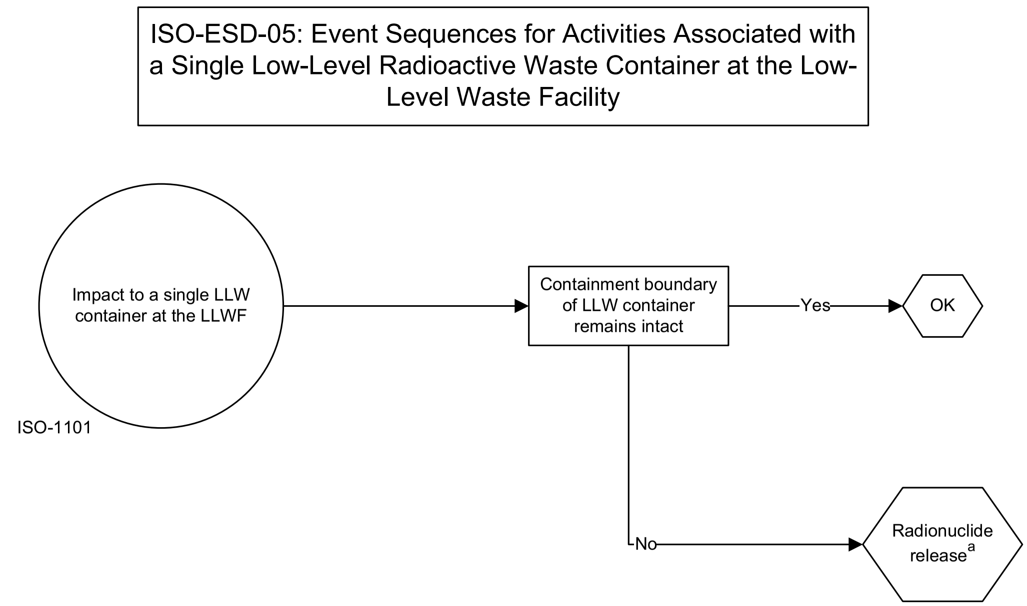
[c] Radionuclide release, also important to criticality, involves radionuclide release as described above, accompanied by the potential for nuclear criticality, which may arise when liquid moderator is available to enter a breached container.

This ESD applies to HTCs containing HDPCs; HSTCs containing HDPCs; and HAMs containing HDPCs.

ESD = event sequence diagram; HAM = horizontal aging module; HDPC = horizontal dual-purpose canister; HSTC = horizontal shielded transfer cask; HTC = transportation cask that is never upended; ISO = Intra-Site Operations.

Source: Original

Figure F-4. ISO-ESD-04 Event Sequences Associated with Impacts during Canister Operations at a Horizontal Aging Module



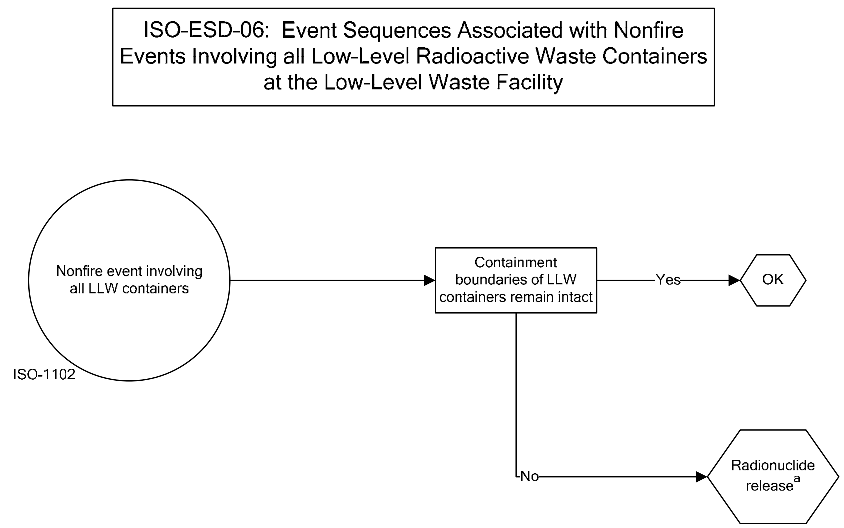
NOTE: [a]Radionuclide release describes a condition where radioactive material has been released from the container creating a potential inhalation or ingestion hazard, accompanied by the potential for immersion in a radioactive plume.

This ESD applies to dry active LLW, wet-solid LLW, and liquid LLW.

ESD = event sequence diagram; ISO = Intra-Site Operations; LLW = low-level radioactive waste.

Source: Original

Figure F-5. ISO-ESD-05 Event Sequences for Activities Associated with a Single Low-Level Radioactive Waste Container at the Low-Level Waste Facility



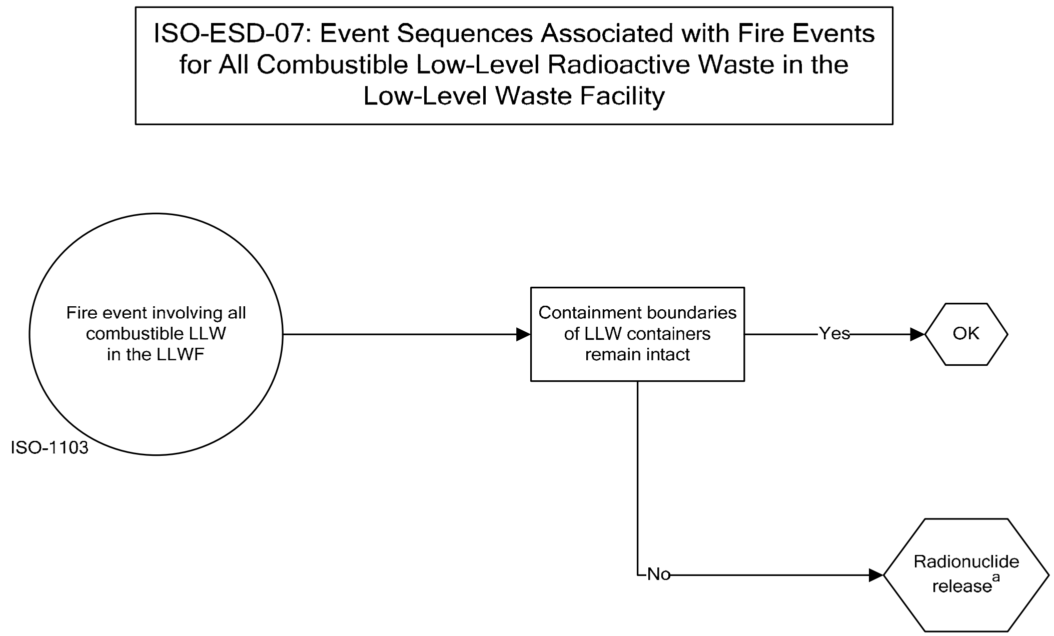
NOTE: [a]Radionuclide release describes a condition where radioactive material has been released from the container creating a potential inhalation or ingestion hazard, accompanied by the potential for immersion in a radioactive plume.

This ESD applies to dry active LLW, wet-solid LLW, and liquid LLW.

ESD = event sequence diagram; ISO = Intra-Site Operations; LLW = low-level radioactive waste.

Source: Original

Figure F-6 ISO-ESD-06 Event Sequences Associated with Nonfire Events Involving all Low-Level Radioactive Waste Containers at the Low-Level Waste Facility



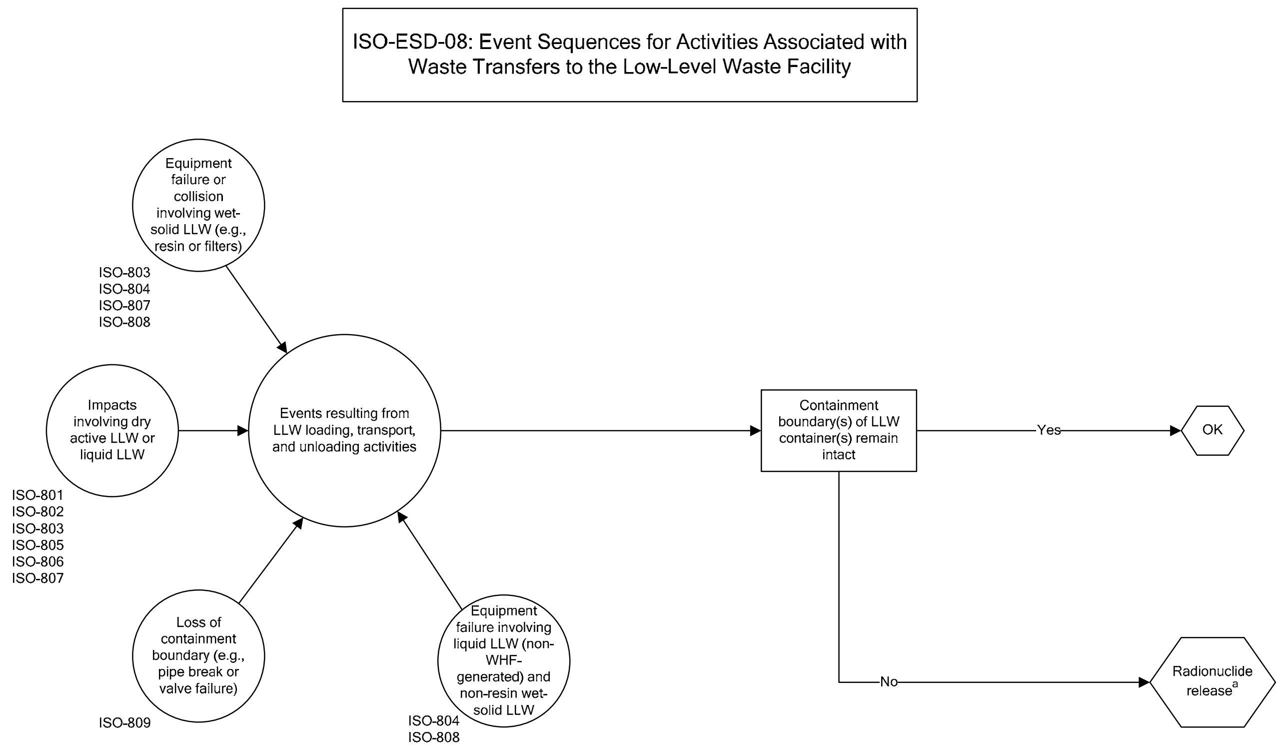
NOTE: [a]Radionuclide release describes a condition where radioactive material has been released from the container creating a potential inhalation or ingestion hazard, accompanied by the potential for immersion in a radioactive plume.

This ESD applies to the entire inventory of combustible LLW at the LLWF..

ESD = event sequence diagram; ISO = Intra-Site Operations; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility.

Source: Original

Figure F-7. ISO-ESD-07: Event Sequences Associated with Fire Events for All Combustible Low-Level Radioactive Waste in the Low-Level Waste Facility

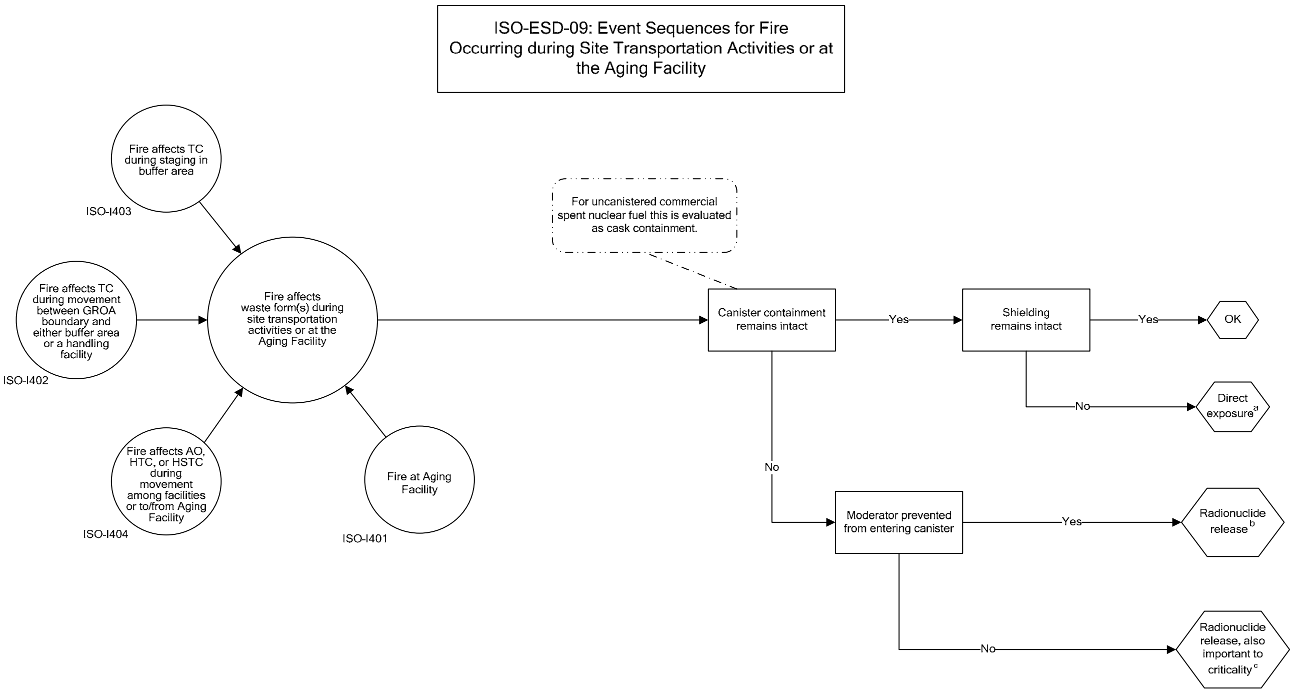


NOTE: [a]Radionuclide release describes a condition where radioactive material has been released from the container creating a potential inhalation or ingestion hazard, accompanied by the potential for immersion in a radioactive plume.

This ESD applies to dry active LLW, wet-solid LLW, and liquid LLW.
ESD = event sequence diagram; ISO = Intra-Site Operations; LLW = low-level radioactive waste; WHF = Wet Handling Facility.

Source: Original

Figure F-8. ISO-ESD-08: Event Sequences for Activities Associated with Waste Transfers to the Low-Level Waste Facility



NOTE: [a]Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a breach of a waste form container.

[b] Radionuclide release describes a condition where radioactive material has been released from the container creating a potential inhalation or ingestion hazard, accompanied by the potential for immersion in a radioactive plume.

[c] Radionuclide release, also important to criticality, involves radionuclide release as described above, accompanied by the potential for nuclear criticality, which may arise when liquid moderator is available to enter a breached container.

This ESD applies to TCs containing naval canisters; TCs containing MCOs; TCs containing DOE standardized canisters; TCs containing DOE HLW (multi-canister); TCs containing DOE HLW (single canister); TCs containing UCSNF (no canister – TC provides containment); TCs containing TAD canisters; TCs containing DPCs; HTCs containing HDPCs; HSTCs containing HDPCs; AOs containing TAD canisters; AOs containing DPCs; and HAMs containing HDPCs.

AO = aging overpack; DOE = Department of Energy; DPC = dual-purpose canister; ESD = event sequence diagram; GROA = geologic repository operations area; HAM = horizontal aging module; HDPC = horizontal dual-purpose canister; HLW = high-level radioactive waste; HSTC = horizontal shielded transfer cask; HTC = transportation cask that is never upended; ISO = Intra-Site Operations; MCO = multi-canister overpack; SNF = spent nuclear fuel; TAD = transportation, aging, and disposal; TC = transportation cask; UCSNF = uncanistered commercial spent nuclear fuel.

Source: Original

Figure F-9. ISO-ESD-09: Event Sequences for Fire Occurring during Site Transportation Activities or at the Aging Facility

ATTACHMENT G
INTRA-SITE OPERATIONS AND BOP EVENT TREES

This attachment presents event trees that are derived from the ESDs in Attachment F. Figure G-1 provides an example initiator event tree with navigation aids. Navigation from an initiator event tree to the corresponding system response event tree is assisted by the rightmost two columns on the initiator event trees. The numbers under the "#" symbol can be used by the analyst to reference a particular branch of an event tree, but it is not used elsewhere by SAPHIRE in this analysis. The title of the corresponding system response event tree is listed under the heading "XFER-TO-RESP-TREE". Refer to Table G-1 for the relationship between the ESDs, initiating event trees, and system response event trees.

The event trees are presented in Figures G-2 through G-36 according to the hierarchical ordering option in SAPHIRE. This ordering places the system response event trees after the first of the corresponding initiator event trees. The initiator event trees are presented in order of ascending ESD number, with system response trees systematically intermingled. Each system response event tree is placed immediately after the first initiator event tree that transfers to that system response event tree. Self-contained event trees (i.e., event trees for which separate initiator and system response event trees are not needed) appear in ESD order along with the initiator event trees.

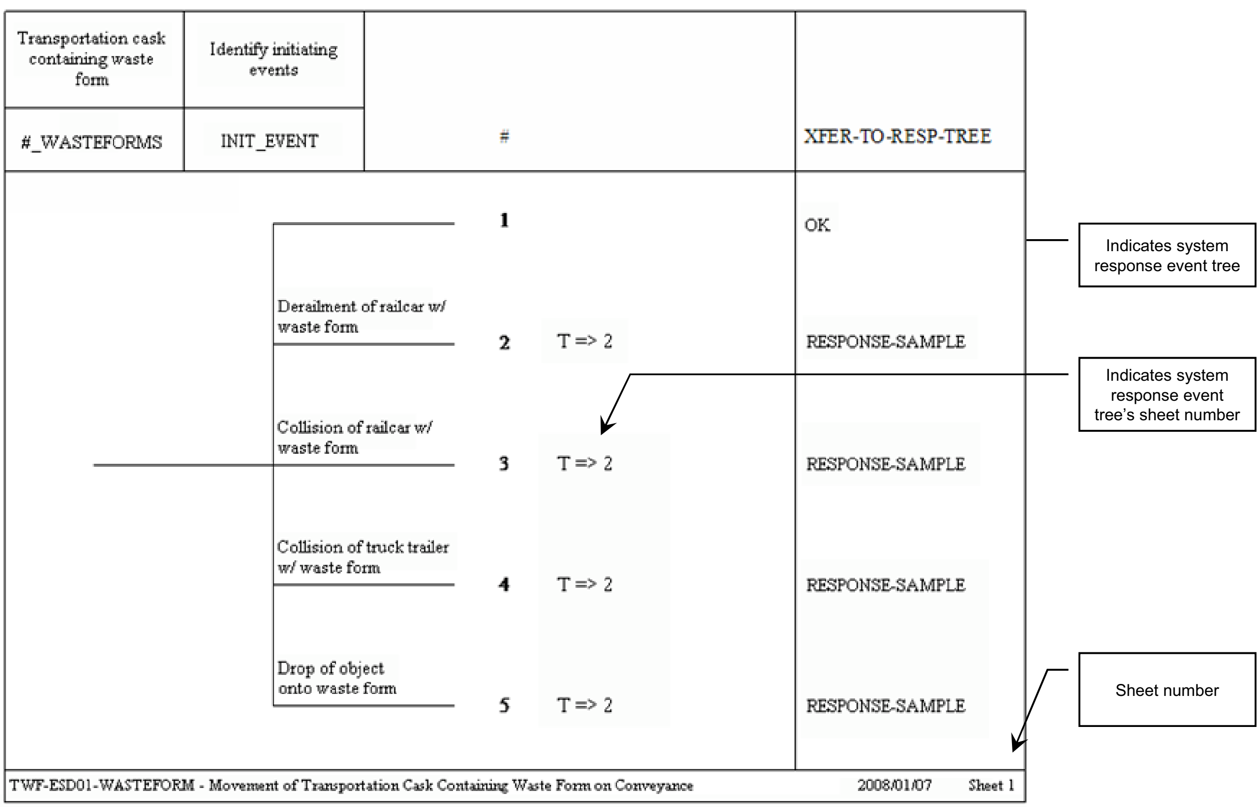


Figure G-1. Example Initiator Event Tree Showing Navigation Aids

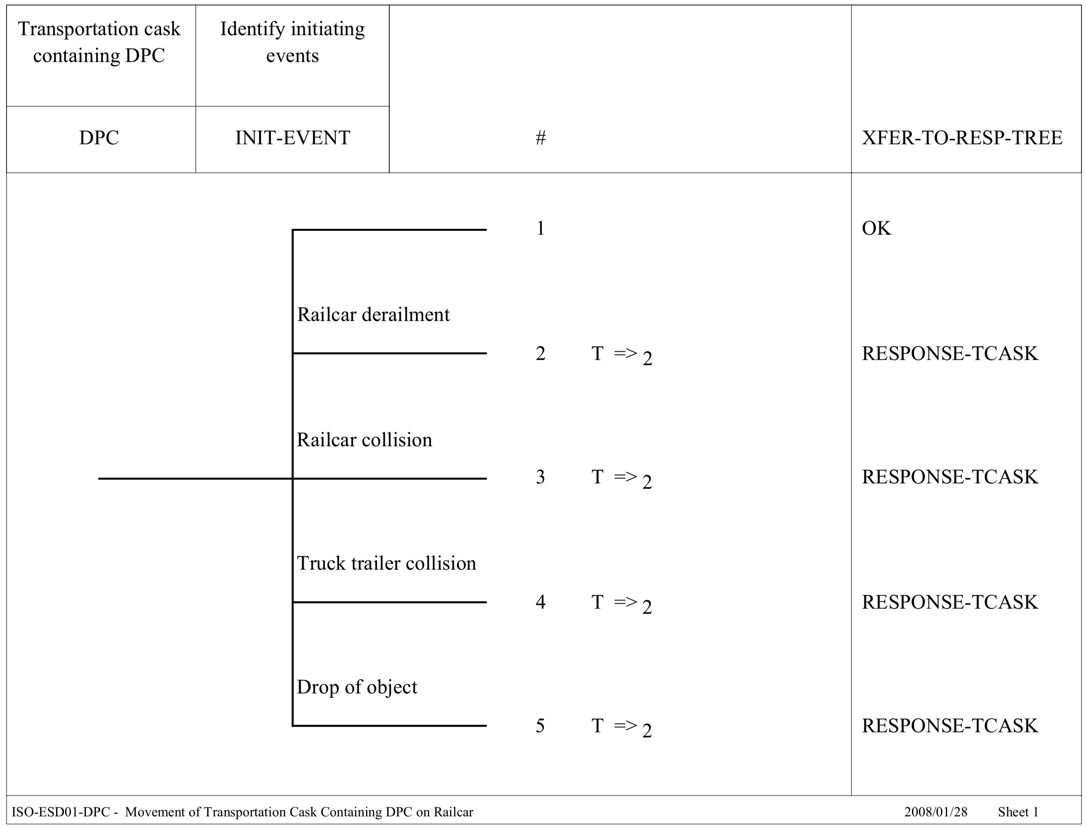
Table G-1. Relation of Event Sequence Diagrams to Event Trees

ESD#	ESD Title	IE Event Tree Name	IE Event Tree Location	Response Tree Name	Response Tree Location
ISO-ESD-01	Event Sequences for Activities Associated with Movements of Transportation Casks during Transportation on Conveyance	ISO-ESD-01-DPC ISO-ESD-01-DSTD ISO-ESD-01-HDPC ISO-ESD-01-HLW ISO-ESD-01-MCO ISO-ESD-01-NAV ISO-ESD-01-TAD ISO-ESD-01-UCSNF	Figure G-2 Figure G-4 Figure G-5 Figure G-6 Figure G-7 Figure G-8 Figure G-9 Figure G-10	RESPONSE-TCASK	Figure G-3
ISO-ESD-02	Event Sequences for Activities Associated with Aging Overpack Transit, Placement, and Retrieval	ISO-ESD-02-DPC ISO-ESD-02-TAD	Figure G-11 Figure G-13	RESPONSE-AO	Figure G-12
ISO-ESD-03	Event Sequences for Activities Associated with the Transporting and Positioning of an HTC or an HSTC	ISO-ESD-03-HDPC	Figure G-14	RESPONSE-HTC	Figure G-15
ISO-ESD-04	Event Sequences Associated with Impacts during Canister Insertion or Retrieval Operations at a Horizontal Aging Module	ISO-ESD-04-HDPC	Figure G-16	RESPONSE-HAM	Figure G-17
ISO-ESD-05	Event Sequences for Activities Associated with a Single Low-Level Radioactive Waste Container at the Low-Level Waste Facility	ISO-ESD-05-LLWDAW	Figure G-18	N/A	N/A
ISO-ESD-05	Event Sequences for Activities Associated with a Single Low-Level Radioactive Waste Container at the Low-Level Waste Facility	ISO-ESD-05-LLWLIQ	Figure G-19	N/A	N/A

ESD#	ESD Title	IE Event Tree Name	IE Event Tree Location	Response Tree Name	Response Tree Location
ISO-ESD-05	Event Sequences for Activities Associated with a Single Low-Level Radioactive Waste Container at the Low-Level Waste Facility	ISO-ESD-05-LLWWETNR	Figure G-20	N/A	N/A
ISO-ESD-06	Event Sequences Associated with Non-Fire Events Involving all Low-Level Radioactive Waste Containers at the Low-Level Waste Facility	ISO-ESD-06-LLW	Figure G-21	N/A	N/A
ISO-ESD-07	Event Sequences Associated with Fire Events for All Combustible Low-Level Radioactive Waste in the Low-Level Waste Facility	ISO-ESD-07-LLW	Figure G-22	N/A	N/A
ISO-ESD-08	Event Sequences for Activities Associated with Waste Transfers to the Low-Level Waste Facility	ISO-ESD-08-LLWDAW ISO-ESD-08-LLWLIQ ISO-ESD-08-LLWWETNR ISO-ESD-08-LLWWETR	Figure G-23 Figure G-25 Figure G-26 Figure G-27	RESPONSE-LLW	Figure G-24
ISO-ESD-09	Event Sequences for Fire Occurring during Site Transportation Activities or at the Aging Facility	ISO-ESD-09-DPC ISO-ESD-09-DSTD ISO-ESD-09-HDPC ISO-ESD-09-HLW ISO-ESD-09-MCO ISO-ESD-09-NAV ISO-ESD-09-TAD ISO-ESD-09-UCSNF	Figure G-28 Figure G-30 Figure G-31 Figure G-32 Figure G-33 Figure G-34 Figure G-35 Figure G-36	RESPONSE-FIRE	Figure G-29

NOTE: AO = aging overpack; DAW = dry active low-level radioactive waste; DPC = dual-purpose canister; DSTD = Department of Energy standardized canister; ESD = event sequence diagram; HAM = horizontal aging module; HDPC = horizontal dual-purpose canister; HLW = high-level radioactive waste; HSTC = horizontal shielded transfer cask; HTC = a transportation cask that is never upended; ISO = Intra-Site Operations; LIQ = liquid; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; MCO = multicanister overpack; NAV = naval; TAD = transportation, aging and disposal; TCASK = transportation cask; UCSNF = uncanistered spent nuclear fuel; WETNR = wet-solid (non-resin) low-level radioactive waste; WETR = wet-solid (resin) low-level radioactive waste.

Source: Original

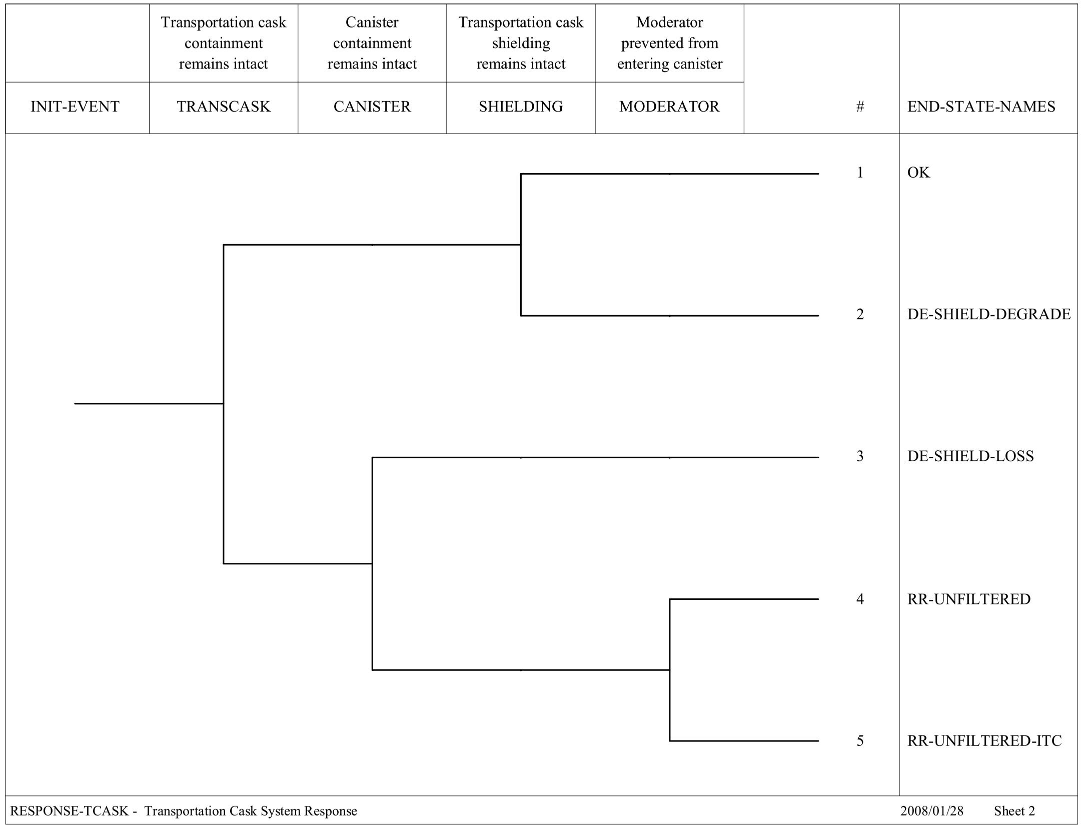


NOTE: The system response event tree for this initiator event tree is RESPONSE-TCASK (Figure G-3).

DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; RESP = response; T = transfer; TCASK = transportation cask; XFER = transfer.

Source: Original

Figure G-2. Initiator Event Tree for ISO-ESD-01-DPC – Movement of Transportation Cask Containing DPC on Railcar

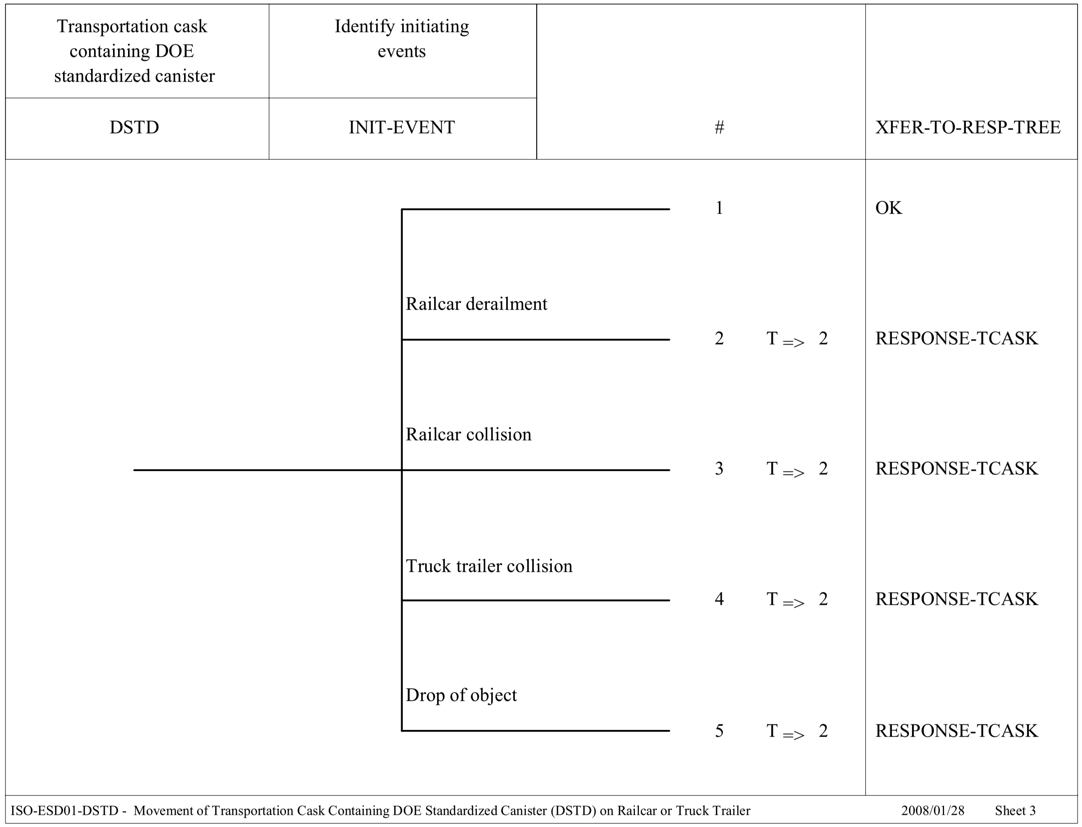


NOTE: For UCSNF, the "CANISTER" pivotal event is not applicable.

DE = direct exposure; ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; ITC = important to criticality; RR = radionuclide release; TCASK = transportation cask; TRANSCASK = transportation cask; UCSNF = uncanistered spent nuclear fuel

Source: Original

Figure G-3. System Response Event Tree for ISO-ESD-01 – RESPONSE-TCASK – Transportation Cask System Response



NOTE: The system response event tree for this initiator event tree is RESPONSE-TCASK (Figure G-3)

DSTD = DOE standardized canister; DOE = Department of Energy; ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; RESP = response; T = transfer; TCASK = transportation cask; XFER = transfer.

Source: Original

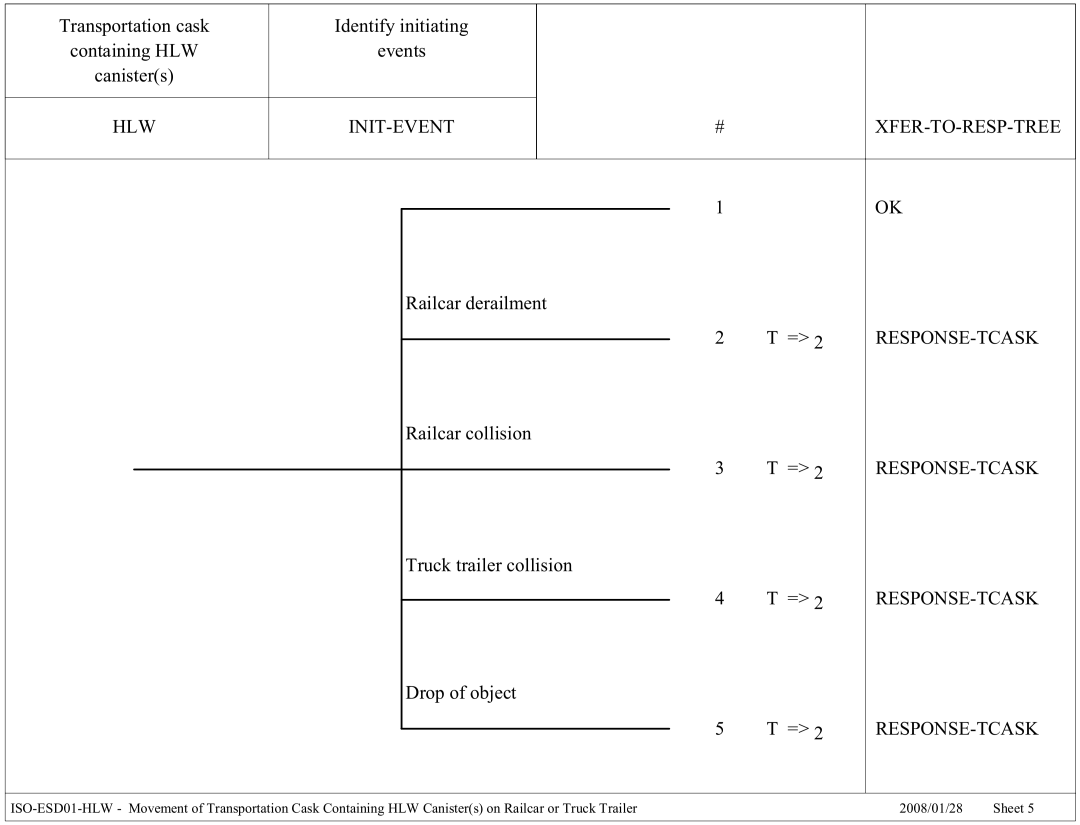
Figure G-4. Initiator Event Tree for ISO-ESD-01-DSTD – Movement of Transportation Cask Containing DOE Standardized Canister on Railcar or Truck Trailer

NOTE: The system response event tree for this initiator event tree is RESPONSE-TCASK (Figure G-3)

DOE = Department of Energy; ESD = event sequence diagram; HDPC = horizontal dual-purpose canister; HTC = a transportation cask that is never upended; INIT = initiating; ISO = Intra-Site Operations; RESP = response; TCASK = transportation cask; XFER = transfer.

Source: Original

Figure G-5. Initiator Event Tree for ISO-ESD-01-HDPC – Movement of HTC (Transportation Cask) Containing HDPC on Railcar



NOTE: The system response event tree for this initiator event tree is RESPONSE-TCASK (Figure G-3)

ESD = event sequence diagram; HLW = high-level radioactive waste; INIT = initiating; ISO = Intra-Site Operations; RESP = response; T = transfer ; TCASK = transportation cask; XFER = transfer.

Source: Original

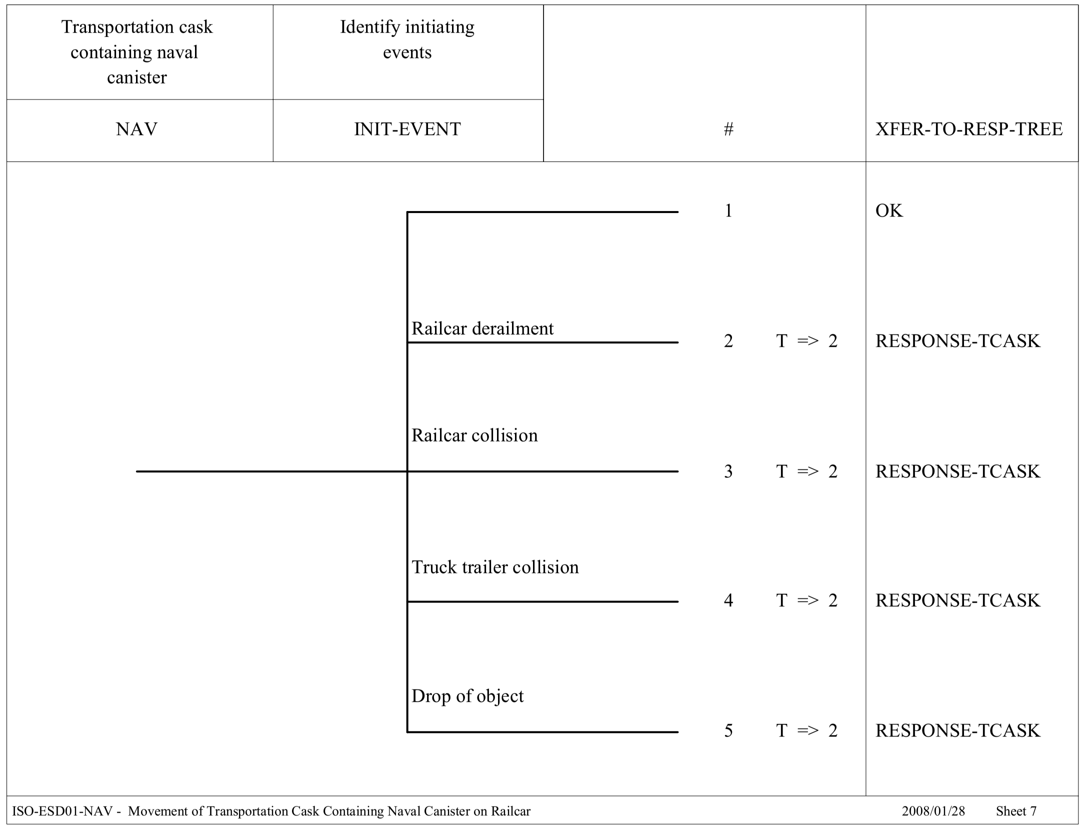
Figure G-6. Initiator Event Tree for ISO-ESD-01-HLW – Movement of Transportation Cask Containing HLW Canister(s) on Railcar or Truck Trailer

NOTE: The system response event tree for this initiator event tree is RESPONSE-TCASK (Figure G-3)

DOE = Department of Energy; ESD = event sequence diagram; HLW = high-level radioactive waste; INIT = initiating; ISO = Intra-Site Operations; MCO = multicanister overpack; RESP = response; T = transfer; TCASK = transportation cask; XFER = transfer.

Source: Original

Figure G-7. Initiator Event Tree for ISO-ESD-01-MCO – Movement of Transportation Cask Containing DOE MCO on Railcar or Truck Trailer

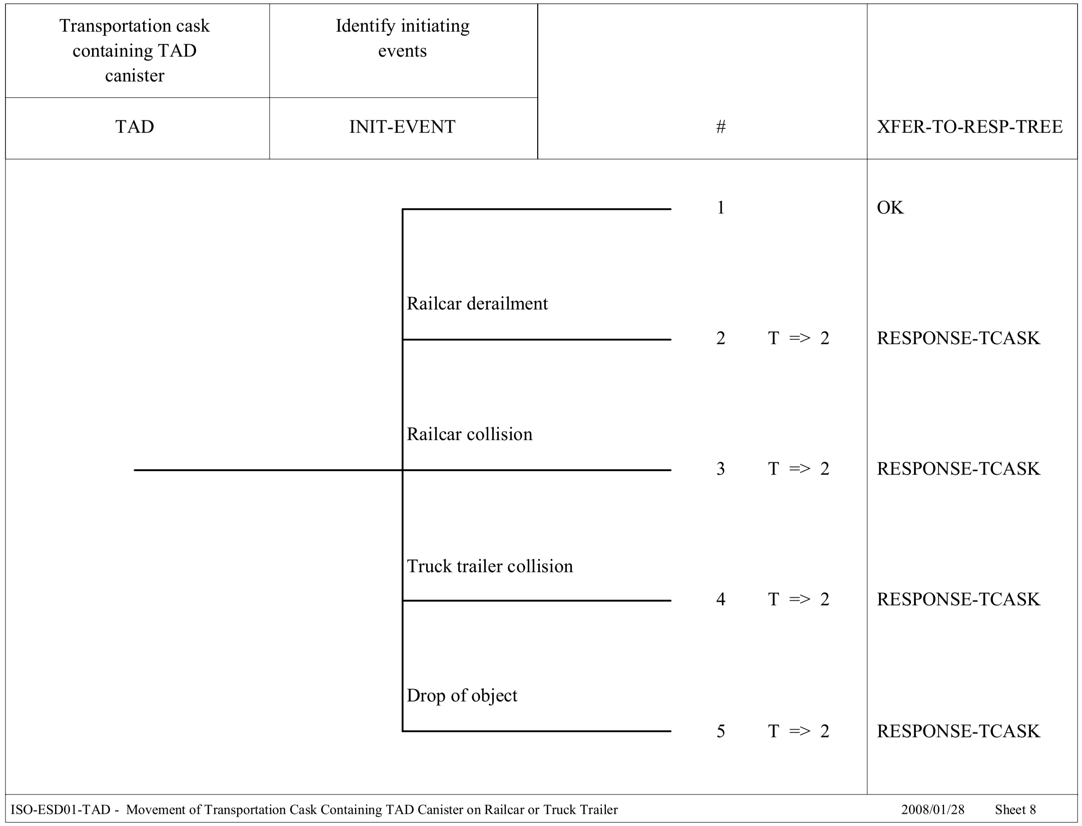


NOTE: The system response event tree for this initiator event tree is RESPONSE-TCASK (Figure G-3)

ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; NAV = naval; RESP = response; T= transfer; TCASK = transportation cask; XFER = transfer.

Source: Original

Figure G-8. Initiator Event Tree for ISO-ESD-01-NAV – Movement of Transportation Cask Containing Naval Canister on Railcar

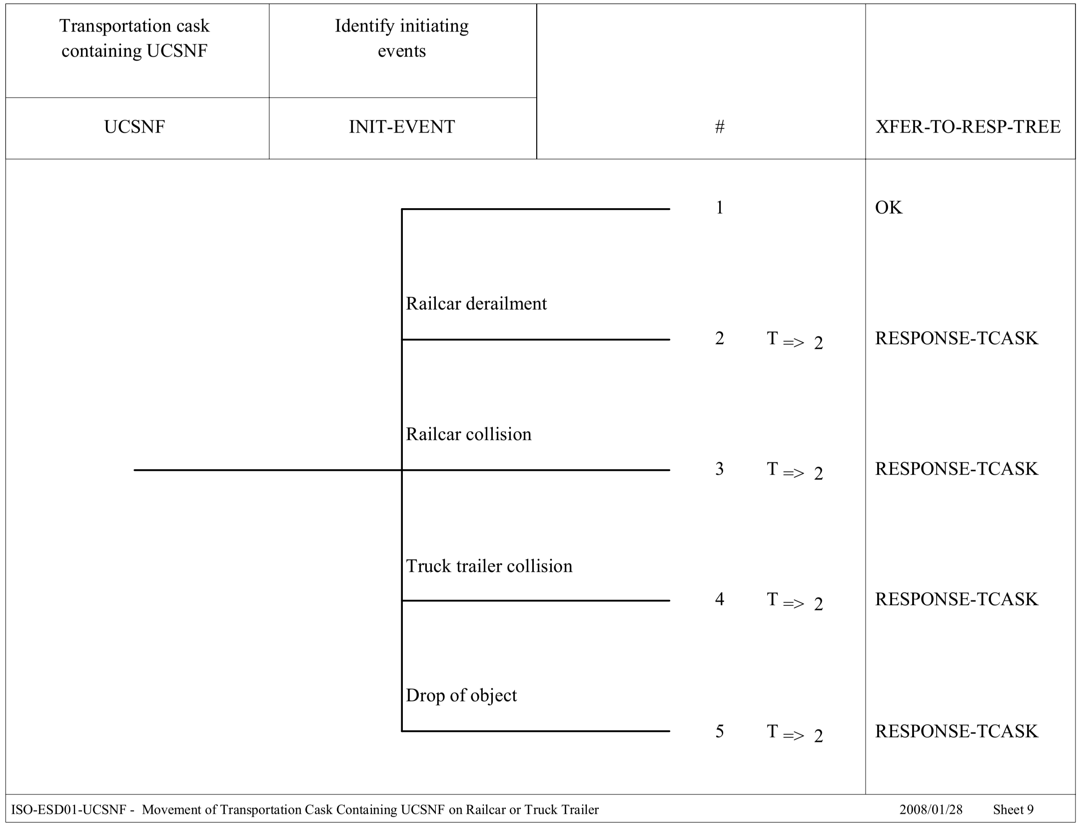


NOTE: The system response event tree for this initiator event tree is RESPONSE-TCASK (Figure G-3)

ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; RESP = response; T = transfer; TAD = transportation, aging, and disposal; TCASK = transportation cask; XFER = transfer.

Source: Original

Figure G-9. Initiator Event Tree for ISO-ESD-01-TAD – Movement of Transportation Cask Containing TAD Canister on Railcar or Truck Trailer

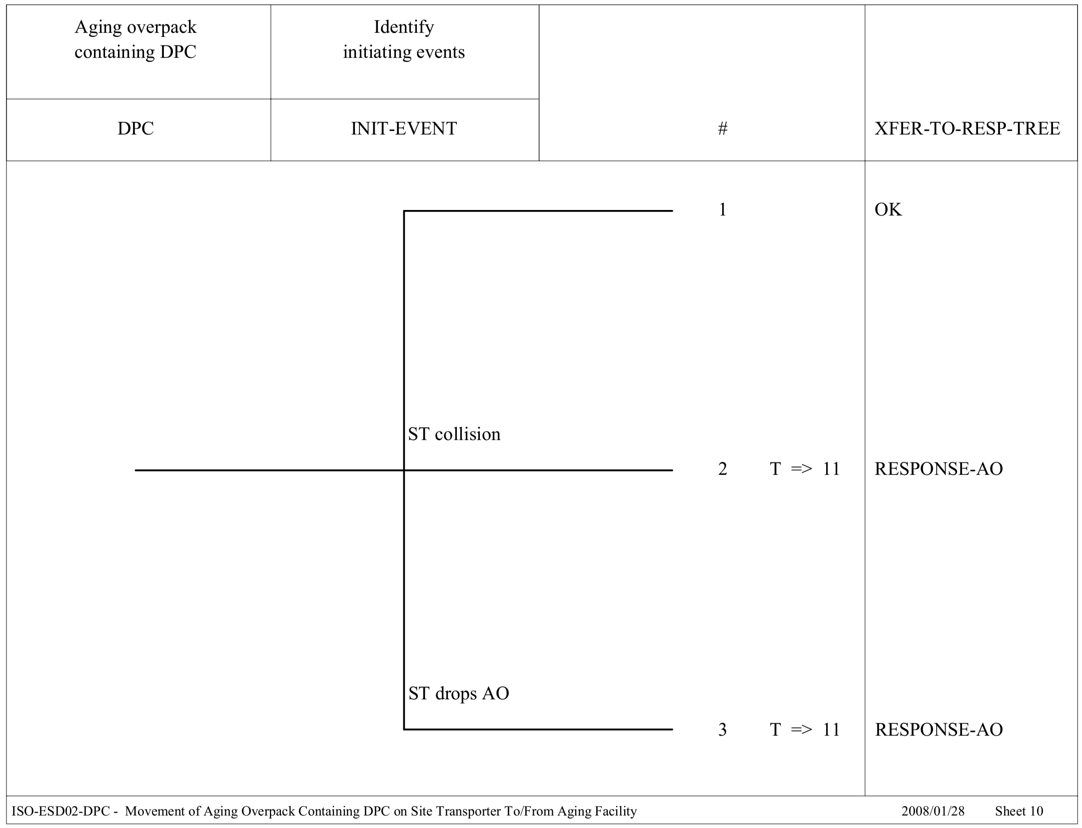


NOTE: The system response event tree for this initiator event tree is RESPONSE-TCASK (Figure G-3)

ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; RESP = response; T = transportation cask; TCASK = transportation cask; UCSNF = uncanistered commercial spent nuclear fuel; XFER = transfer.

Source: Original

Figure G-10. Initiator Event Tree for ISO-ESD-01-UCSNF – Movement of Transportation Cask Containing UCSNF on Railcar or Truck Trailer

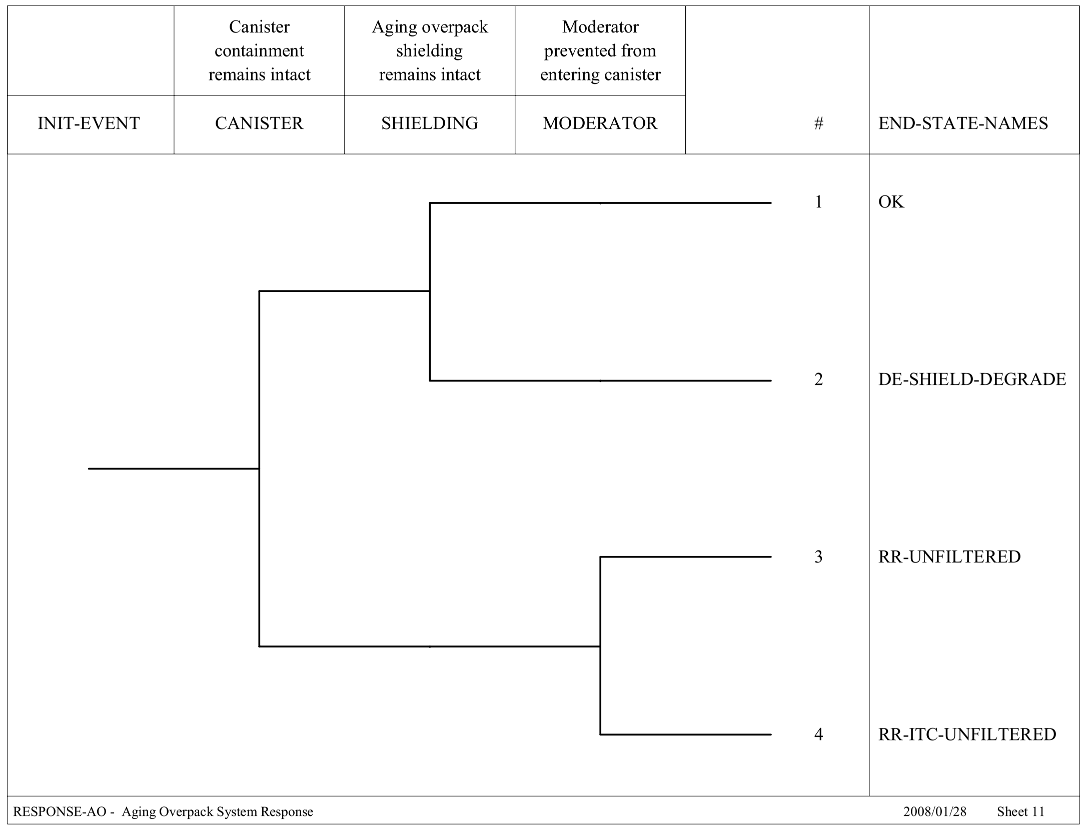


NOTE: The system response event tree for this initiator event tree is RESPONSE-AO (Figure G-12)

AO = aging overpack; DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; RESP = response; ST = site transporter; T = transfer; XFER = transfer.

Source: Original

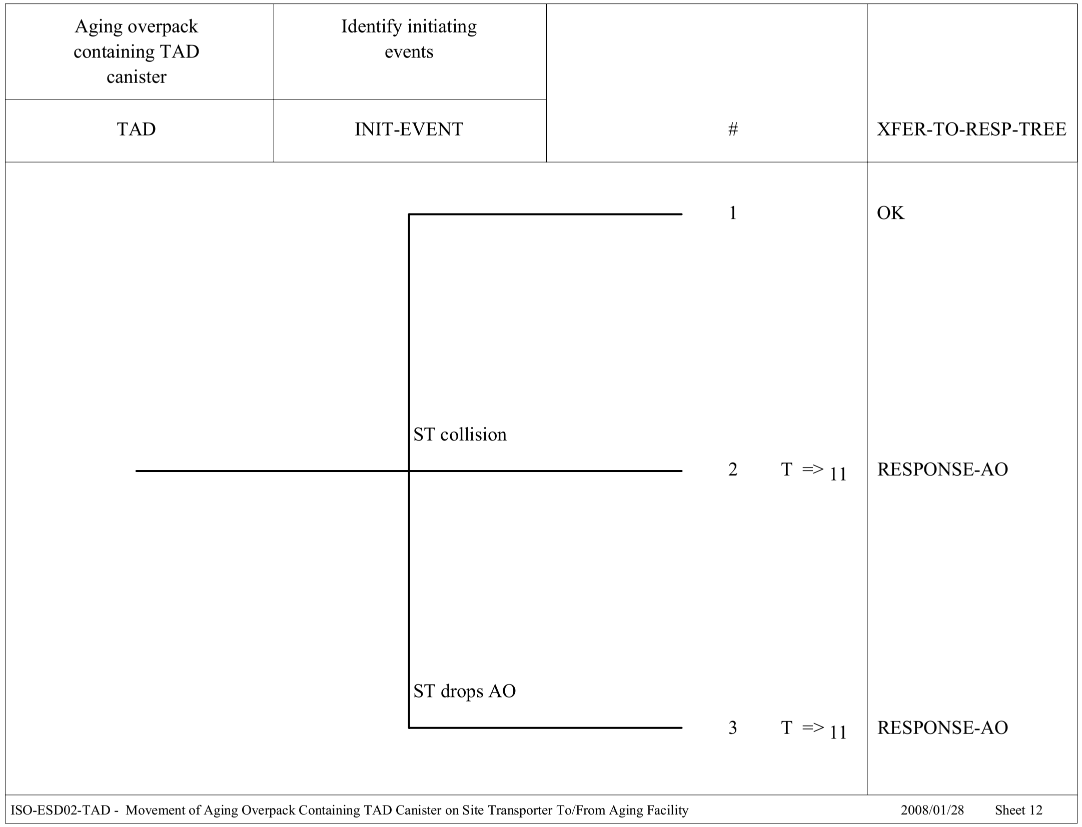
Figure G-11. Initiator Event Tree for ISO-ESD-02-DPC – Movement of Aging Overpack Containing DPC on Site Transporter To/From Aging Facility



NOTE: AO = aging overpack; DE = direct exposure; ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; ITC = important to criticality; RR = radionuclide release.

Source: Original

Figure G-12. System Response Event Tree for ISO-ESD-02 – RESPONSE-AO – Aging Overpack System Response

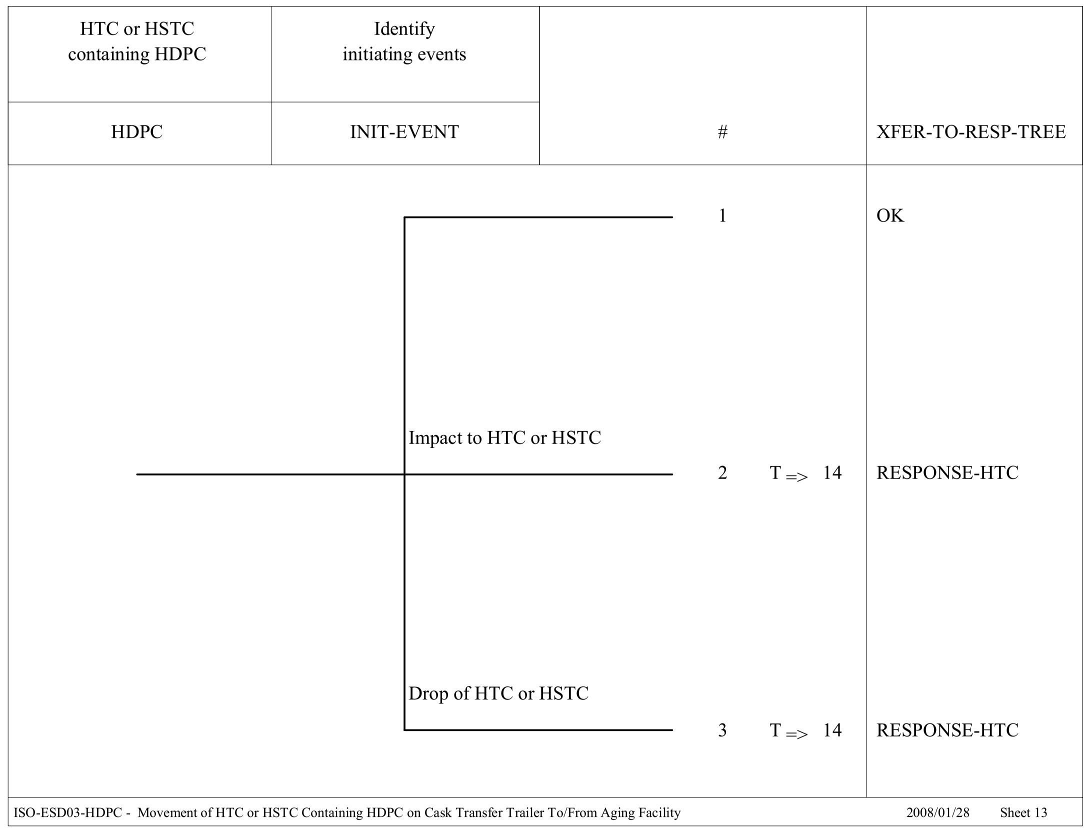


NOTE: The system response event tree for this initiator event tree is RESPONSE-AO (Figure G-12)

AO = aging overpack; ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; RESP = response; ST = site transporter; T = transfer; TAD = transportation, aging, and disposal; XFER = transfer.

Source: Original

Figure G-13. Initiator Event Tree for ISO-ESD-02-TAD – Movement of Aging Overpack Containing TAD Canister on Site Transporter To/From Aging Facility

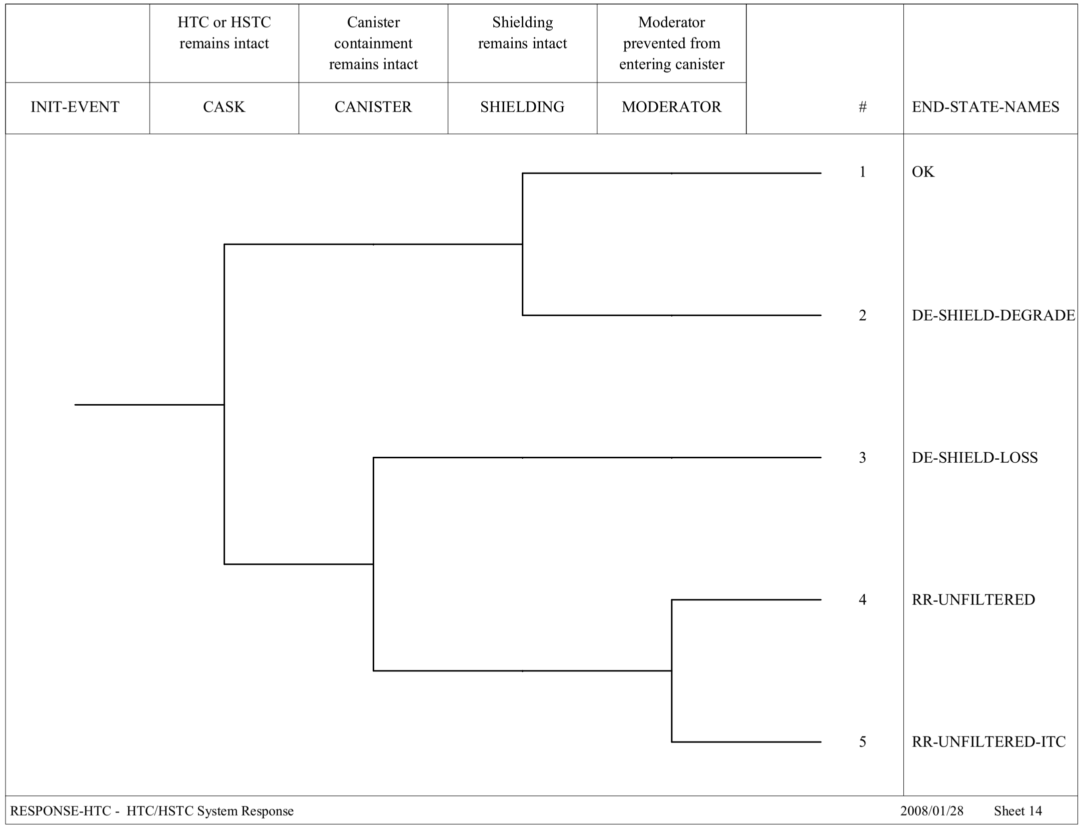


NOTE: The system response event tree for this initiator event tree is RESPONSE-HTC (Figure G-15)

ESD = event sequence diagram; HDPC = horizontal dual-purpose canister; HSTC = horizontally shielded transportation cask; HTC = a transportation cask that is never upended; INIT = initiating; ISO = Intra-Site Operations; RESP = response; T = transfer; XFER = transfer.

Source: Original

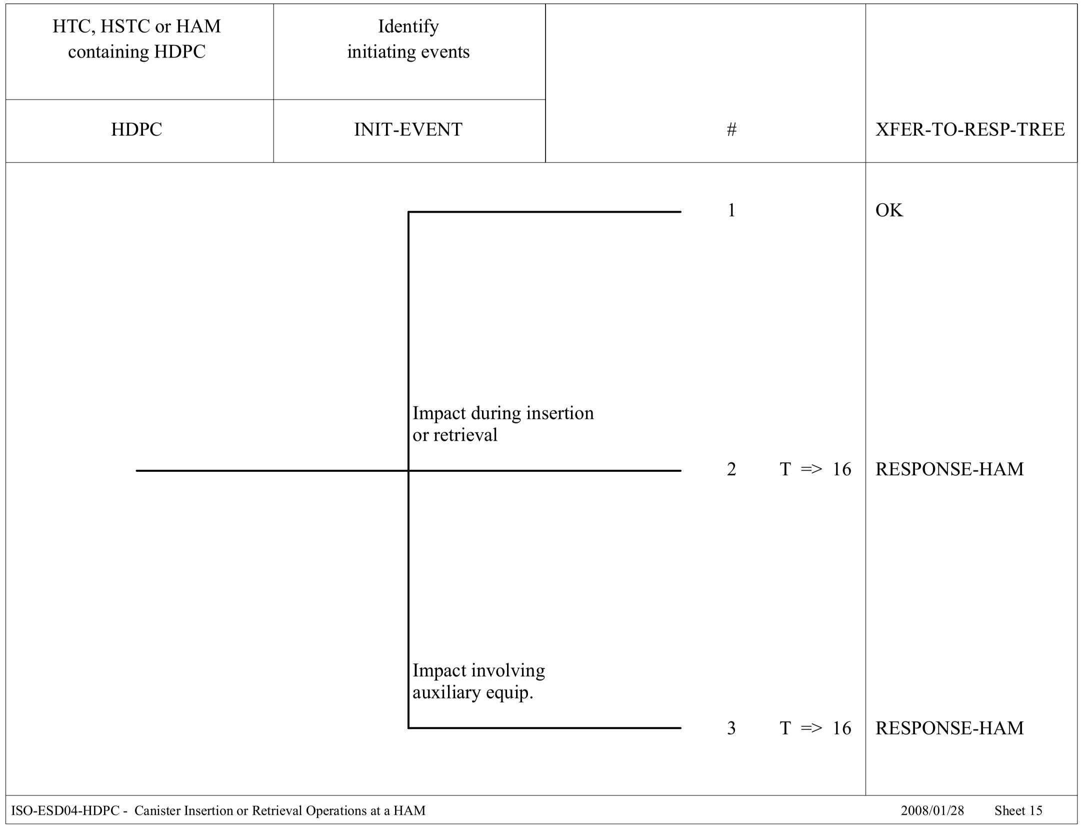
Figure G-14. Initiator Event Tree for ISO-ESD-03-HDPC– Movement of HTC or HSTC Containing HDPC on Cask Transfer Trailer To/From Aging Facility



NOTE: DE = direct exposure; ESD = event sequence diagram; HSTC = horizontally shielded transportation cask; HTC = a transportation cask that is never upended; INIT = initiating; ISO = Intra-Site Operations; ITC = important to criticality; RR = radionuclide release.

Source: Original.

Figure G-15. System Response Event Tree for ISO-ESD-03 –RESPONSE-HTC – HTC/HSTC System Response

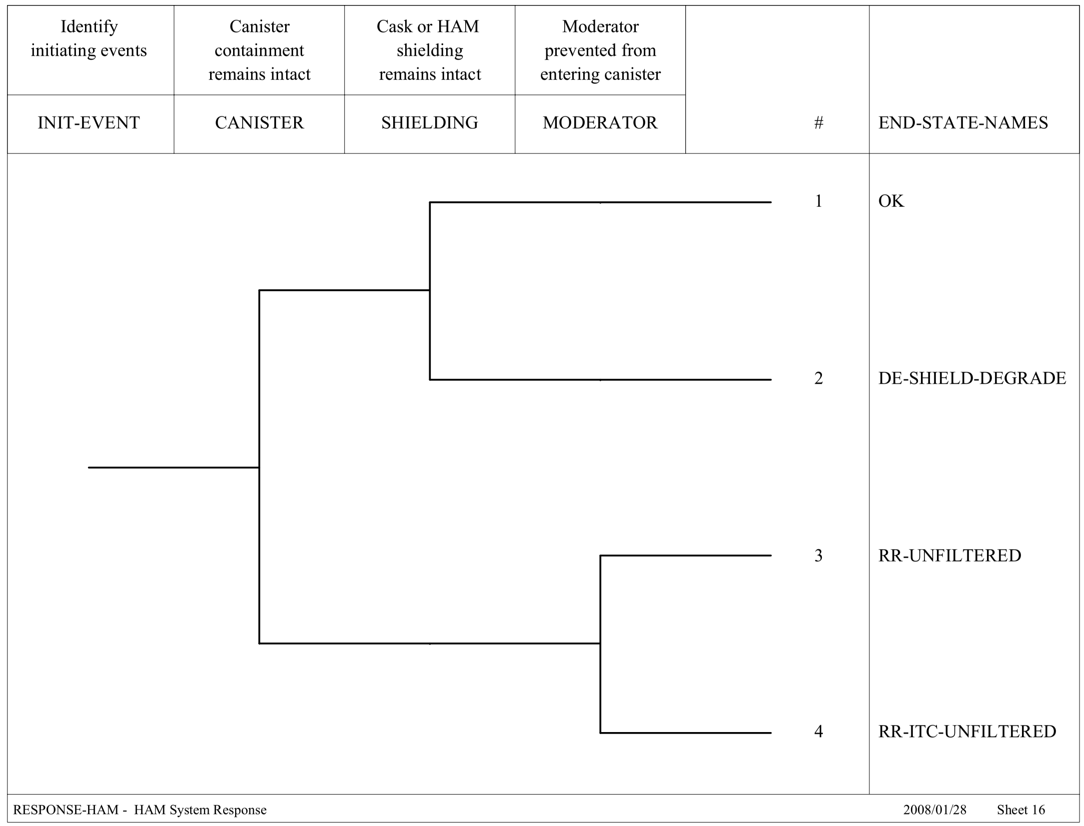


NOTE: The system response event tree for this initiator event tree is RESPONSE-HAM (Figure G-17)

ESD = event sequence diagram; HAM = horizontal aging module; HDPC = horizontal dual-purpose canister; HSTC = horizontally shielded transportation cask; HTC = a transportation cask that is never upended; INIT = initiating; ISO = Intra-Site Operations; RESP = response; T= transfer; XFER = transfer.

Source: Original

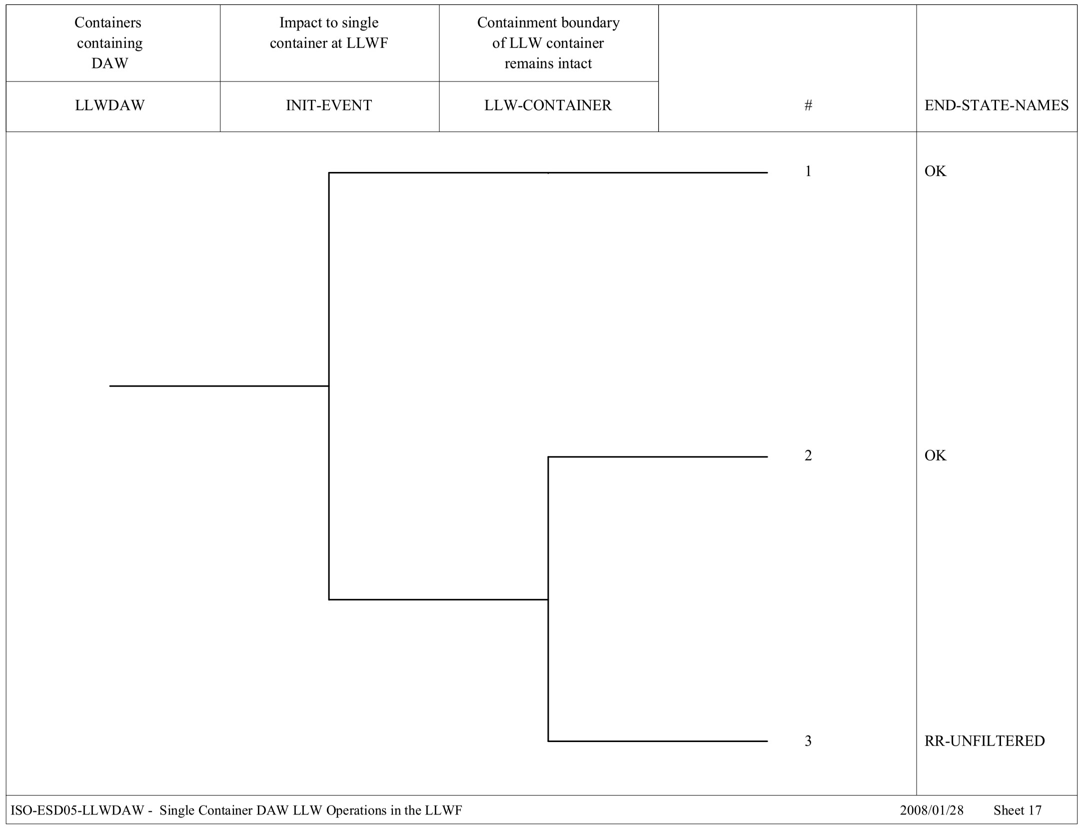
Figure G-16. Initiator Event Tree for ISO-ESD-04-HDPC– Canister Insertion or Retrieval Operations at a HAM



NOTE: DE = direct exposure; ESD = event sequence diagram; HAM = horizontal aging module; INIT = initiating; ISO = Intra-Site Operations; ITC = important to criticality; RR = radionuclide release.

Source: Original

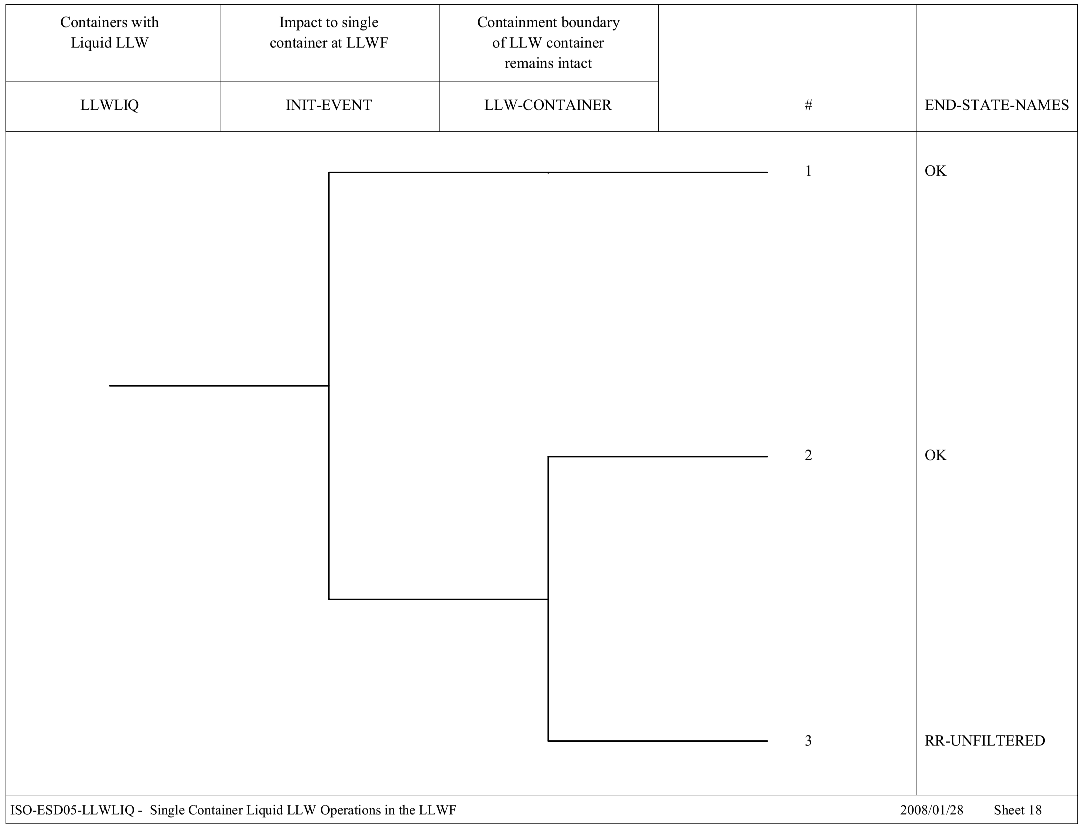
Figure G-17. System Response Event Tree for ISO-ESD-04 – RESPONSE-HAM – HAM System Response



NOTE: DAW = dry active radioactive waste; ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; RR = radionuclide release.

Source: Original

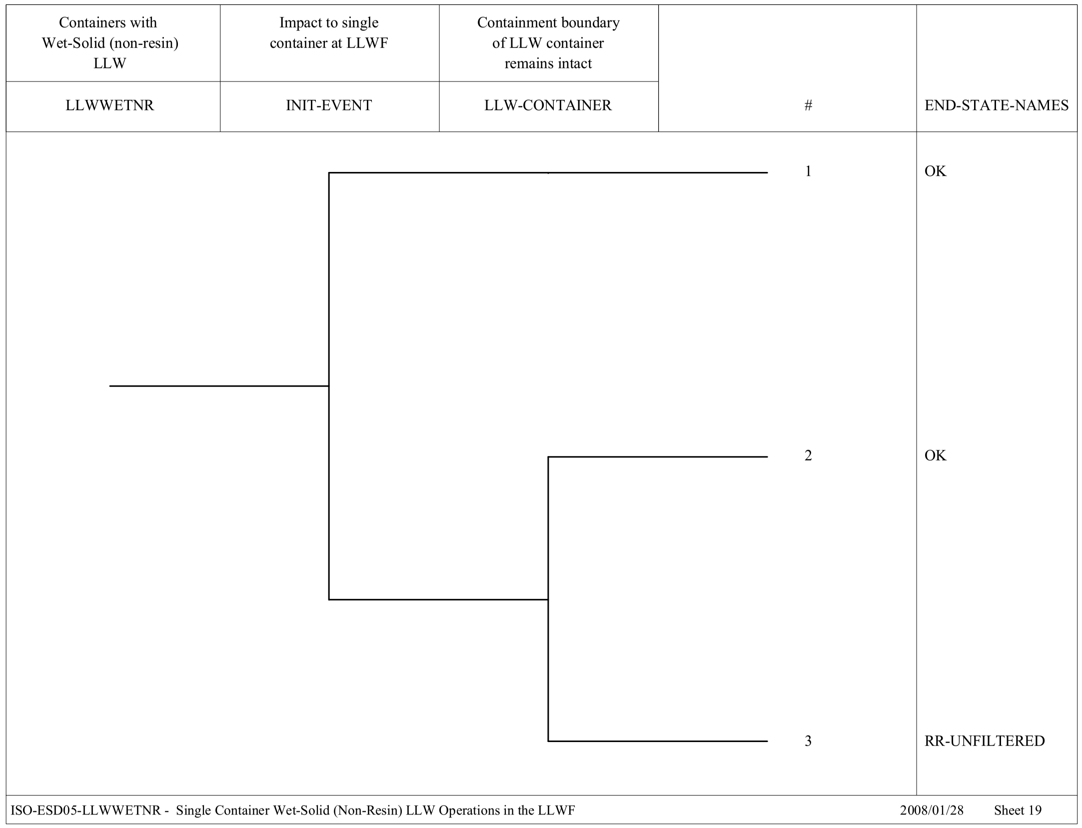
Figure G-18. Event Tree for ISO-ESD-05-LLWDAW –Single Container DAW LLW Operations in the LLWF



NOTE: ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; LIQ = Liquid; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; RR = radionuclide release.

Source: Original

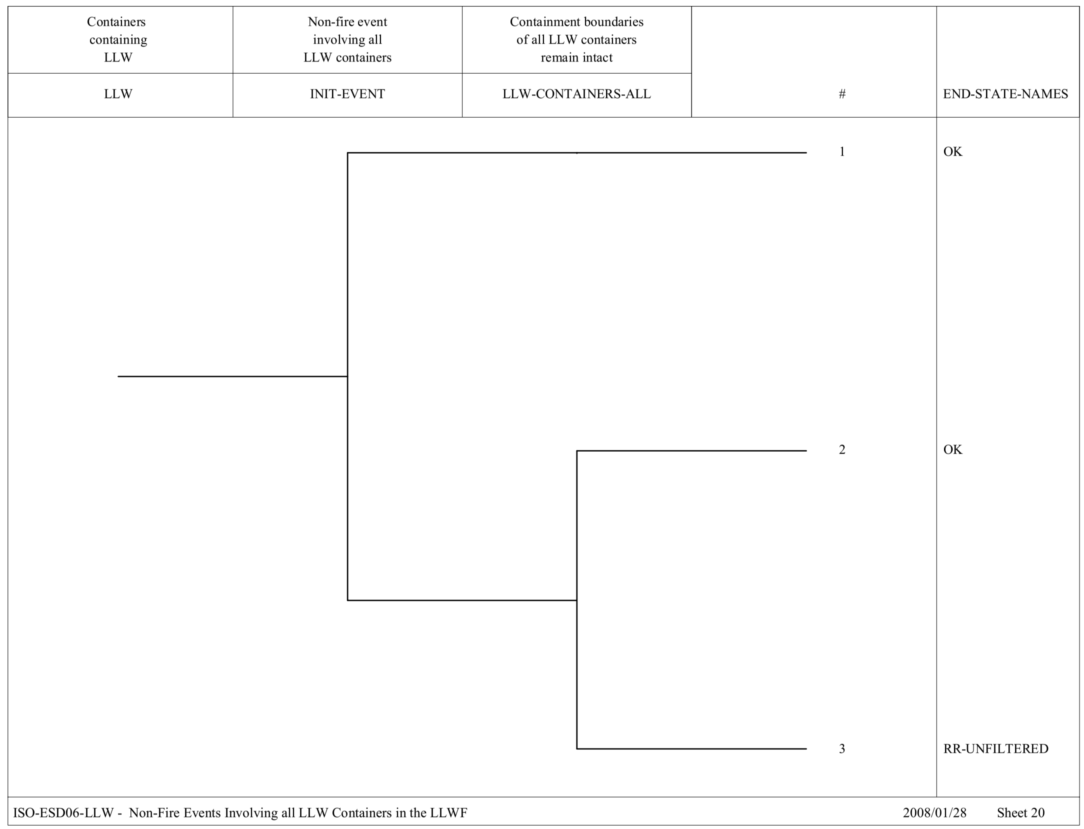
Figure G-19 Event Tree for ISO-ESD-05-LLWLIQ –Single Container Liquid LLW Operations in the LLWF



NOTE: ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; NR = non-resin; RR = radionuclide release.

Source: Original

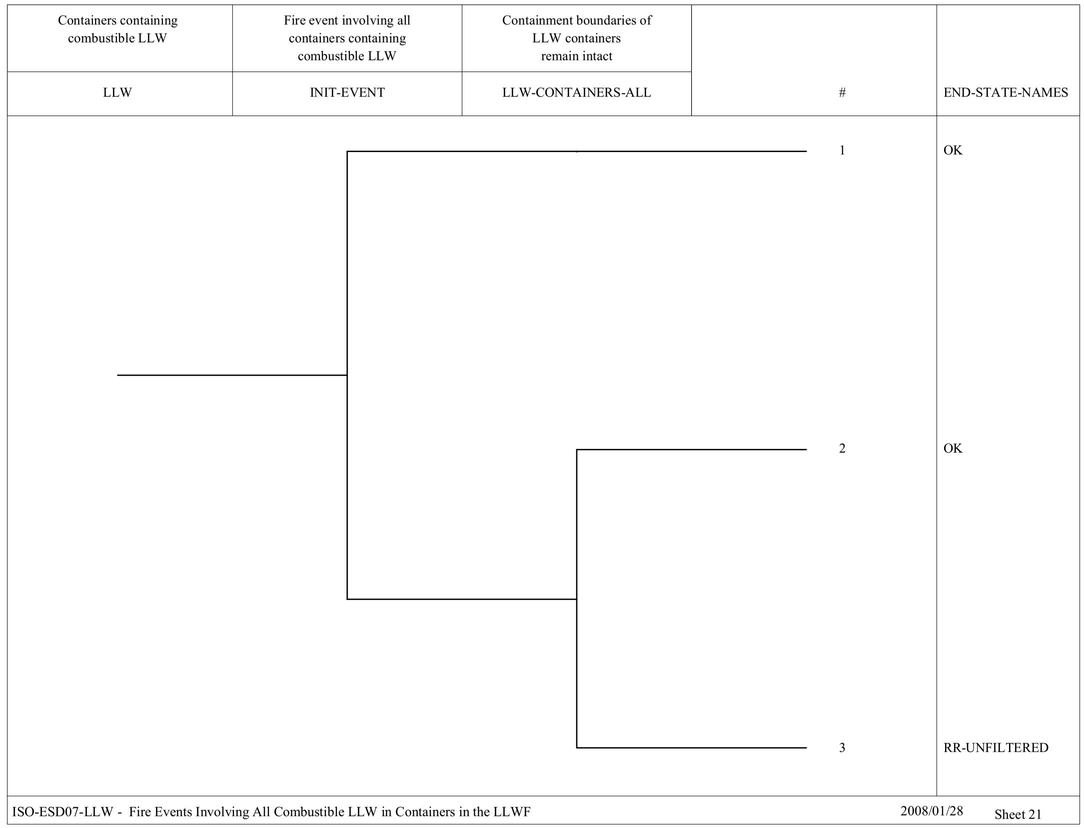
Figure G-20 Event Tree for ISO-ESD-05-LLWWETNR –Single Container Wet-Solid (Non-Resin) LLW Operations in the LLWF



NOTE: ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; RR = radionuclide release.

Source: Original

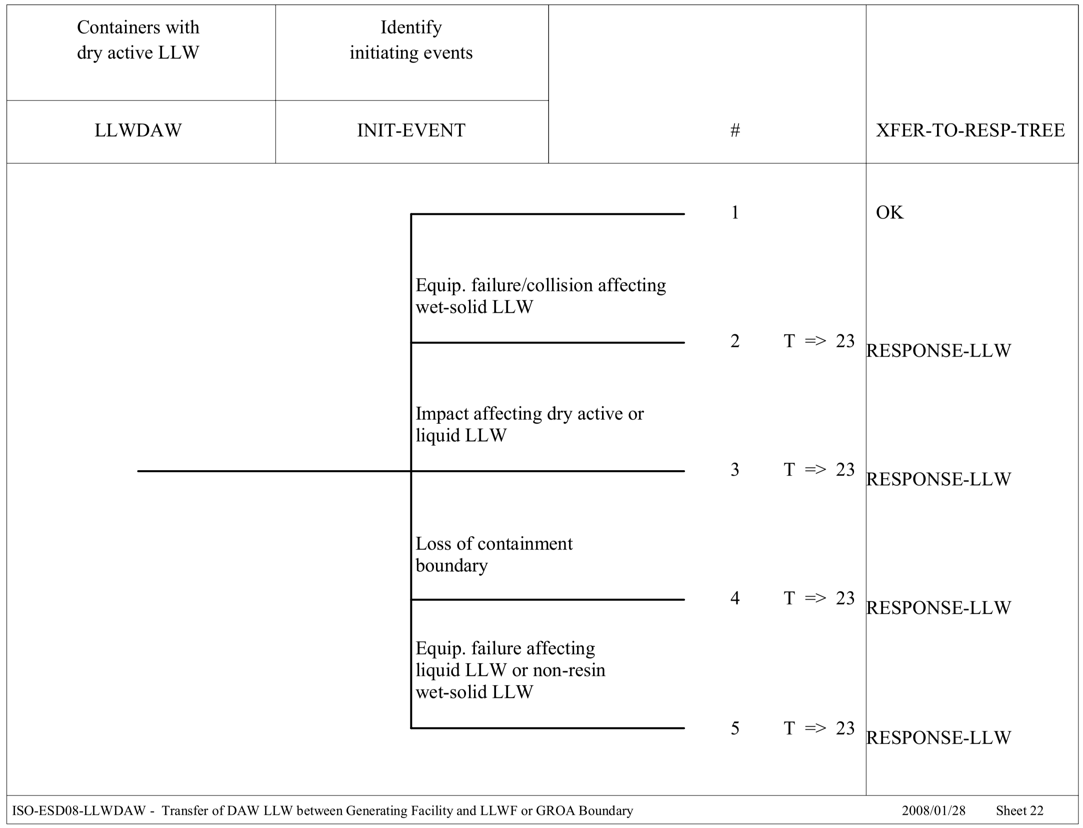
Figure G-21. Event Tree for ISO-ESD-06-LLW – Non-Fire Events Involving all LLW Containers in the LLWF



NOTE: ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; RR = radionuclide release.

Source: Original

Figure G-22. Event Tree for ISO-ESD-07-LLW – Fire Events Involving all Combustible LLW in Containers in the LLWF

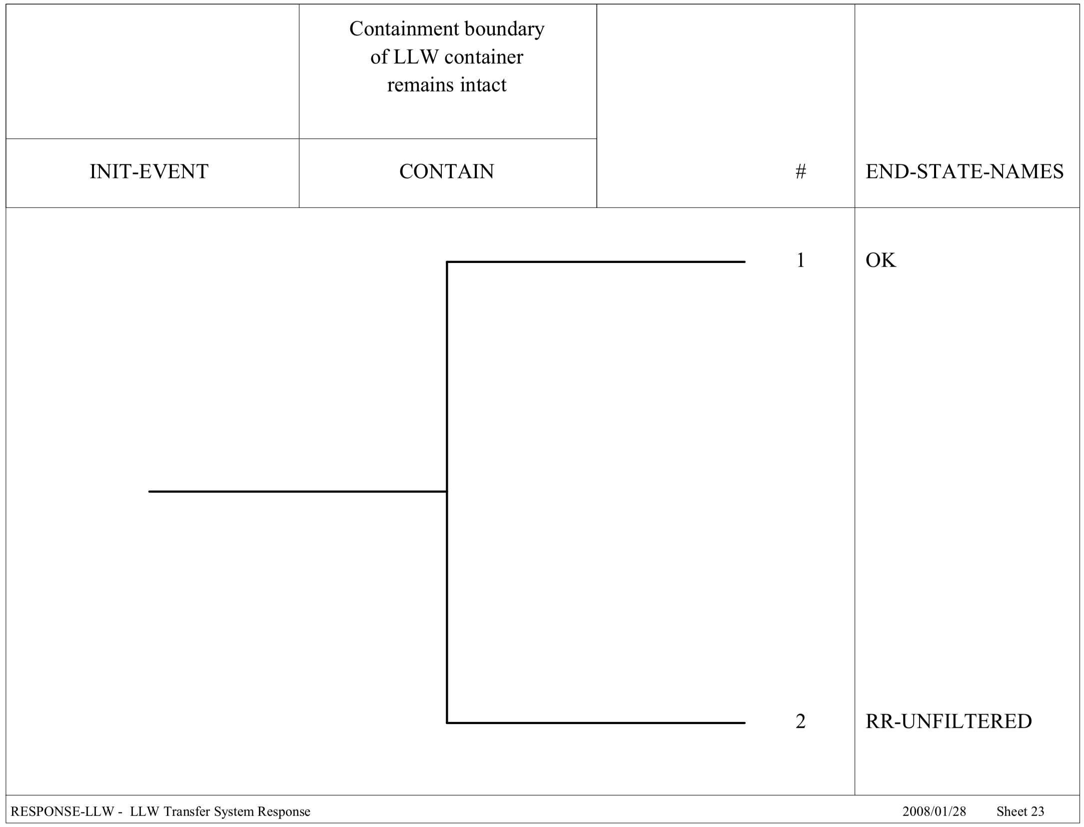


NOTE: The system response event tree for this initiator event tree is RESPONSE-LLW (Figure G-24).

DAW = dry active radioactive waste; ESD = event sequence diagram; INIT = initiating; GROA = geologic repository operations area; ISO = Intra-Site Operations; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; RESP = response; T = transfer; XFER = transfer.

Source: Original

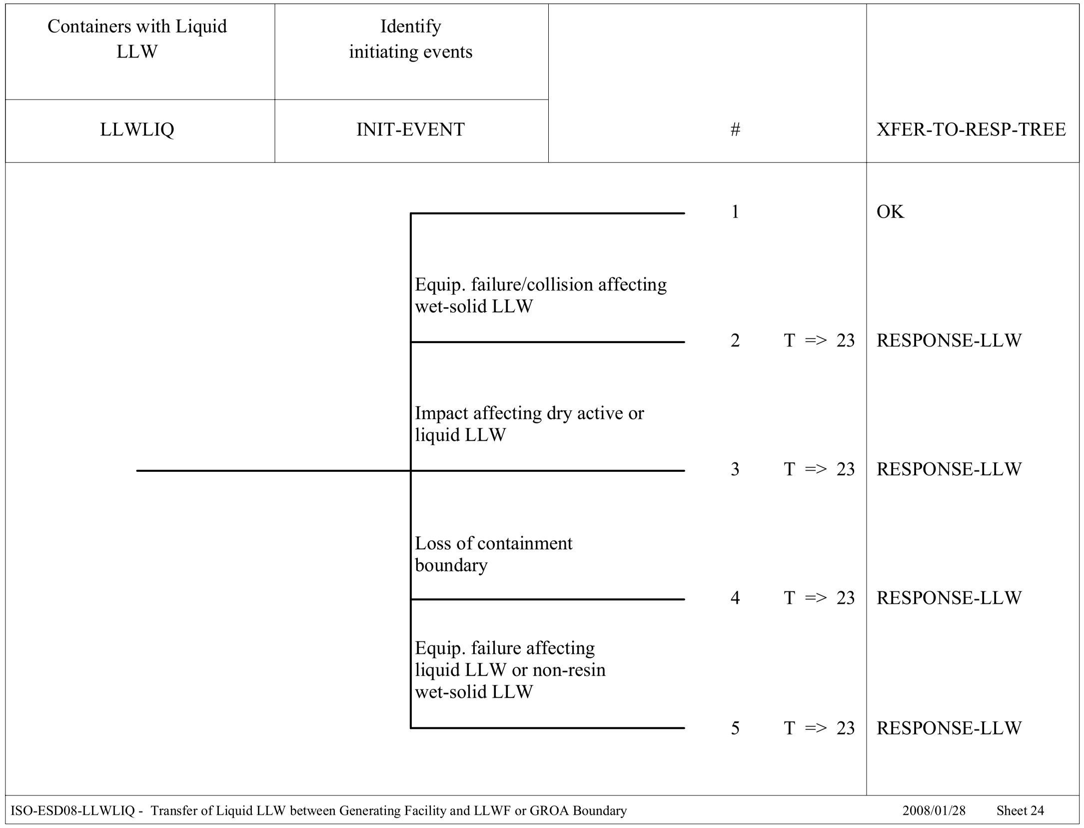
Figure G-23. Initiator Event Tree for ISO-ESD-08-LLWDAW – Transfer of DAW LLW between Generating Facility and LLWF or GROA Boundary



NOTE: CONTAIN = container; ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; RR = radionuclide release.

Source: Original

Figure G-24. System Response Event Tree for ISO-ESD-08 – RESPONSE-LLW – LLW Transfer System Response

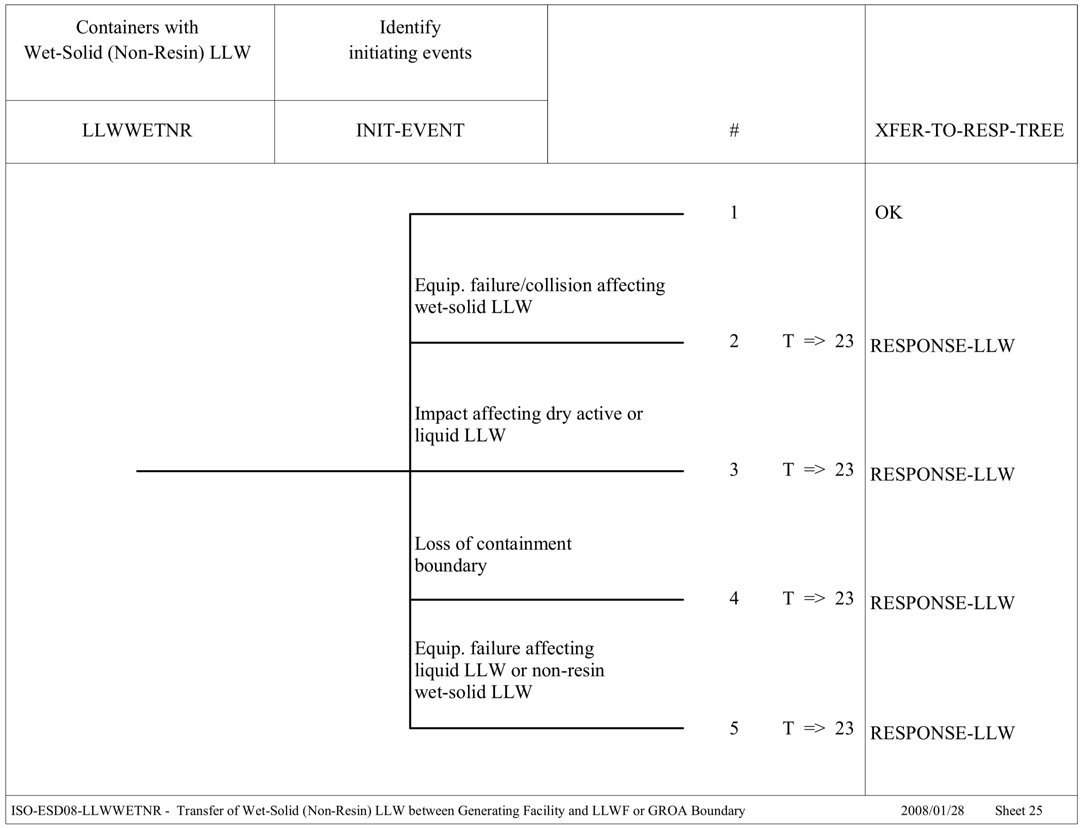


NOTE: The system response event tree for this initiator event tree is RESPONSE-LLW (Figure G-24).

CONTAIN = container; ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; LIQ = liquid; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; RR = radionuclide release.

Source: Original

Figure G-25. Initiator Event Tree for ISO-ESD-08-LLWLIQ – Transfer of Liquid LLW between Generating Facility and LLWF or GROA Boundary

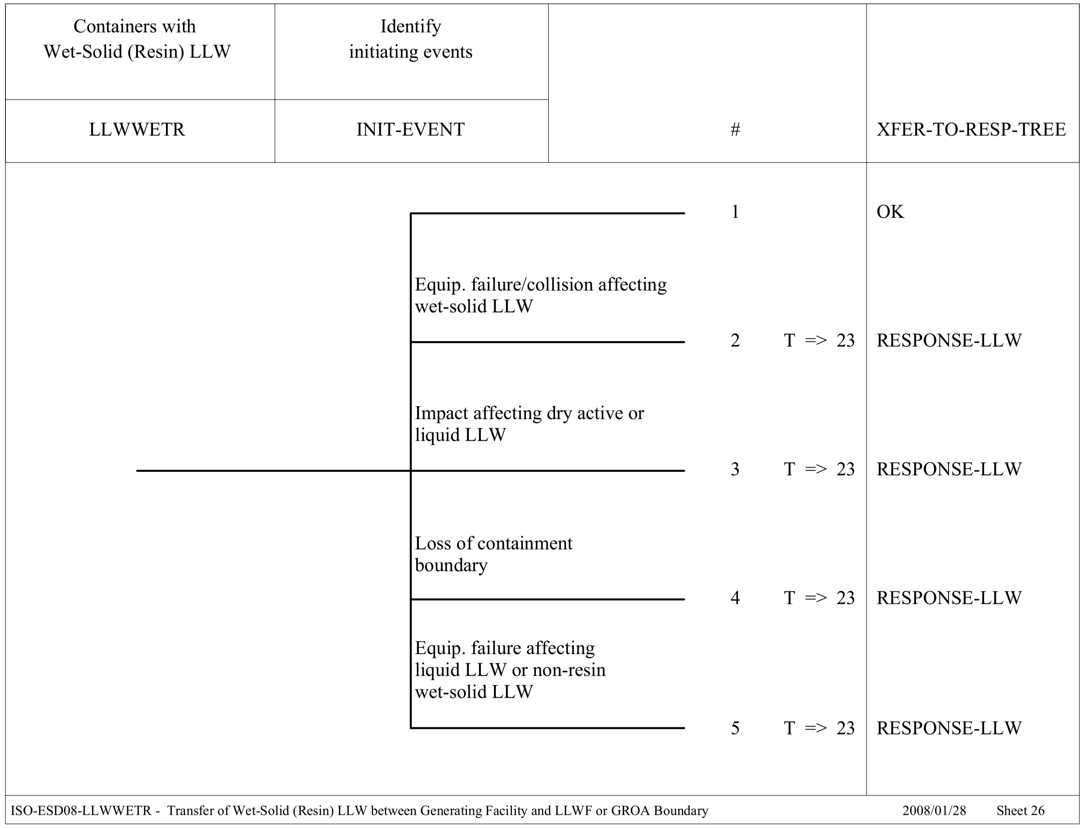


NOTE: The system response event tree for this initiator event tree is RESPONSE-LLW (Figure G-24).

ESD = event sequence diagram; GROA = geologic repository operations area; INIT = initiating; ISO = Intra-Site Operations; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; RESP = response; T = transfer; WETNR = wet-solid non-resin LLW; XFER = transfer.

Source: Original

Figure G-26. Initiator Event Tree for ISO-ESD-08-LLWWETNR – Transfer of Wet-Solid (Non-Resin) LLW between Generating Facility and LLWF or GROA Boundary

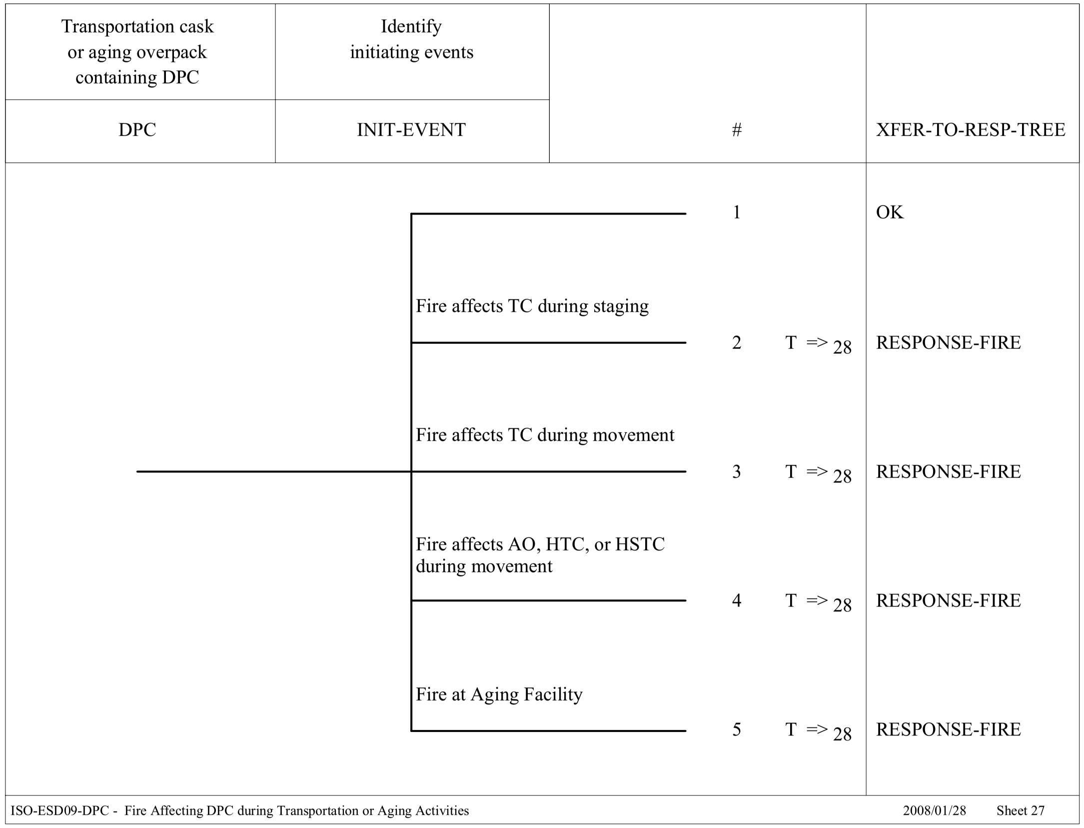


NOTE: The system response event tree for this initiator event tree is RESPONSE-LLW (Figure G-24).

ESD = event sequence diagram; GROA = geologic repository operations area; INIT = initiating; ISO = Intra-Site Operations; LLW = low-level radioactive waste; LLWF = Low-Level Waste Facility; R= resin; RESP = response; T = transfer; WETR = wet-solid resin LLW; XFER = transfer.

Source: Original

Figure G-27. Initiator Event Tree for ISO-ESD-08-LLWWETR – Transfer of Wet-Solid (Resin) LLW between Generating Facility and LLWF or GROA Boundary

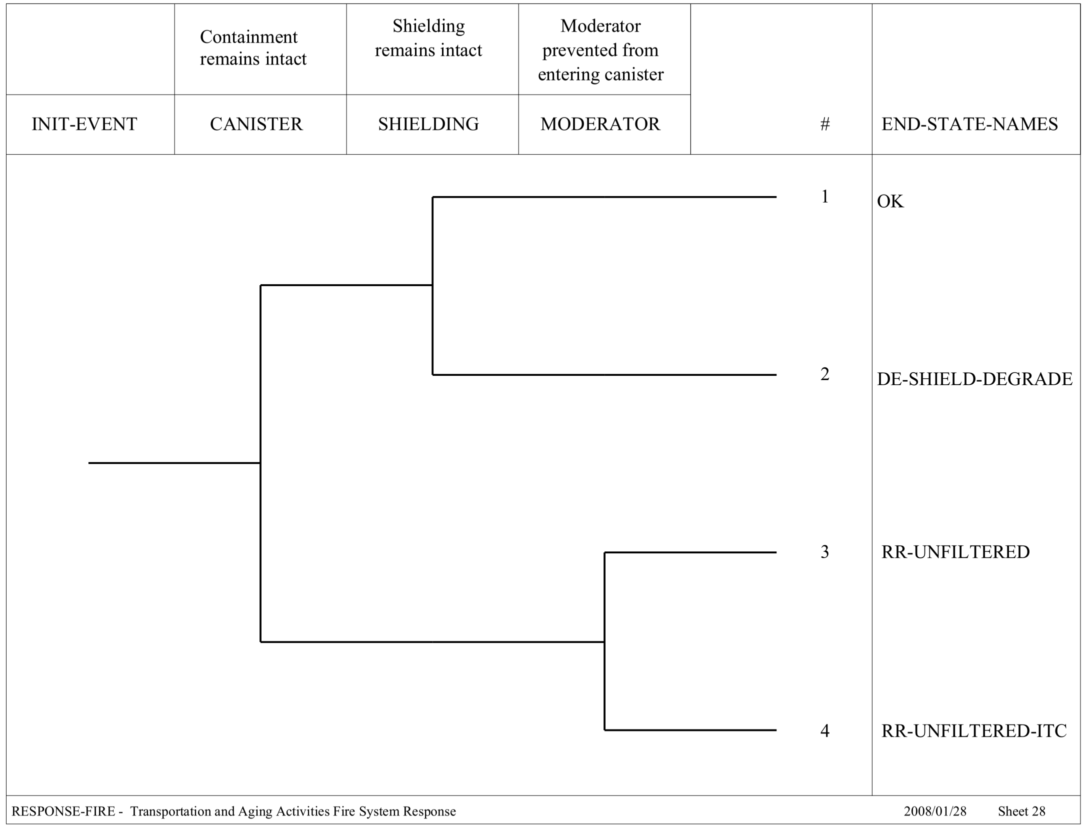


NOTE: The system response event tree for this initiator event tree is RESPONSE-FIRE (Figure G-29).

AO = aging overpack; DPC = dual-purpose canister; ESD = event sequence diagram; HSTC = horizontally shielded transfer cask; HTC = a transportation cask that is never upended; INIT = initiating; ISO = Intra-Site Operations; RESP = response; T = transfer; TC = transportation cask; XFER = transfer.

Source: Original

Figure G-28. Initiator Event Tree for ISO-ESD-09-DPC – Fire Affecting DPC during Transportation or Aging Activities

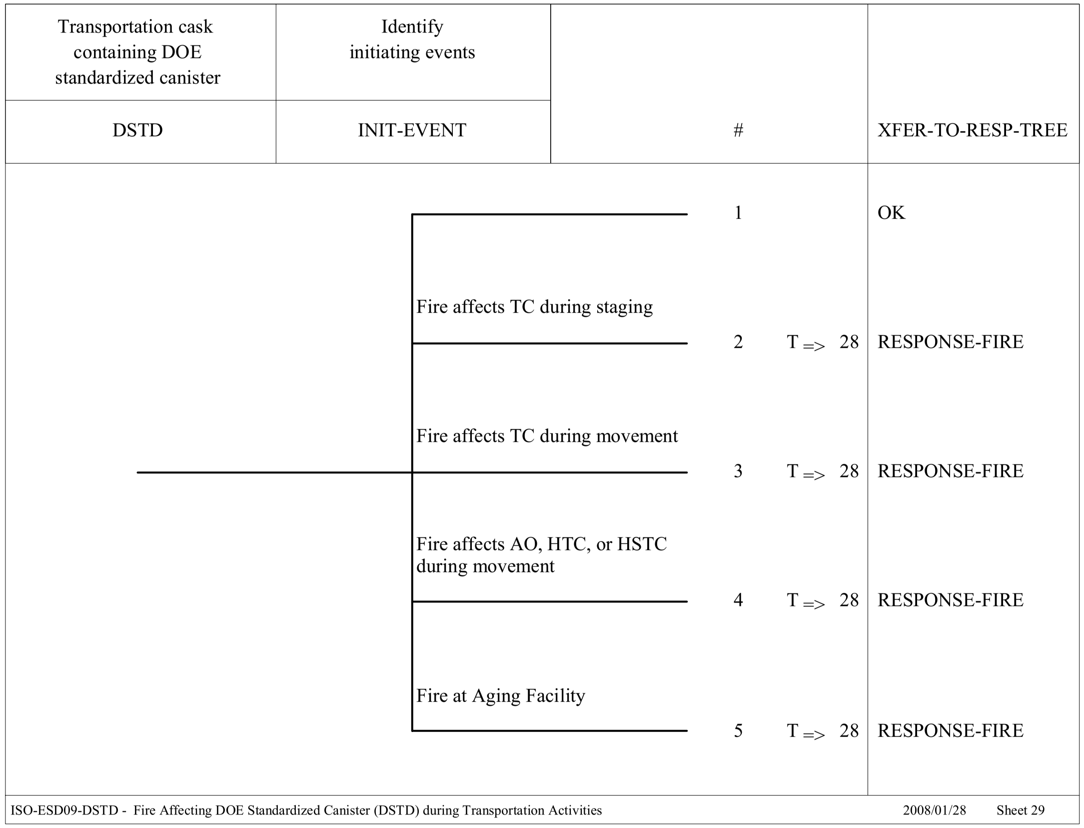


NOTE: The pivotal event "CANISTER" does not apply directly to UCSNF. For UCSNF, a cask passive equipment failure probability is substituted for "CANISTER" during quantification.

DE = direct exposure; ESD = event sequence diagram; INIT = initiating; ISO = Intra-Site Operations; ITC = important to criticality; RR = radionuclide release.

Source: Original

Figure G-29. System Response Event Tree for ISO-ESD-09 – RESPONSE-FIRE – Transportation and Aging Activities Fire System Response

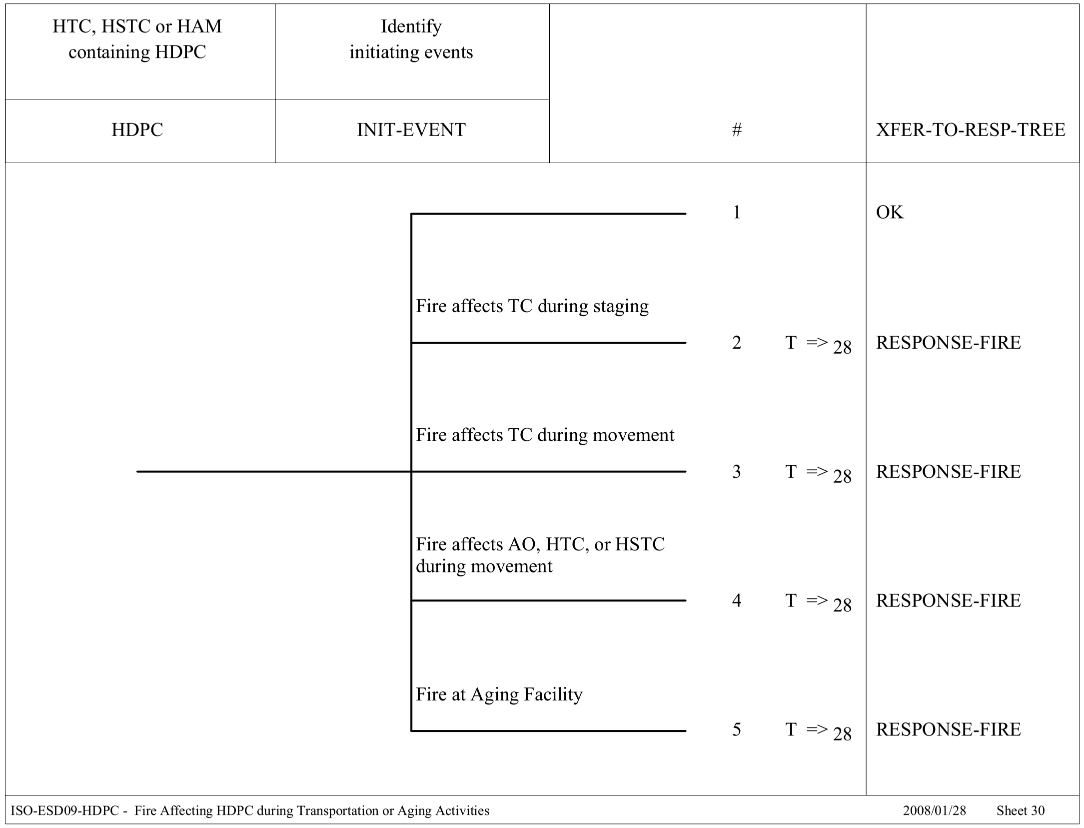


NOTE: The system response event tree for this initiator event tree is RESPONSE-FIRE (Figure G-29).

AO = aging overpack; DOE = Department of Energy; DSTD = DOE standardized canister; ESD = event sequence diagram; HSTC = horizontally shielded transfer cask; HTC = a transportation cask that is never upended; INIT = initiating; ISO = Intra-Site Operations; RESP = response; T = transfer; TC = transportation cask; XFER = transfer.

Source: Original

Figure G-30. Initiator Event Tree for ISO-ESD-09-DSTD – Fire Affecting DOE Standardized Canister (DSTD) during Transportation Activities

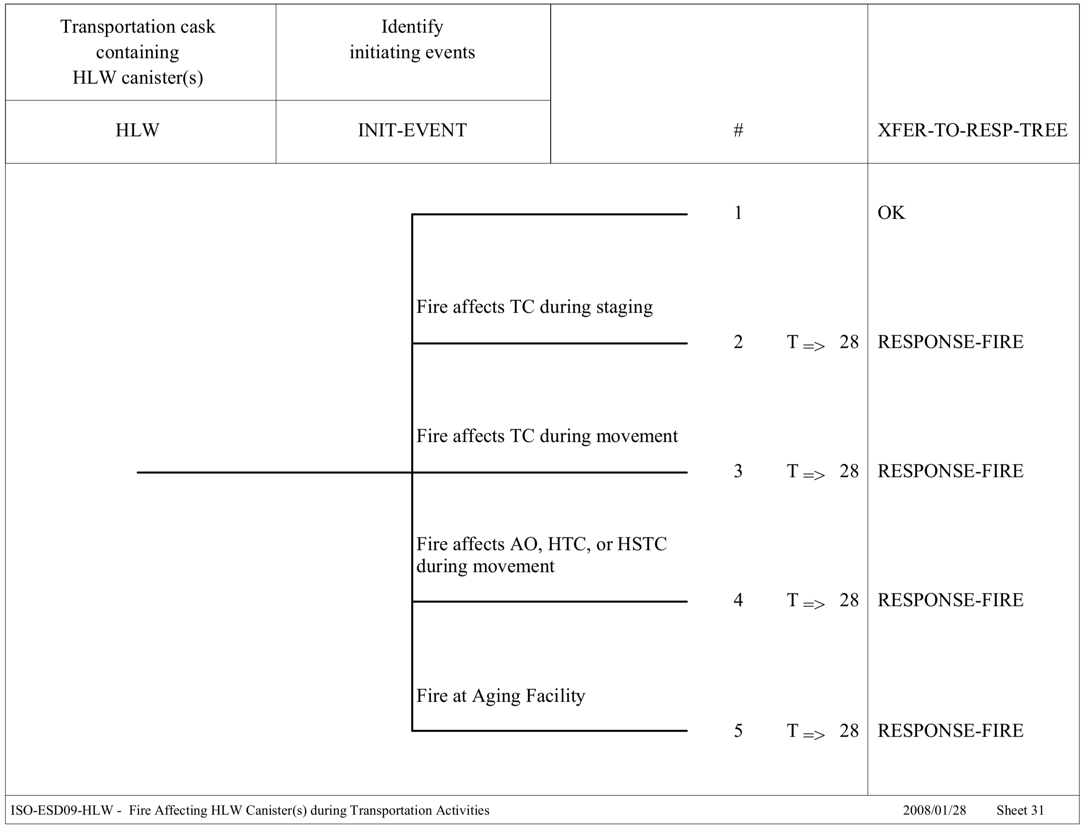


NOTE: The system response event tree for this initiator event tree is RESPONSE-FIRE (Figure G-29).

AO = aging overpack; ESD = event sequence diagram; HAM = horizontal aging module; HDPC = horizontal dual-purpose canister; HSTC = horizontally shielded transfer cask; HTC = a transportation cask that is never upended; INIT = initiating; ISO = Intra-Site Operations; RESP = response; T = transfer; TC = transportation cask; XFER = transfer.

Source: Original

Figure G-31. Initiator Event Tree for ISO-ESD-09-HDPC – Fire Affecting HDPC during Transportation or Aging Activities

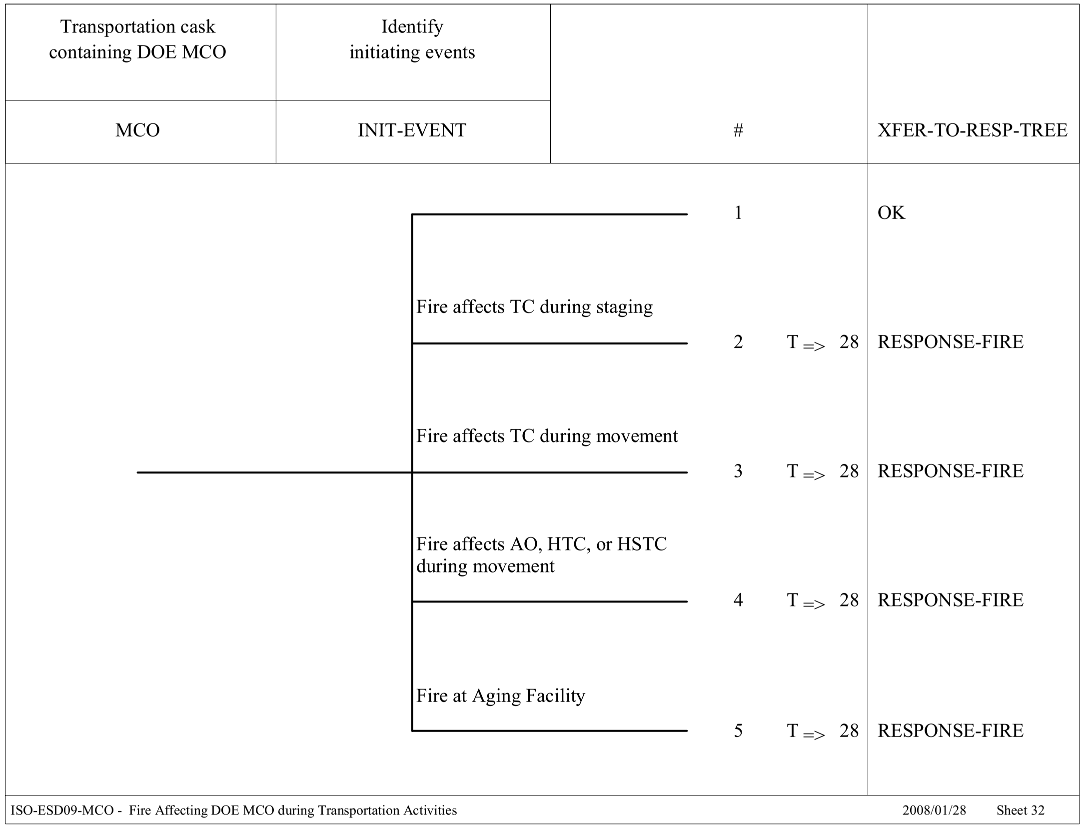


NOTE: The system response event tree for this initiator event tree is RESPONSE-FIRE (Figure G-29).

AO = aging overpack; ESD = event sequence diagram; HSTC = horizontally shielded transfer cask; HLW = high-level radioactive waste; HTC = a transportation cask that is never upended; INIT = initiating; ISO = Intra-Site Operations; RESP = response; T = transfer; TC = transportation cask; XFER = transfer.

Source: Original

Figure G-32. Initiator Event Tree for ISO-ESD-09-HLW – Fire Affecting HLW Canister(s) during Transportation Activities

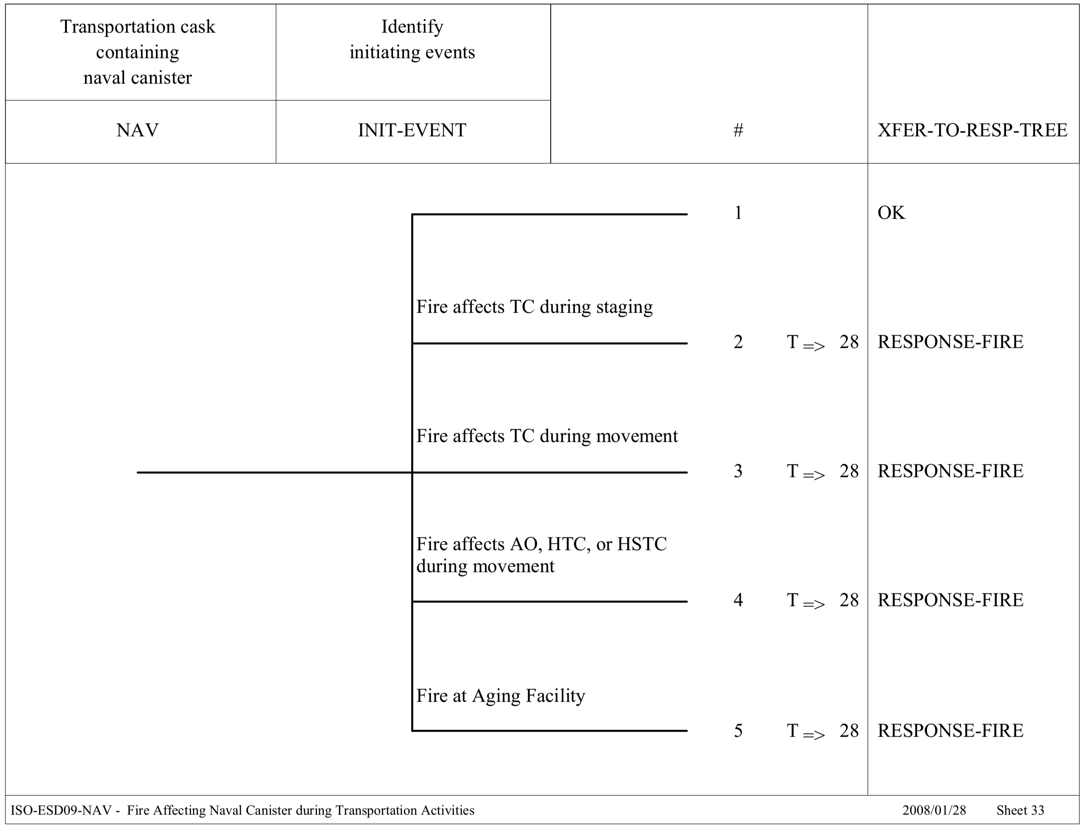


NOTE: The system response event tree for this initiator event tree is RESPONSE-FIRE (Figure G-29).

AO = aging overpack; DOE = Department of Energy; ESD = event sequence diagram; HSTC = horizontally shielded transportation cask; HTC = a transportation cask that is never upended; INIT = initiating; ISO = Intra-Site Operations; MCO = multicanister overpack; RESP = response; T = transfer; TC = transportation cask; XFER = transfer.

Source: Original

Figure G-33. Initiator Event Tree for ISO-ESD-09-MCO – Fire Affecting DOE MCO during Transportation Activities

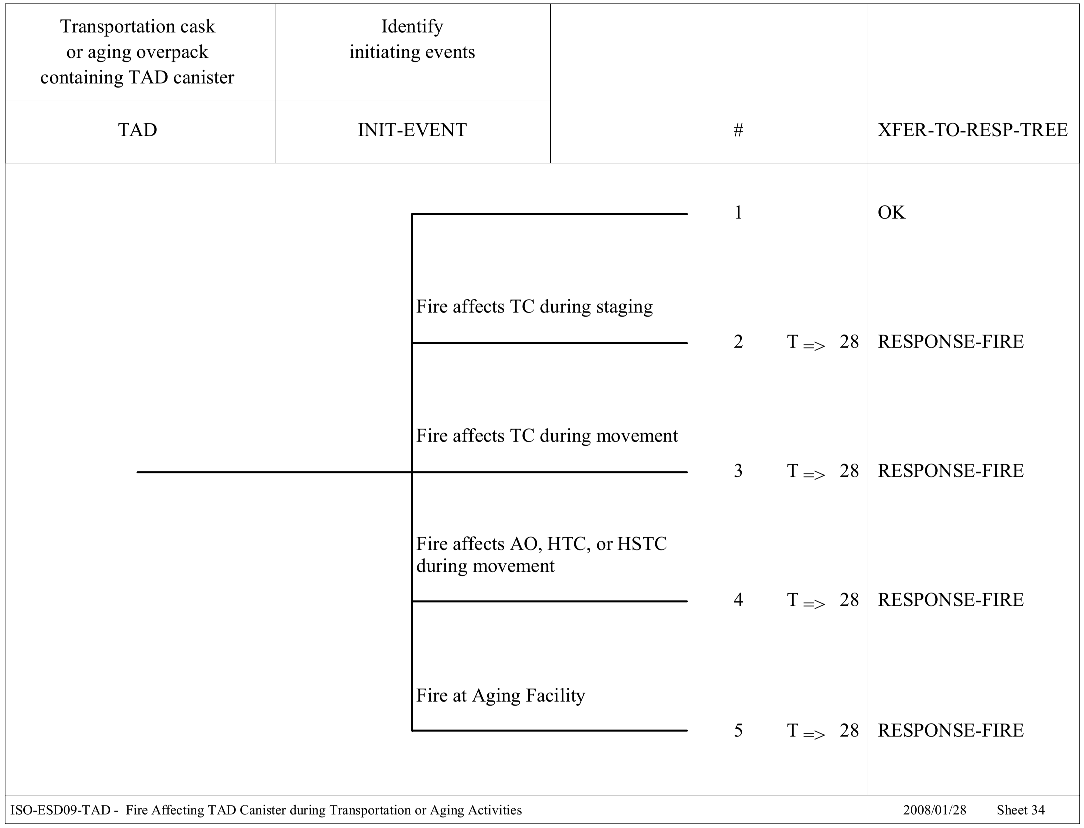


NOTE: The system response event tree for this initiator event tree is RESPONSE-FIRE (Figure G-29).

AO = aging overpack; ESD = event sequence diagram; HSTC = horizontally shielded transfer cask; HTC = a transportation cask that is never upended; INIT = initiating; ISO = Intra-Site Operations; NAV = naval; RESP = response; T = transfer; TC = transportation cask; XFER = transfer.

Source: Original

Figure G-34. Initiator Event Tree for ISO-ESD-09-NAV – Fire Affecting Naval Canister during Transportation Activities

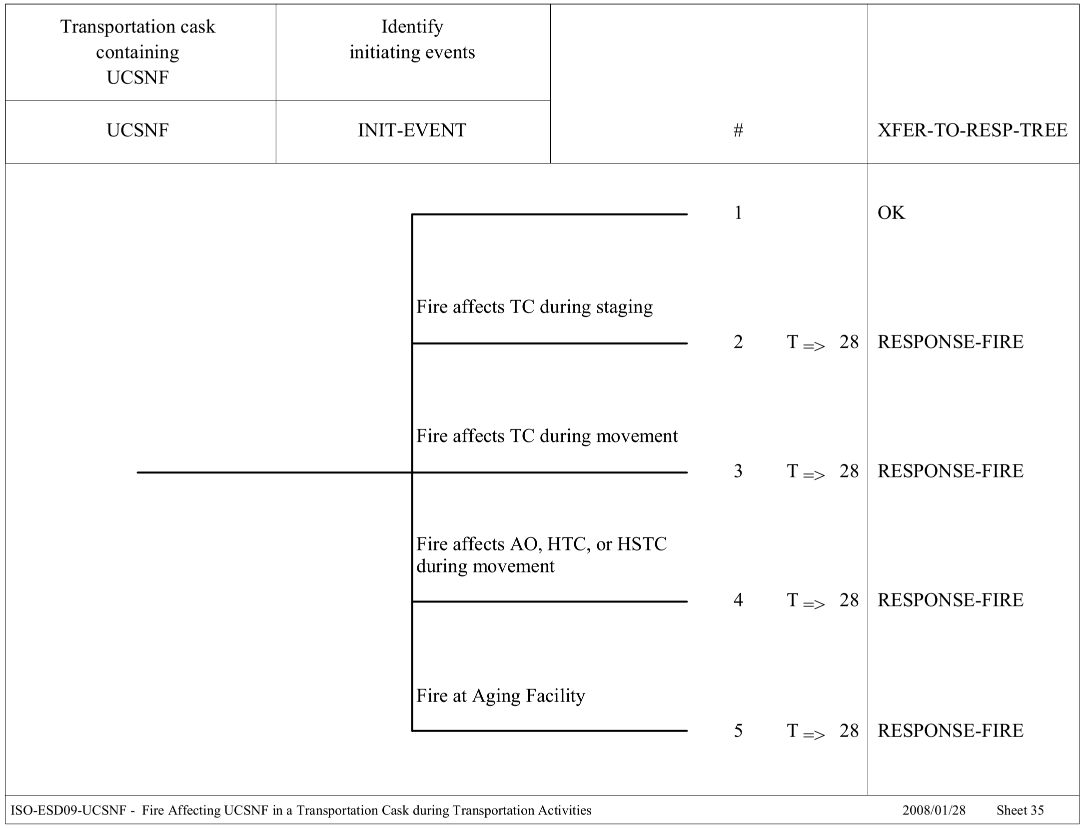


NOTE: The system response event tree for this initiator event tree is RESPONSE-FIRE (Figure G-29).

AO = aging overpack; ESD = event sequence diagram; HSTC = horizontally shielded transfer cask; HTC = a transportation cask that is never upended; INIT = initiating; ISO = Intra-Site Operations; RESP = response; T = transfer; TAD = transportation, aging, and disposal; TC = transportation cask; XFER = transfer.

Source: Original

Figure G-35. Initiator Event Tree for ISO-ESD-09-TAD – Fire Affecting TAD Canister during Transportation or Aging Activities



NOTE: The system response event tree for this initiator event tree is RESPONSE-FIRE (Figure G-29).

AO = aging overpack; ESD = event sequence diagram; HSTC = horizontally shielded transfer cask; HTC = a transportation cask that is never upended; INIT = initiating; ISO = Intra-Site Operations; RESP = response; T = transfer; TC = transportation cask; USNF = uncanistered spent nuclear fuel; XFER = transfer.

Source: Original

Figure G-36. Initiator Event Tree for ISO-ESD-09-UCSNF – Fire Affecting UCSNF in a Transportation Cask during Transportation Activities