BSC	**Design Calculation or Analysis Cover Sheet** *Complete only applicable items.*	1. QA: QA 2. Page 1

3. System	4. Document Identifier
Monitored Geologic Repository	200-PSA-RF00-00100-000-00A

5. Title

Receipt Facility Event Sequence Development Analysis

6. Group

Preclosure Safety Analyses

7. Document Status Designation

☐ Preliminary ☒ Committed ☐ Confirmed ☐ Cancelled/Superseded

8. Notes/Comments

Attachments		Total Number of Pages
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RECORD OF REVISIONS

9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. EGS (Print/Sign/Date)	16. Approved/Accepted (Print/Sign/Date)
00A	Initial Issue	213	G-29	Norman Graves 2/8/08	Alan Ross 2/7/08	M. Frank 2/8/08	M. Wisenburg 2/8/2008

DISCLAIMER

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TABLES

ACRONYMS AND ABBREVIATIONS

Acronyms

AIChE	American Institute of Chemical Engineers
BSC	Bechtel SAIC Company, LLC
CFR	Code of Federal Regulations
CSNF	commercial spent nuclear fuel
CRCF	Canister Receipt and Closure Facility
CTM	canister transfer machine
CTT	cask transfer trolley
DOE	U.S. Department of Energy
DPC	dual-purpose canister
ESD	event sequence diagram
GROA	geologic repository operations area
HAM	horizontal aging module
HAZOP	hazard and operability
HEPA	high efficiency particulate air
HLW	high-level radioactive waste
HTC	a transportation cask that is never upended
HVAC	heating, ventilation, and air conditioning
ITC	important to criticality
MAP	mobile access platform
MLD	master logic diagram
P&ID	piping and instrumentation diagram
PCSA	preclosure safety analysis
PFD	process flow diagram
PRA	probabilistic risk assessment
RF	Receipt Facility
RHS	remote handling system
SNF	spent nuclear fuel
SPM	site prime mover
SSC	structure, system, or component

ACRONYMS AND ABBREVIATIONS (Continued)

TAD	transportation, aging, and disposal
TTC	a transportation cask that is upended using a tilt frame
TEV	transport and emplacement vehicle
TWF	typical waste-handling facility
VTC	a transportation cask that is upended on a railcar
WHF	Wet Handling Facility
WPTT	waste package transfer trolley
YMP	Yucca Mountain Project

Abbreviations

ft	feet
in.	inch

1. PURPOSE

This document, along with its companion document entitled *RF 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 (Ref. 2.4.1) uses the event sequences developed in this analysis to perform a quantitative analysis of the event sequences for the purpose of categorization per the definition provided by 10 CFR 63.2 (Ref. 2.3.2).

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. 2.2.62). 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 on-site members of the public, radiological releases that may affect the public or workers (on-site and off-site), and criticality. The radiological consequence assessment relies on bounding inputs with deterministic methods to obtain bounding dose estimates. These were developed using broad categories of scenarios that might cause a radiological release or direct exposure to workers and the public, both on-site and off-site. These broad categories of scenarios were characterized by conservative meteorology and dispersion parameters, conservative estimates of material at risk, conservative source terms, conservative leak path factors, and filtration of releases via facility high-efficiency particular 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.

“Event sequence” is defined in 10 CFR 63.2 (Ref. 2.3.2) 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. 2.3.2) 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 that are beyond the scope of the present analysis. However, the event sequence analyses serve as an 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 a 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 for 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. The presence of a 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. 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, or 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, tornado 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 Parts 50 (Ref. 2.3.1), 71(Ref. 2.3.3), and 72 (Ref. 2.3.4)) 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.

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 PRA 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 cause the operations of the waste handling facility to cease, 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 an 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 operations spanning the receipt of transportation casks on rail or truck conveyances into the Cask Preparation Room of the RF through the loading of a waste form into an aging overpack and bolting the overpack lid in place in the Lid Bolting Room of the RF. Transport of the aging overpack on a site transporter from the Lid Bolting Room to its eventual destination (WHF, CRCF, or aging pad) is covered in the *Intra-Site Operations and BOP Event Sequence Development Analysis*.

This analysis includes: a process flow diagram (PFD), a master logic diagram (MLD), a hazard and operability (HAZOP), event sequence diagrams (ESDs), and event trees. Initiating events considered in this analysis include internal events (i.e., events that are initiated within the RF) as well as external events (i.e., events that are initiated from outside the RF). However, event sequences for external events (including seismic events) are not developed in this analysis. External events and any associated event sequences are evaluated and documented separately.

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2.4 DESIGN OUTPUTS

This calculation is used as input to the following analysis:

2.4.1 BSC 2008. *RF Reliability and Event Sequence Categorization Analysis*. 200-PSA-RF00-00200-000-00A. 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 Analysis 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. 2.2.24).

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: N/A. The suitability of these diagrams for the intended use here is justified as follows:

Documentation of suitability for intended use of "QA: N/A" drawings. Engineering drawings are treated the same whether they are designated "QA: N/A" 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 with other engineering disciplines before review and approval by the Engineering Group Supervisor and the Discipline Engineering Manager. The check, review, and approval process provides assurance that these drawings accurately document the design and operational philosophy of the facility. The pertinent drawings are:

- *CRCF & IHF WP Shield Ring Lift Beam Mechanical Equipment Envelope* (Ref. 2.2.13)
- *CRCF, RF, WHF & IHF Impact Limiter Lifting Device Mechanical Equipment Envelope* (Ref. 2.2.19)
- *CRCF, RF, WHF & IHF Personnel Barrier Lifting Device Mechanical Equipment Envelope* (Ref. 2.2.20)
- *Geologic Repository Operations Area North Portal Site Plan* (Ref. 2.2.50)
- *CRCF, RF, and WHF Mobile Access Platform Mechanical Equipment Envelope Sheet 1 of 2* (Ref. 2.2.15)
- *CRCF, RF, and WHF Mobile Access Platform Mechanical Equipment Envelope Sheet 2* (Ref. 2.2.16)
- *Nuclear Facilities Rail Cask Lid Adapter Mechanical Equipment Envelope* (Ref. 2.2.23)
- *Geologic Repository Operations Area Overall Site Plan* (Ref.2.2.51)
- *Receipt Facility Lid Bolting Room Crane Mechanical Equipment Envelope* (Ref. 2.2.37).

Documentation of suitability for intended use of other inputs. Because the following documents are used for illustrative purposes, not as direct inputs, they are suitable for their intended use:

- *Nonelectronic Parts Reliability Data 1995* (Ref. 2.2.55)
- *Master Logic Diagram* (Ref. 2.2.65)
- *Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR): Data Manual, Part 4: Summary Aggregations* (Ref. 2.2.56)
- *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. 2.2.52)
- *Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants* (Ref. 2.2.53)
- *Canister Storage Building Design Basis Accident Analysis Documentation* (Ref. 2.2.54)
- *Safety Analysis Report, Idaho Spent Fuel Facility* (Ref. 2.2.57)
- *A Survey of Crane Operating Experience at U.S. Nuclear Power Plants from 1968 through 2002* (Ref. 2.2.58)
- *Control of Heavy Loads at Nuclear Power Plants* (Ref. 2.2.60).

4.2 USE OF SOFTWARE

Visio Professional 2003 and Word 2003, which are part of the Microsoft Office 2003 suite of 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). The visual information displayed is verified by visual inspection as a part of the preparation, checking, and review processes.

The computer code, SAPHIRE, Version 7.26 (Ref. 2.2.63 and Ref. 2.2.64), is used in this analysis but only to develop event trees, which are a graphical representation 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 personal computers and operated under one or more of the following:

- Microsoft Windows 2000 Professional (Ref. 2.2.63)
- Windows XP (Ref. 2.2.63)

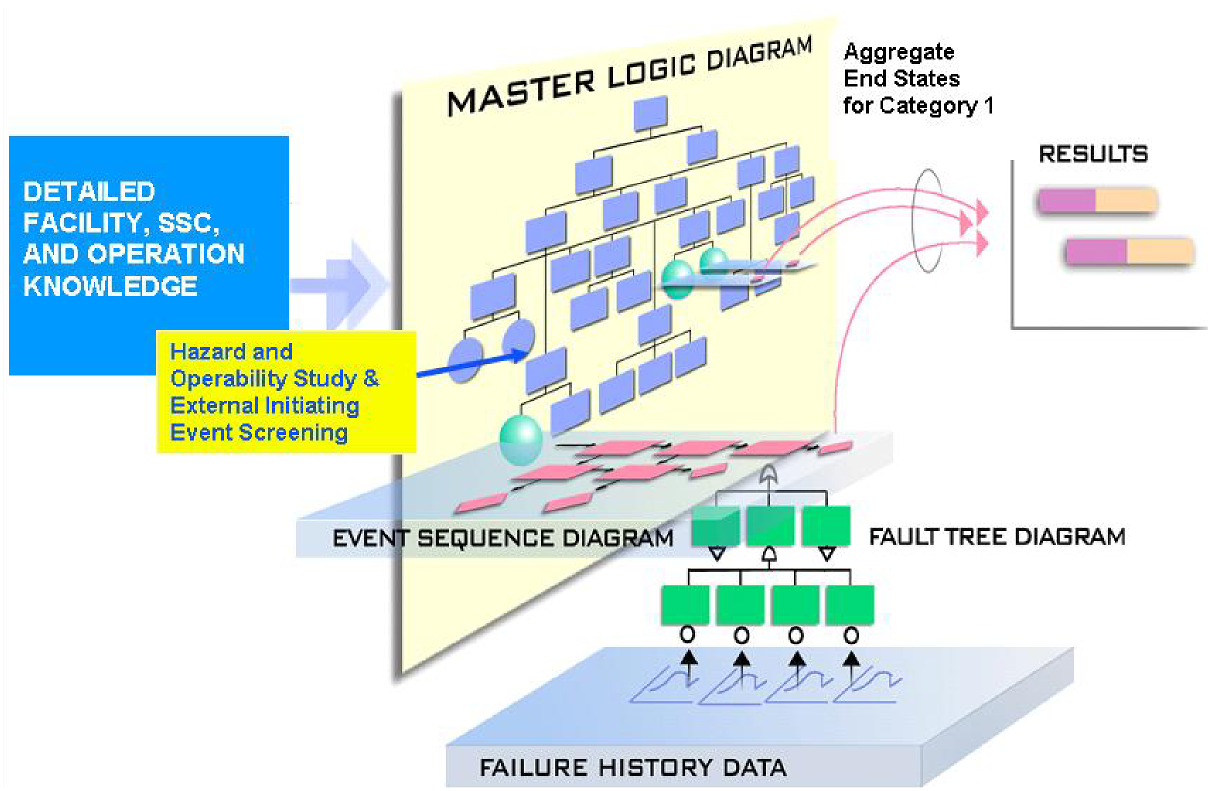
- Windows XP running inside a VMware virtual machine with VMware Player (Ref. 2.2.64).

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 to the RF. Specific features of the RF and its operations are not discussed until Section 6, where the methods described here are applied to RF. The PCSA uses the technology of probabilistic risk assessment (PRA) as described in references such as American Society of Mechanical Engineers RA-S-2002, *Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications* (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.



Source: Modified from *Master Logic Diagram* (Ref. 2.2.65)

Figure 1. Event Sequence Analysis Process

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 HAZOP – a technique for identifying and evaluating hazards associated with a facility or operation.

The basis of the PCSA is the development of event sequences. An event sequence may be thought of as a string of events that begins with an initiating event and eventually leads 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* (Ref. 2.2.55) and *Nuclear Computerized Library for Assessing Reactor Reliability* (Ref. 2.2.56)), 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 conditional probabilities of pivotal events.

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 geologic repository operations area through permanent closure in 10 CFR 63.111 (Ref. 2.3.2), each event sequence is categorized based on its frequency. Therefore, the focus of this analysis is to:

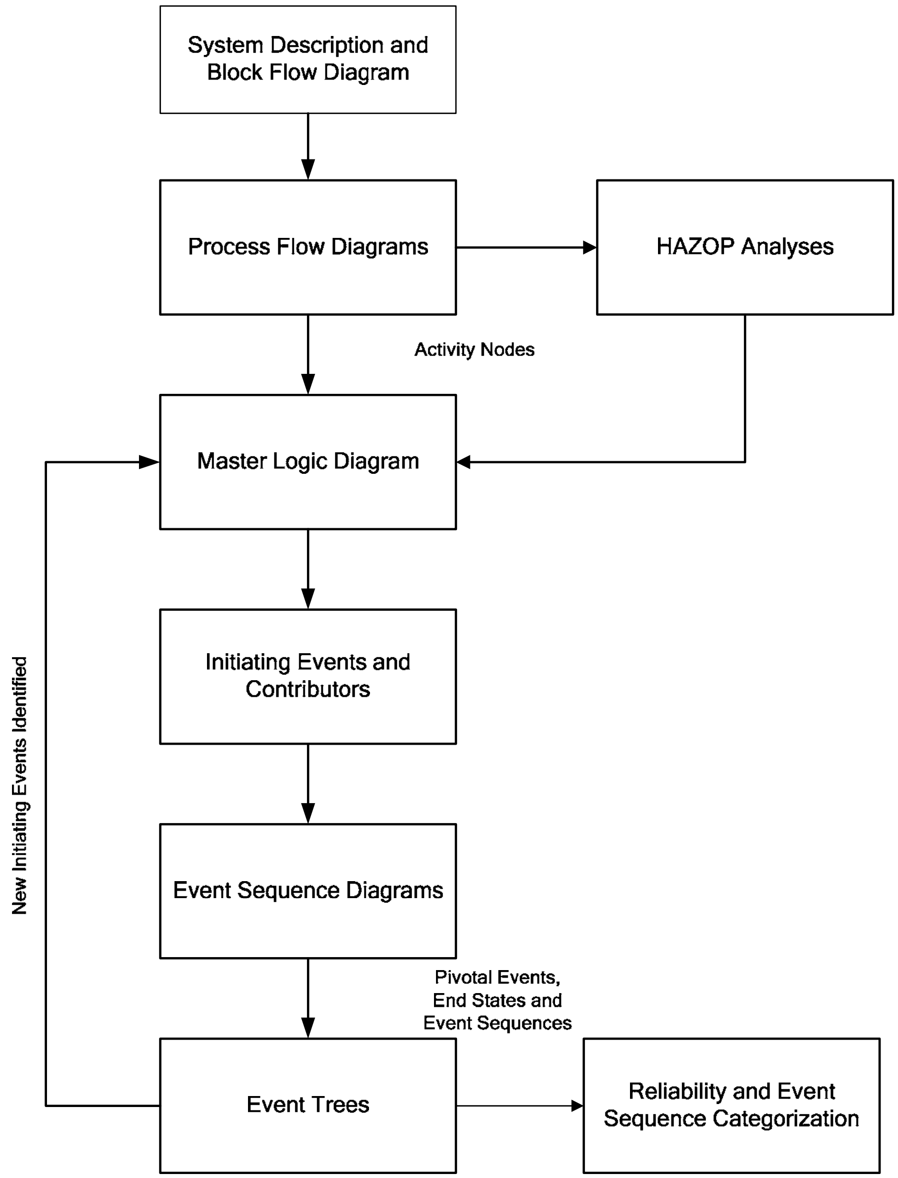
1. Identify potential internal initiating events, and external events relevant to this analysis, as described in Section 4.3.1.

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 process flow diagram of Section 6 and the equipment and operations descriptions of Attachments A and B. Accordingly, an event sequence, represented in an event sequence diagram, is particular to a given operational activity in a given operational area.

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



NOTE: HAZOP = hazard and operability.

Source: Original

Figure 2. Preclosure Safety Analysis Process

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 bubbles surrounding a larger bubble. Each small bubble 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 bubble is termed an aggregated initiating event[1]. It is appropriate for

[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. 2.3.2)

purposes of categorization to add, within a given event sequence diagram and for a given waste form configuration, event sequences that elicit the same combination of failure and success of pivotal events and have the same end states.

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 canister transfer machine) to SSCs for which reliability information is available. The PCSA, therefore, relies on event sequence diagrams and fault trees to represent the facility, equipment and personnel responses to an initiating event.

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) as 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, it was added to the MLD. Typically, the HAZOP addressed deviations at a lower level of 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. It was found that deviations identified in the HAZOP were often already identified on the MLD as initiating events. 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 HAZOP results are provided in Attachment E and the complete MLD results are provided in Attachment D.

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 of the facility. 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. 2.2.61, Section 3.4.2.2).

Development of a 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. These documents include 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 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 Preclosure Safety Analysis 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. 2.2.52).

- *Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants* (Ref. 2.2.53).

- *Canister Storage Building Design Basis Accident Analysis Documentation* (Ref. 2.2.54).

- *Safety Analysis Report, Idaho Spent Fuel Facility* (Ref. 2.2.57).

- *A Survey of Crane Operating Experience at U.S. Nuclear Power Plants from 1968 through 2002* (Ref. 2.2.58).

- *Control of Heavy Loads at Nuclear Power Plants* (Ref. 2.2.60).

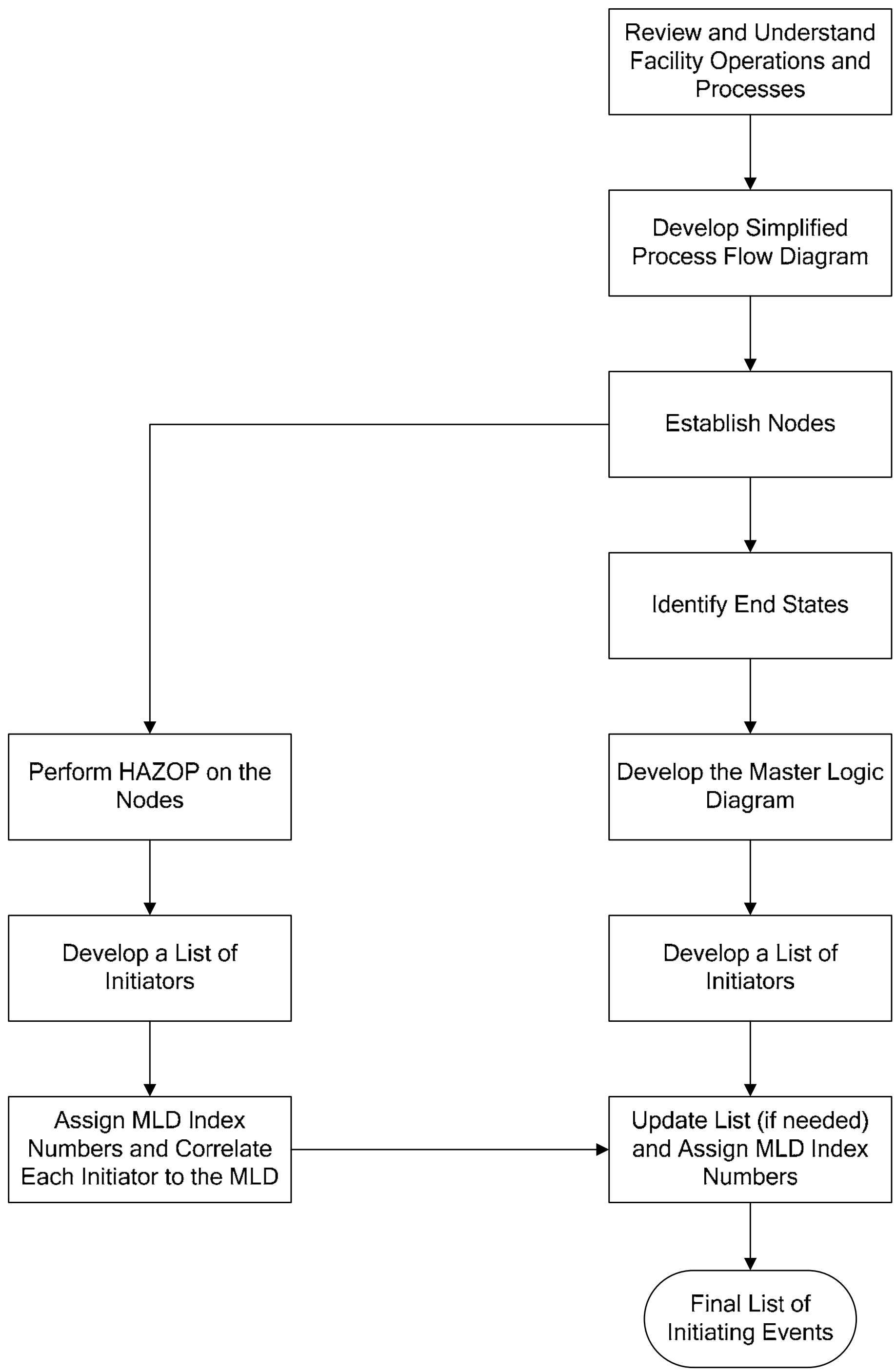
The MLD is cross-checked to the HAZOP, which is performed on the facility processes and operations and based on nodes, that is, specifically defined portions of the handling operation, established in the PFD. Although the repository is in some ways to be the first of its kind, the operations are based on established technologies: transportation cask movement by truck and rail, crane transfers of casks and canisters, rail-based trolleys, air-based conveyances, robotic welding, pool operations, etc. The team assembled for the HAZOP (and available on call when questions came up) 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 and contributors that are identified in the HAZOP, which are not already included in the MLD. The entire process is iterative in nature (Figure 3) 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 have been 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 the HAZOP are used for defining initiating events, and the methodology for grouping of initiating events.

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, and transfer. 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., TWF-201) in the HAZOP table. 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.

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. As the example in Figure 7 in Section 4.3.4.2 shows, the general flow and relationships of the major operations and related systems that comprise a specific process are aggregated into nodes. 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.



NOTE: HAZOP = hazard and operability; MLD = master logistic diagram.

Source: Original

Figure 3. Initiating Event Identification

For this analysis, the analyst defines nodes in the PFD to identify those activities or processes that are evaluated for potential to initiate an event. The individual blocks within nodes are used to identify processes and operations that are further evaluated in the MLD (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. 2.2.61, 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 contributors to 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 200-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, Figure 6), this structure is generally followed for each branch until initiators are identified. Once initiators are identified, the process is terminated in that branch.

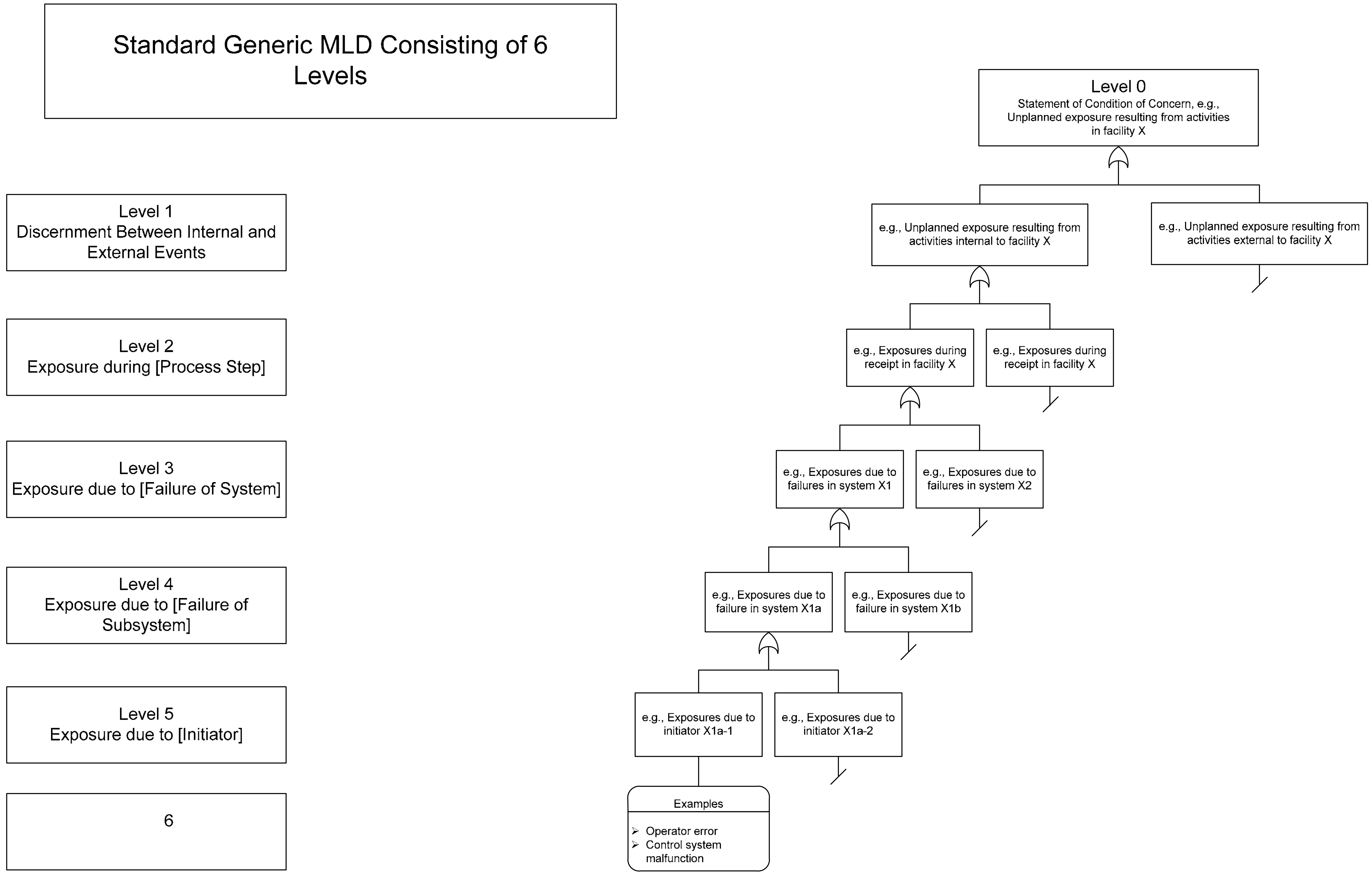
- Level 0: The entry point into the MLD is an expression of the undesired condition for a given facility. Level 0 is the top event of the MLD. In the MLD framework shown in Figure 4, the top event is expressed as "Unplanned exposure of individuals to radiation or radioactive materials due to operations 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 where the initiating events can occur.

- Level 3: This level identifies the exposure pathways of concern for the operational areas identified in Level 2.

- Level 4: This level identifies the specific operational activities to be evaluated.



Source: Original

Figure 4. Master Logic Diagram Framework

- Level 5: This level specifies the initiating event that can result in the failure in the specified operational activity (i.e., the actual deviations from successful operation that could lead to the exposure type). In the MLD used herein to describe a typical waste-handling facility, each of the initiating event boxes is given an initiating-event identifier, e.g. TWF-201, 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.

4.3.1.3 Hazard and Operability Study

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., TWF-202) 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 Section 4.3.4.2, Figures 8 and 9.

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 PFD (Section 4.3.1.1). 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 6 of the PFD for the example facility in Section 4.3.4.2, Figure 7 is entitled “Move CTT to Unloading Room.”

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. 2.3.2).

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 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.

This PCSA follows the HAZOP guidance provided in the *Guidelines for Hazard Evaluation Procedures* (Ref. 2.2.2). The *Yucca Mountain Review Plan, Final Report* (Ref. 2.2.62, 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.

Table 2. Common Hazard and Operability Analysis 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 that 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.
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).

NOTE: HAZOP = hazard and operability.

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

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 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 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 a complete and 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, SSCs, their safety functions, and the procedural safety controls that are relied upon to control the frequency of occurrence of event sequences, or mitigate their consequences.

The first two objectives are addressed in this analysis. The third objective is addressed in the *RF Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1).

It is important to recognize that the ESDs are used to identify, before operation begins, potential future event sequences. An identified event sequence may or may not occur during 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 *RF 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 *RF 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. 2.2.61, 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 (including seismic events) are not developed in this analysis. External events and any associated event sequences are evaluated and documented separately.

Five possible mutually exclusive end states are considered in the ESDs. The first end state addresses absence of radiation exposure; the other four end states classify the type of radiation exposure that could occur, as follows:

1. "OK"–Indicates the absence of radiation exposure.

2. Direct Exposure–Indicates potential exposure of individuals to direct or reflected radiation. Excludes radionuclide release.

3. Radionuclide Release–Indicates, in addition to a potential exposure of individuals to direct or reflected radiation, the radiation exposure resulting from a release of radioactive material from its confinement.

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 criticality should be investigated without a radionuclide release.

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 radiation exposure.

2. Direct Exposure, Degraded Shielding–Applies to event sequences where an SSC providing shielding is not breached, but its 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. Excludes radionuclide release.

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 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. Excludes radionuclide release.

4. Radionuclide Release, Filtered–Indicates a release of radioactive material from its confinement, 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. Excludes moderator intrusion.

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. Excludes moderator intrusion.

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

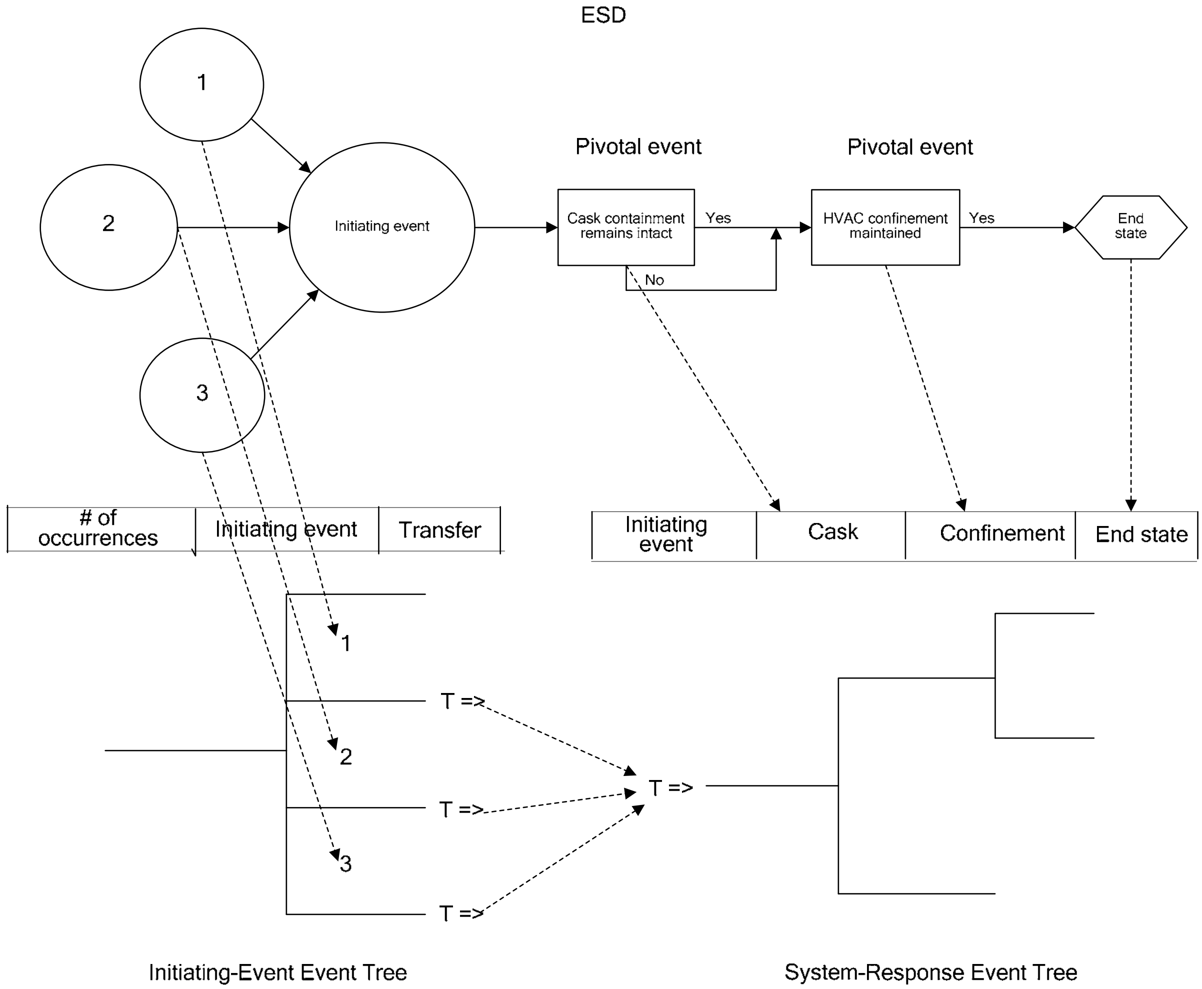
7. Radionuclide Release, Unfiltered, Also Important to Criticality–This end state refers to a situation in which an unfiltered radionuclide release occurs and (unless the associated event sequence is Beyond Category 2) a criticality investigation is indicated.

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 of moderation must be included in the event sequence analysis in order to complement the separate deterministic criticality analysis. Under normal conditions, sealed canisters containing dry waste are received in sealed transportation casks. Normal conditions also include receipt of uncanistered dry SNF 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, failure of piping associated with fire suppression or other water-distribution system, or by failure of lubricating oil reservoirs associated with cranes. Therefore, event sequences involving radiological release are identified with the end state 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. 2.2.61, 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.



NOTE: HVAC = heating, ventilation, and air conditioning.

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. 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. If a pivotal event does not appear in a particular event sequence (as indicated in the ESD), 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 bubbles to the left, also known as small bubbles, represent individual initiators. The larger bubble, also known as a big bubble, to the right of the small bubbles represents the aggregated initiator. The cask and confinement rectangles to the right of the big bubble 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 bubbles 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 and flooding initiating events identified in the MLDs are analyzed in the *RF Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1).

4.3.3 Non-seismic External Events

Non-seismic external initiating events are discussed further in the *Monitored Geologic Repository External Events Hazards Screening Analysis* (Ref. 2.2.5).

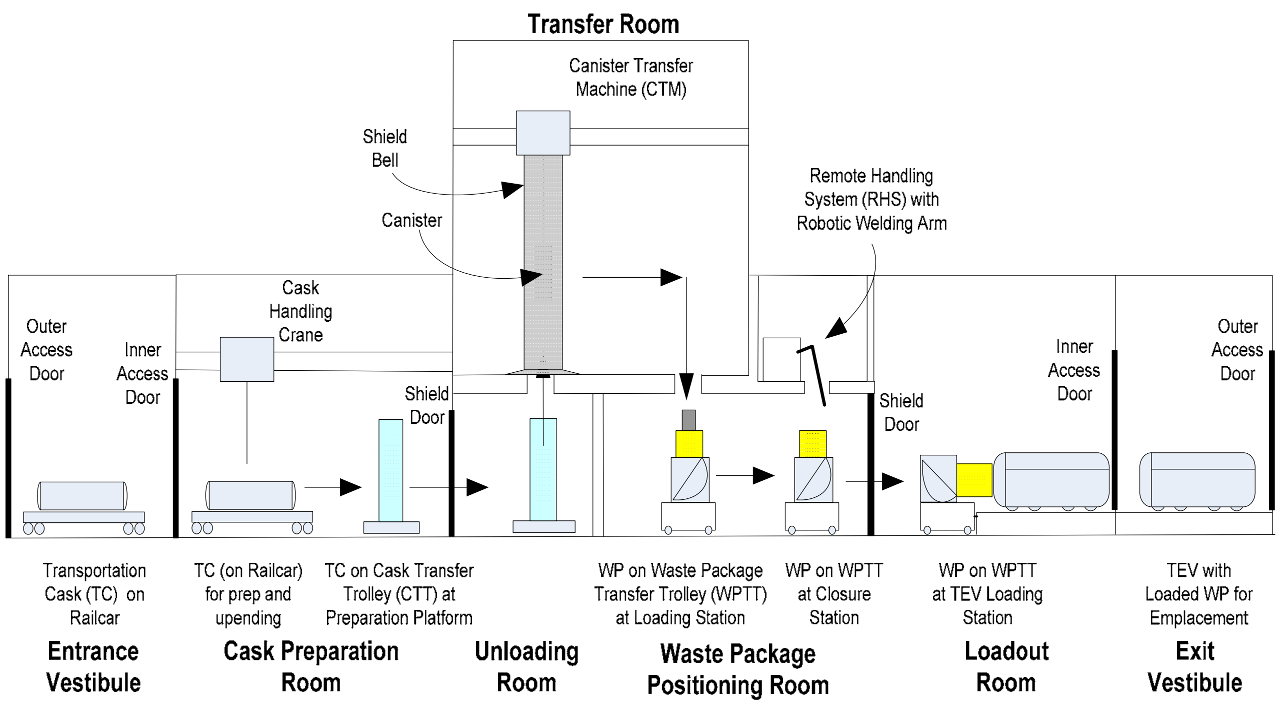
4.3.4 Example Facility Analysis

This section illustrates the overall event sequence development approach using an example "typical waste facility" (TWF). It is particularly useful for understanding the relationships among the PFD, MLD, HAZOP, ESDs and event trees. This example portrays a TWF in which the design and operations are generalized; as such, some of the specific features of the TWF are different from similar features in the RF. RF specific features, initiating events, and event sequences are presented beginning in Section 6. This TWF receives, repackages, and exports waste forms for emplacement, employing equipment and processes that are representative of an actual facility. This example describes the facility, shows a generic PFD and a generalized

MLD, provides a sample HAZOP, and describes development of an ESD and event tree for waste transfer activities of the facility using the canister transfer machine (CTM). The analysis presented here focuses on a particular operation: the transfer of a waste form using a CTM. The objective of this example is to demonstrate how event sequences are developed employing the methodologies identified above. A generic description of the TWF operations is provided below.

Typical Waste-Handling Facility Overview

A simplified schematic of the operations of the example facility, TWF, is shown in Figure 6. Note that the example facility is not the same as the RF and it has a fictitious mission, design features, and operations that differ from those of the RF. The example facility receives radioactive waste in a transportation, aging, and disposal (TAD) canister and prepares it for emplacement in the repository. The radioactive material is generically referred to as a waste form. The canisters provide the primary containment barrier to prevent release of radioactive materials, and the canisters are contained in either transportation casks (incoming) or waste packages (outgoing), providing a secondary containment barrier. Off-site waste forms are received from commercial sites in transportation casks, which also provide shielding in addition to being a containment barrier. The canisters containing the waste forms are transferred from the transportation casks to waste packages for final emplacement. The waste package, which is designed for disposal of the waste form in the repository, provides only a secondary containment barrier and no shielding.



NOTE: TEV = transport and emplacement vehicle; WP = waste package.

Source: Original

Figure 6. Typical Waste-Handling Facility Simplified Schematic

The example facility has direct rail access for receipt of transportation casks and direct transport and emplacement vehicle (TEV) access for the removal of waste packages.

The mechanical handling systems, which are operated by the facility personnel, move and open transportation casks, and remove and transfer the canisters to waste packages for emplacement. The mechanical handling equipment includes such major pieces of equipment as the overhead bridge cranes, cask transfer trolleys (CTT), CTM, waste package transfer trolley (WPTT), and associated lifting fixtures and devices.

The example facility has one Entrance Vestibule for receiving railcars carrying loaded transportation casks. The vestibule provides air locks to ensure facility HVAC design flows and pressures are maintained. The HVAC system is designed to ensure that potential radioactive releases are confined within the facility.

Loaded transportation casks received through the Entrance Vestibule of the example facility are moved through the Entrance Vestibule inner access door and into the Cask Preparation Room where personnel inspect the cask for damage and survey for radioactive contamination. A personnel barrier, two impact limiters, and cask tie-downs are removed by personnel accessing the cask using a mobile access platform (MAP). Operators use the cask handling crane to upend and lift the transportation cask off the railcar and place it on a CTT in the preparation area, where personnel prepare it for canister unloading. Once the CTT is prepared for unloading, operators move the CTT carrying the transportation cask to the Cask Unloading Room.

Prior to CTM operations, operators signal the WPTT carrying an empty waste package to move into position under the loading port in the Waste Package Positioning Room.

The CTM is located in the Transfer Room on the facility's second level. After operators position the loaded transportation cask and empty waste package correctly, the CTM aligns over the unloading port and lifts the canister from the transportation cask and into the Transfer Room. The CTM then moves horizontally to the proper position over the loading port, where it lowers the canister into the empty waste package.

Following insertion of the canister into the waste package, operators use the CTM to set the waste package inner lid in place. Operators signal the WPTT to move the loaded waste package with the inner lid from the loading station to the closure station below the remote handling system (RHS). The robotic arm, using the weld end effector, welds the inner lid, and then the weld is inspected. If the weld is satisfactory, the RHS is used to place the outer lid on the waste package. The robotic arm, using the weld end effector, welds the outer lid, and similarly inspects this weld. When the welds are satisfactory, the operators signal the WPTT to move the waste package into the Loadout Room where it is rotated into horizontal orientation and loaded into a TEV for removal from the facility and emplacement into the repository.

4.3.4.1 Process Flow Diagram Development

The initial effort in identifying initiating events and developing ESDs and event trees involves gathering and reviewing facility design and operating information and documentation, which is then used to develop a PFD that summarizes the processes occurring within the facility. Relationships between operations and systems that characterize a specific process with defined boundaries are combined into distinct nodes on the PFD. A PFD for the example TWF is shown in Figure 7. Explanations of the operations encompassed within each node are provided in Table 4. Descriptions for special equipment used in the TWF and identified in Table 4 are provided in Table 5. The CTM operations for this example are emphasized on the PFD (Node 8, Figure 7).

As shown in the PFD (Figure 7) and as described above, these 13 nodes represent operational boundaries in the example facility. These are analyzed further in the MLD. Figure 7 emphasizes those nodes relevant to CTM operations. Node 8 is the focus of the illustrated example of the interrelationships between the MLD, HAZOP, ESD, and event tree.

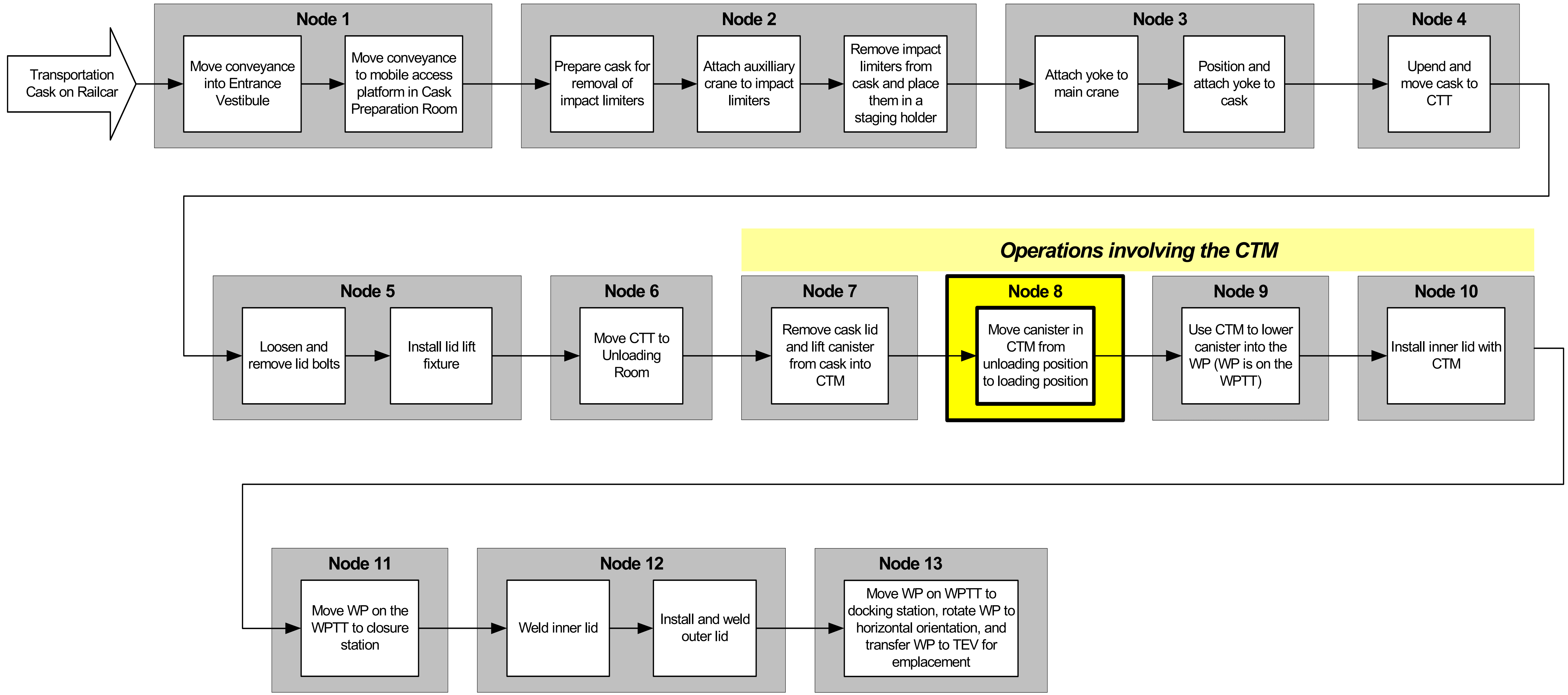
4.3.4.2 Master Logic Diagram Development

With the PFD complete, development of the MLD begins. For the TWF, the MLD top event end state used is: "Unplanned exposure of individuals to radiation or radioactive materials" (Figures 8 and 9).

After the MLD top event is determined, the immediate and necessary causes for the occurrence of this top event are determined. These are not the basic causes of the event but the immediate causes or immediate mechanisms for the next level events. In turn, the causes of these events are listed in the next level of the MLD. The immediate and necessary causes of the top event are now treated as subsidiary events. In turn, the causes of these subsidiary events are listed in the next level of the MLD. In this way the diagram is expanded, continually transferring the point of view from mechanism to mode, and continually approaching finer resolution in the mechanisms and modes, until ultimately the limits of resolution necessary to identify initiating events are reached.

The top event is decomposed into facility events that are external or internal, in accordance with the MLD methodology described in Section 4.3.1.2. The analyst identifies the external events (i.e., those events that generally affect the entire facility, such as natural hazards or internal flooding) and then analyzes these events separately. This is a reasonable approach because these initiators are generally outside the control of facility personnel or are not a result of facility operations. In addition, these initiators are common to all or most facilities on a site, and much of the analysis could be applicable for all. Note that the external events appear on the left branch in Figure 8, and the next logical split is illustrated but not decomposed further for this example.

The right branch, "Exposures due to activities internal to the TWF," begins the evaluation of the internal initiators that are not related to fire or flooding, and includes the facility operating activities identified in the PFD. For the TWF, the analyst defines the next level in terms of the PFD operational boundaries. In accordance with the generalized logic structure for the PCSA MLD, the boundaries should be operational areas where the events occur. The operational areas are not necessarily divided by physical boundaries, such as facility rooms, but rather by activities that are related or that share a goal. So for the example analysis, the nodes identified in the PFD are reviewed for the facility's operational goals.



NOTE: CTT = cask transfer trolley; CTM = canister transfer machine; TEV = transport and emplacement vehicle; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure 7. Simplified Process Flow Diagram for a Typical Waste-Handling Facility (with Node 8 Emphasized for Further Discussion)

Table 4. Process Node Descriptions

Node No.	Description
1	Node 1 on the PFD for the example facility, TWF, represents the waste handling receiving activities, which begin with the receipt of a waste form (by rail in a transportation cask) from the national transportation system at the TWF. Transportation casks are moved on the railcar using a site prime mover (SPM), passing through the Entrance Vestibule and into the Cask Preparation Room. The maximum speed for a SPM is 2.5 miles per hour. The Entrance Vestibule serves as an airlock for the facility, providing an environmental separation between the Cask Preparation Room and the outside environment. To allow the HVAC system to maintain negative pressure within the facility, the vestibule has interlocked inner and outer access doors. Only one door can open at a time when moving equipment in or out. To allow a SPM and the transportation cask on the railcar to enter the facility, the Entrance Vestibule inner access door is closed, the Entrance Vestibule outer access door is opened. The cask/railcar passes through the outer doorway into the Entrance Vestibule. The Entrance Vestibule outer access door is closed, and then the Entrance Vestibule inner access door is opened. The cask/railcar passes through the inner access door to a location near the MAP in the Cask Preparation Room. At this point, the SPM is disconnected from the railcar and exits the facility. The Entrance Vestibule inner access door is closed before any operation begins inside the facility. Equipment involved in Node 1 operations: • SPM • Interlocked inner and outer access doors. Additional equipment present during Node 1 operations: • Mobile access platform • Cask handling crane • Common hand tools.
2	Node 2 includes operating activities performed to remove the impact limiters from the transportation cask. Impact limiters are honeycomb-shaped devices installed on each cask by the shipper to protect it from damage in the event of an accident during transport to the repository. They are removed while the cask is still on the railcar. After the cask has been inspected for damage and has been surveyed for contamination (using industry standard equipment and techniques), the MAP is engaged to facilitate personnel access to the transportation cask on the railcar. This platform allows personnel to access all areas of the horizontal cask. The personnel barrier, which prevents personnel from directly touching the transportation cask during shipment, is detached and stored using the auxiliary hook on the cask handling crane. The two impact limiters are unbolted using common hand tools. Both impact limiters are lifted from the cask and placed in their respective staging locations using the 20-ton auxiliary hook on the 200-ton overhead cask handling crane. Finally the tie-downs are removed to allow the cask to be upended and removed from the railcar. Equipment involved in Node 2 operations: • Common hand tools • Cask handling crane • MAP. Additional equipment present during Node 2 operations: • Entrance Vestibule inner access door (closed) • CTT Unloading Room shield door (closed).

Table 4. Process Node Descriptions (Continued)

Node No.	Description
3	The operations occurring in Node 3 include the following cask lift preparation activities: attaching the cask handling crane's lift yoke to the 200-ton cask handling crane; moving the yoke into position above the cask; and securely attaching the yoke to the cask to ensure it is not dropped. The MAP is then moved away from the cask, and the cask is upended on the railcar in preparation for moving the cask to the CTT. Equipment involved in Node 3 operations: • Lift yoke • Common hand tools • Cask handling crane • MAP. Additional equipment present during Node 3 operations: • Railcar • Entrance Vestibule inner access door (closed) • CTT • Unloading Room shield door (closed).
4	In Node 4, the cask is lifted sufficiently to clear any obstructions and, while suspended, is moved by the cask handling crane to the CTT. The CTT is pre-staged at the cask preparation platform prior to moving the cask into the facility. The cask preparation platform is used to access the cask on the CTT to prepare it for removal of the canister. A cask pedestal appropriate to the size of the incoming transportation cask is also pre-staged on the CTT using the cask handling crane's 20-ton auxiliary hook. The cask is placed on the pedestal inside the CTT, and the CTT gate is closed and secured. The CTT's restraining brackets and steel frame maintain the cask in its vertical orientation during preparation activities and cask movement. Equipment involved in Node 4 operations: • Cask pedestal • CTT • Cask handling crane • Lift yoke. Additional equipment present during Node 4 operations: • Entrance Vestibule inner access door (closed) • Common hand tools • Unloading Room shield door (closed).
5	While on the CTT and still in the Cask Preparation Room, personnel access the cask lid via the preparation platform and remove the bolts securing the cask lid. Personnel then attach a lid lift fixture using standard tools and the 20-ton auxiliary hook on the cask handling crane. Equipment involved in Node 5 operations: • Common hand tools • Cask handling crane • CTT (within the cask preparation platform). Additional equipment present during Node 5 operations: • Lift yoke • MAP • Entrance Vestibule inner access door (closed) • Unloading Room shield door (closed).

Table 4. Process Node Descriptions (Continued)

Node No.	Description
6	The Unloading Room is located between the Cask Preparation Room and the loading station in the Waste Package Positioning Room. The Cask Unloading Room shield door between the Cask Preparation Room and the Cask Unloading Room is opened to allow the CTT to pass through. The Entrance Vestibule inner access door is interlocked with the Unloading Room shield door and remains closed. Transportation casks are moved on the CTT from the preparation platform area to the Cask Unloading Room and positioned under the closed unloading port. Workers use hand-held controls to operate and maneuver the CTT between locations. When the cask is properly positioned beneath the unloading port, the Unloading Room is cleared of personnel and the Unloading Room shield door is closed. Equipment involved in Node 6 operations: • CTT • Cask Unloading Room shield door. Additional equipment present during Node 6 operations: • Entrance Vestibule inner access door (closed) • Unloading port shield gate (closed) • CTM (in the Transfer Room above the Cask Unloading Room, behind the closed unloading port shield gate).
7,9	Nodes 7 and 9 include lifting and lowering operational activities for unloading transportation casks and loading waste packages. These operations are initiated by positioning the transportation cask under the unloading port and placing a waste package under the loading port. The shield gates on both ports are closed. Only one port shield gate is opened at a time and only when the CTM is positioned above the port. While operations are conducted, the shield doors for the Cask Unloading Room and the Waste Package Positioning Room are both closed. After the cask and waste package are properly positioned beneath their respective port, personnel are cleared from the Cask Unloading Room, Transfer Room, and the Waste Package Positioning Room. The Cask Unloading Room shield door and the Waste Package Positioning Room shield door are then closed. The main equipment used for unloading/loading operations is the CTM, which is a remotely operated bridge crane located in the Transfer Room on the facility's second level. To initiate the cask unloading operations, the CTM is moved into position above the unloading port such that the CTM canister grapple is aligned with the lid lift fixture on the cask. The shield bell, attached to the CTM trolley, houses the canister and provides shielding to decrease radiation levels in the Transfer Room during the operations. A shield skirt on the bottom of the shield bell is lowered to shield the gap between the bottom of the shield bell and the floor of the Transfer Room. There is also a shield gate on the bottom of the shield bell which is opened to allow the canister to be lifted from the transportation cask to the CTM shield bell. The unloading port shield gate is opened to allow the CTM to access the cask. The CTM grapple is lowered to engage the lid lift fixture, and the lid is removed and placed in a staging area. The CTM realigns above the unloading port and cask, and lowers its grapple again to engage the canister. The CTM raises the canister through the unloading port and into the shield bell, and the shield gate on the bottom of the shield bell is shut. At this point, the canister is completely enclosed. The shield skirt is raised, and the unloading port shield gate is closed. (Refer to Node 8 operation description regarding horizontal movement of the CTM through the Transfer Room.) Loading operations identified as Node 9 on the PFD are essentially the reverse of the Node 7 unloading operations. The CTM (aligned above the loading port) lowers the shield skirt to close the gap between the bottom of the shield bell and the floor of the Transfer Room. The loading port shield gate is opened, the shield gate on the bottom of the shield bell is opened, and the CTM lowers the canister through the loading port. The canister is lowered into the waste package, and the grapple is released and withdrawn. The CTM then retrieves the waste package inner lid and places it in the waste package (refer to Node 10 description).

Table 4. Process Node Descriptions (Continued)

Node No.	Description
7,9 Cont'd	Equipment involved in Node 7,9 operations: • Unloading Room shield door (open or closed, as appropriate) • Waste Package Positioning Room shield door (open or closed, as appropriate) • CTM (with grapple and shield bell) • Unloading port shield gate • Lid lifting fixture (and cask lid) • Loading port shield gate. Additional equipment present during Node 7,9 operations: • CTT • WPTT
8	Node 8 operations include the horizontal movement within and through the Transfer Room above the Cask Unloading Room and the loading station in the Waste Package Positioning Room. Both the unloading port and the loading port are closed. The bottom shield door of the bell is closed and the shield skirt is raised. Although shielding provided by the shield bell allows workers to be present in the Transfer Room during transfers, they normally leave the room and CTM operations are conducted remotely from the Control Room. The remotely controlled CTM moves the vertically oriented canister within the shield bell horizontally through the Transfer Room. The canister is moved from the unloading port to the loading port, so that it is aligned over the waste package, which is positioned below at the loading station in the Waste Package Positioning Room. The horizontal movement through the Transfer Room is identified as Node 8 on the PFD. Equipment involved in Node 8 operations: • CTM (with grapple and shield bell) • Unloading port shield gate • Loading port shield gate. Additional equipment present during Node 8 operations: • None
10	Node 10 includes operations performed to install the waste package inner lid. For canister transfer operations, this is the final use of the CTM. Note that all facility operations from this point until the waste package is exported are remotely executed because the waste package provides limited shielding. After waste package loading is complete, the CTM retrieves the waste package inner lid from its staging location, then aligns and lowers the lid into position. The CTM then retracts all equipment into the Transfer Room, and the loading port is closed. Equipment involved in Node 10 operations: • CTM • Loading port shield gate. Additional equipment present during Node 10 operations: • WPTT (assembly with waste package pedestals and transfer carriage) • Waste Package Positioning Room shield door (closed).
11	After the waste package inner lid is in place, the waste package in the WPTT is moved on rails to the closure station in the Waste Package Positioning Room. These activities are represented as Node 11 on the PFD. The WPTT moves the loaded waste package from the loading station to the closure station, still in the Waste Package Positioning Room. The waste package is maneuvered to a position below the RHS for inner and outer waste package lid welding (refer to Node 12 description). Equipment involved in Node 11 operations: • WPTT • Waste Package Positioning Room shield door (closed). Additional equipment present during Node 11 operations: • RHS.

Table 4. Process Node Descriptions (Continued)

<table>
<tr><th>Node No.</th><th>Description</th></tr>
<tr><td>12</td><td>The robotic arms are used to assist in closure of waste packages and to perform nondestructive examination inspections of the closure welds. The closure equipment is located above the closure station in the Waste Package Positioning Room. The equipment accesses the waste package through a portal.

After the waste package is positioned under the portal, the robotic arms use the weld end effectors to weld the inner lid in place. The inner lid weld is inspected. After passing the inspection, The RHS is used to retrieve the outer lid and place it on the waste package. The robotic arms then use the end effectors to weld the outer lid into place. Another non-destructive examination inspection is performed to ensure this weld is also completed correctly. After this operation, the waste package can leave the facility for emplacement.

Equipment involved in Node 12 operations:
• RHS
• Robotic arms
• Weld end effectors
• Inspection equipment.

Additional equipment present during Node 12 operations:
• WPTT
• Waste Package Positioning Room shield door (closed).</td></tr>
<tr><td>13</td><td>The sealed waste package is moved on the WPTT from the closure station in the Waste Package Positioning Room to the TEV loading station in the Loadout Room. The Loadout Room is used for transferring loaded waste packages to TEVs for removal from the facility and emplacement in the repository.

After the lid welding operations are complete, the Exit Vestibule inner access door is closed and the Waste Package Positioning Room shield door is opened. The WPTT moves the waste package from the closure station to the Loadout Room TEV loading station.

At the TEV loading station, the WPTT mechanically engages to the docking station. The waste package, waste package pallets, and transfer carriage are rotated by the trolley to a horizontal orientation. In the horizontal orientation, the waste package pallets are supporting the waste package on the transfer carriage. A TEV is at the docking station and set to receive the waste package. A worm drive (also referred to as a screw drive) engages the transfer carriage pulling it and the waste package riding on the waste package pallet into the TEV. (A worm drive is a gear that uses a spiral shaft to control speed and movement. It provides smooth movement and efficient speed control.)

Inside the TEV, arms lift the waste package pallet supporting the waste package. The worm drive then reverses and returns the transfer carriage to the WPTT. The TEV door is closed.

The waste package is now secured in the TEV, and the TEV exits the facility. With both the Waste Package Positioning Room shield door and the Exit Vestibule outer access door closed, the Exit Vestibule inner access door is opened. The loaded TEV transports the waste package out of the facility to the Exit Vestibule, which is the interface point between the facility and the outside. The Exit Vestibule inner access door is closed, completing the facility’s canister transfer operation. The Exit Vestibule outer access door is opened, and the TEV takes the waste package to the repository for emplacement.

Equipment involved in Node 13 operations:
• WPTT (with transfer carriage)
• Waste Package Positioning Room shield door
• TEV
• Exit Vestibule inner access door.

Additional equipment present during Node 13 operations:
• Exit Vestibule outer access door.</td></tr>
</table>

NOTE: CTM = cask transfer machine; CTT = cask transfer trolley; HVAC = heating, ventilation, and air conditioning; MAP = mobile access platform; PFD = Process Flow Diagram; RHS = remote handling system; SPM = site prime mover; TEV = transport and emplacement vehicle; TWF = typical waste-handling facility; WPTT = waste package transfer trolley.

Source: Original

Table 5. Equipment Descriptions

Equipment Type	Description
Site Prime Mover	Small locomotive-type machine for moving railcars.
Interlocked Shield Doors	Shield doors on the openings to the Unloading Room and the Waste Package Positioning Room protect against shine from radioactive materials during facility operations. Each is a single slide-open type door, made of 16-in.-thick steel plate and weighing approximately 268 tons. Each door is operated by an electric motor turning a screw, which interacts with a door-mounted bracket. The door overlaps the aperture on the top, bottom, and both sides to provide shielding. Each door has an obstruction sensor that halts door travel when an obstacle is detected in the pathway of the door.
Mobile Access Platform	The MAP is used in the Cask Preparation Room to allow personnel to access the cask on its railcar. The platform is a rail-mounted structure that bridges over the horizontal transportation cask. The MAP includes adjustable platforms (up/down and in/out) to provide access by personnel to different features on the cask (e.g., impact limiters or personnel barriers). The upper level limit of the platform lift is controlled by electric power limit switches backed-up by mechanical stops. The platform is designed to run freely up or down without any interference with equipment or structures adjacent to the platform. It has manual override features to lower the platform by controls operable from the platform or the operation floor. The mobile access platform dimensional envelope is approximately 27 ft 0 in. × 16 ft 0 in. × 29 ft 0 in. height.
Cask Handling Crane (with 200-ton main hook and 20-ton auxiliary hook)	The cask handling crane is located in the Cask Preparation Room and has a dimensional envelope of approximately 65 ft × 89 ft × 60 ft. The crane houses two trolleys on a single overhead gantry bridge: one trolley is rated for 200 tons ("main hook") and the other is rated for 20 tons ("auxiliary hook"). The estimated bridge weight is 99 tons, the estimated main trolley weight is 44 tons, and the estimated block weight is 10 tons. The crane bridge girders traverse in the north-south direction and the crane trolley travels in the east-west direction. Video equipment monitors and records crane operations. The cask handling crane is used for heavy load lifts in the Cask Preparation Room. The main function is to transfer a transportation cask from the railcar to the CTT. The auxiliary hook is used to move impact limiters and other equipment and lighter loads as needed in the Cask Preparation Room.
Common Hand Tools	An array of common hand tools is available for removing/replacing bolts and attaching lid adapters.
Preparation Platform	The CTT can be surrounded by the adjustable preparation platform. This platform is retracted until a transportation cask is transferred to the CTT. Movable platform sections are raised and moved in to allow personnel to access the transportation cask and prepare it for canister unloading operations. The platform provides four working levels for personnel to access the CTT. The platform is split down the center to allow passage of the CTT. The top two levels have articulating walkways between the two sections. Stairs access each level of the platform. The top level of the platform provides access to the CTM operating deck. The dimensional envelope of the platform is 27 ft × 16 ft × 29 ft.
Cask Pedestal	Cask pedestals are used to adjust the seating height of a transportation cask. Multiple pedestal sizes and heights are available to accommodate various transportation casks. This ensures the top of any cask is at a consistent elevation, providing constant clearance between the cask top and the ceiling of the Unloading Room (i.e., the floor of the Transfer Room). Cask pedestals are placed within the CTT using the cask handling crane, then the transportation cask is seated on the pedestal.

Table 5. Equipment Descriptions (Continued)

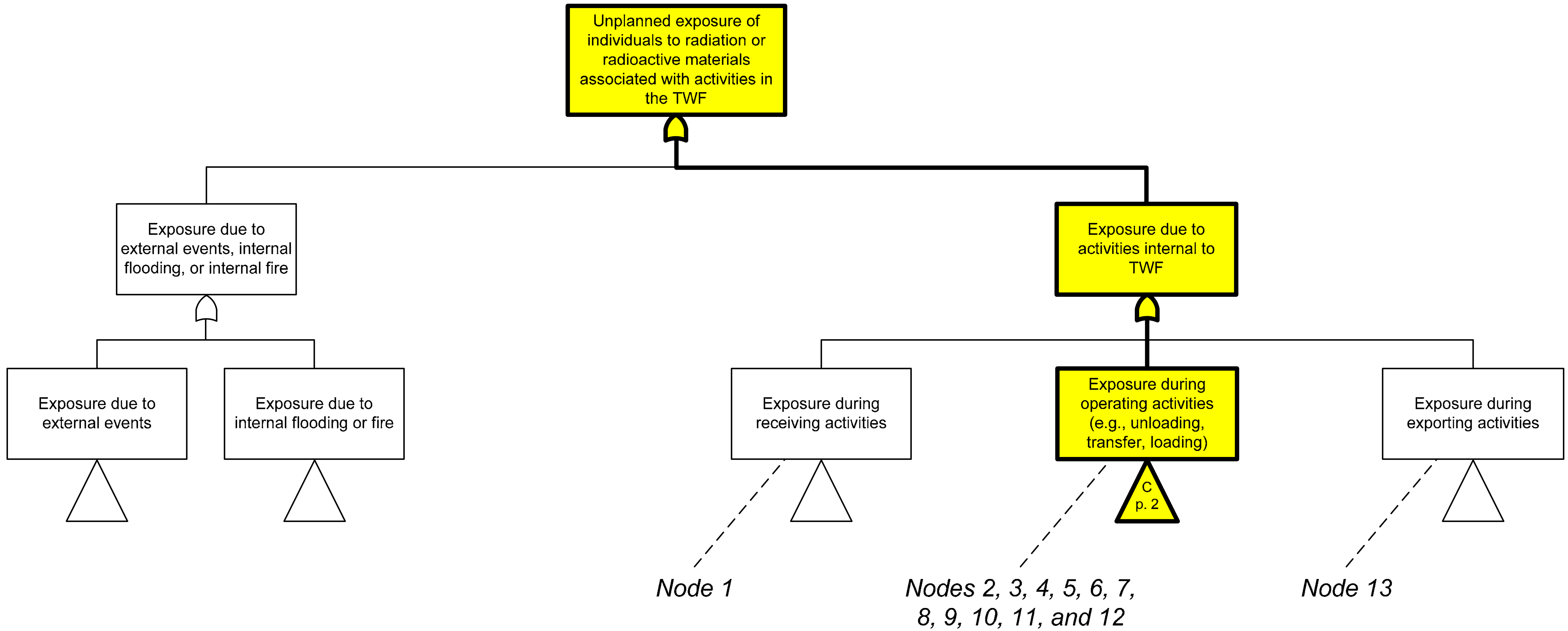
Equipment Type	Description
Cask Transfer Trolley	The CTT is used to transfer transportation casks between the Cask Preparation Room and the Unloading Room. The CTT is a metal frame platform that, when in operation, floats on a thin film of air above the floor surface. The frame and restraining brackets maintain the vertical orientation of the cask during lid preparation, movement, and canister unloading. It operates by electric and pneumatic control and air modules. An automatic programmable logic controller system controls the air pressure and lift height of the trolley platform. Sensors provide control system inputs on the floating height and rate of rise/lowering of the CTT platform.
Lift Yoke	The lift yoke is used to hold casks during transfer between the railcar and the CTT. The lift yoke has two adjustable lifting arms to accommodate various cask diameters and connect to the cask trunnions. The cask handling yoke couples to the cask handling crane's 200-ton crane hook and has a dimensional envelope of approximately 2 ft-4 in. x 15 ft x 13 ft-6 in., weighing 7.5 tons. When not in use, the lift yoke rests in a yoke stand.
Lid Lift Fixture	The function of the transportation cask lid lift fixture is to allow the CTM to grapple cask lids of various sizes. The fixture is adjustable and has multiple mounting positions that accommodate the various casks. The transportation cask lid lift fixture is configured to match the TAD canister lifting feature outline/interface.
Canister Transfer Machine (with grapple and shield bell component)	The CTM is a bridge crane located in the Transfer Room in the second floor above the Cask Unloading and Waste Package Positioning Rooms. The CTM is mounted on a pair of bridge girders that run on rails supported by corbels. The capacity is 70 tons. The primary function of the CTM is to transfer canisters between ports accessing loading and unloading locations located in the floor of the Transfer Room. There are various CTM grapples available that are used to couple different types and sizes of canisters and cask lids to the CTM for lifting and transfer. Each CTM grapple employs three equally spaced jaws to clamp onto a canister or lid for lifting. Grapple actuation mechanisms vary with the grapple type as well as the lifting capacities and estimated weight. The CTM lifts canisters from the transportation cask into a shielded enclosure that is rigidly affixed to the CTM trolley. This enclosure is called a shield bell. The shield bell is designed to prevent radiation exposures to personnel during canister transfer from the cask to the waste package. The shield bell moves horizontally with the CTM trolley through the Transfer Room between the unloading and loading ports. The bottom of the shield bell is a large platform that houses a shield gate and a shield skirt. The shield gate opens to allow a canister to be lifted into or lowered out of the bell, and closes to enclose the canister and provide shielding for the lower portion of the bell. (The crane hook (grapple) travels vertically along the main axis of the shield bell.) The shield skirt is lowered to close the gap between the shield bell and the Transfer Room floor when a canister is being raised or lowered. The shield skirt is raised when the shield gate is closed and when the CTM moves horizontally between the unloading and loading ports.

Table 5. Equipment Descriptions (Continued)

Equipment Type	Description
Port Shield Gates	Port shield gates are slide doors located in the operating floor between the Transfer Room and the unloading/loading stations. When closed, these gates provide shielding to prevent radiation from a canister from streaming through the port into the Transfer Room.
Waste Package Transfer Trolley (with transfer carriage)	The WPTT is a remotely operated electric conveyance that moves on rails to carry waste packages between the loading and closing stations in the Waste Package Positioning Room and the TEV docking station in the Loadout Room. The WPTT contains a shielded enclosure that houses the waste package. The shielded enclosure can be rotated between horizontal and vertical orientations. A transfer carriage rests inside the shielded enclosure on which the waste package pallet rests carrying the waste package. The waste package and its pallet are loaded into the shielded enclosure on the transfer carriage with the waste package handling crane in the Loadout Room. The shielded enclosure and waste package in the shielded enclosure are oriented vertically for loading canisters into the waste package and closure. The shielded enclosure and the waste package are rotated to horizontal orientation to allow the transfer carriage to transfer the waste package and pedestal into the TEV. The WPTT mechanically engages with the TEV docking station for transferring the waste package, pallet, and transfer carriage into the TEV. A worm drive with an integral hook located in the floor of the facility engages a hook on the transfer carriage when the shielded enclosure is rotated to the horizontal position it then pulls the carriage carrying the waste package and pedestal into the TEV. Mechanical arms in the TEV engage the pedestals and lift the waste package off of the transfer carriage.
TEV	The TEV is a remotely controlled, rail-based vehicle, powered by a third rail. For transport, it has eight wheels driven by electric motors. Disc brakes are integral to the motors on each wheel. The TEV has 10-inch shielding, formed by a layered metal/polymer composite. It operates without an onboard crew and is controlled by a programmable logic controller system. TEV progress is monitored from a central control facility; however, these personnel have limited control options and can only stop the TEV or send a confirmation signal to continue operations.

NOTE: CTM = cask transfer machine; CTT = cask transfer trolley; MAP = mobile access platform; TAD = transportation, aging, and disposal canister; TEV = transport and emplacement vehicle; WPTT = waste package transfer trolley; ft = feet; in. = inches.

Source: Original



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as “exposure.”

Source: Original

Figure 8. Master Logic Diagram (Page 1) Typical Waste-Handling Facility (with Emphasis on Initiating Event Branch Relevant to Horizontal Canister Transfer Machine Operations)

Although the facility processes are segregated into 13 operational nodes for the TWF, these nodes suggest a logical grouping into three activity types within the facility containment barrier: receiving, exporting, and waste form handling ("operating activities"). These are expressed on the MLD (Figure 8) as categories of failure: "Exposure during receiving activities"; "Exposure during exporting activities"; and "Exposure during operating activities." These activities are detailed by node in Table 4, and are summarized below with example failures indicated by the MLD.

- **Receiving Activities**: Includes activities that occur from the time the transportation cask on the railcar is in the Entrance Vestibule of the example facility, TWF, until the inner access door is closed behind the conveyance (i.e., the transportation cask and railcar are in the Cask Preparation Room). On the PFD, these activities are included as Node 1. Potential exposure or release events might occur during these activities as a result of, for example, railcar derailment or collision caused by various equipment or human failures.

  - Example equipment failure: Rail distortion (causes derailment leading to possible tipping/drop and breach of transportation cask).

  - Example human failure: Driver of conveyance inadvertently drives in reverse (causes collision leading to possible breach of transportation cask).

- **Exporting Activities**: Includes activities that occur from the time the waste package is moved to the Loadout Room for TEV insertion until the waste package is in the Exit Vestibule. On the PFD, these activities are included as Node 13. Potential exposure or release events might occur during these activities as a result of, for example, collisions or machine malfunctions caused by various equipment or human failures.

  - Example equipment failure: WPTT carriage misaligns with TEV (leading to possible impact and breach of the waste package).

  - Example human failure: Worker enters Loadout Room through a personnel door while waste package is being unloaded from the WPTT (leading to possible direct exposure to the worker).

- **Operating Activities**: Includes activities that are not categorized as "receiving" or "exporting;" i.e., those facility operations that occur after receipt and before export of a waste form. On the PFD, these activities are included as Nodes 2 through 12. Potential exposure or release events might occur during these activities as a result of, for example, cask or canister drops or impacts caused by various equipment or human failures.

  - Example equipment failure: CTM grapple lowers too fast (leading to possible impact and breach of canister).

  - Example human failure: Worker selects the wrong size cask pedestal (leading to possible shear/impact during move into Unloading Room and breach of cask).

The process of identifying more specific types of failures (i.e., developing subsequent MLD levels) is continued until an event that initiates each failure is identifiable. Following the branch for exposure during operating activities (Figure 9), the analyst identified four exposure pathways of concern: (1) exposures during cask/conveyance unloading activities; (2) exposures during pre-transfer activities; (3) exposures during canister transfer (e.g., CTM) activities; and (4) exposures during waste package preparation activities. The relevant PFD nodes are:

- Nodes 2, 3, and 4 are evaluated as cask unloading (from conveyance) activities. Events for these activities tend to involve impacting the cask with objects or vehicles, tipping the cask, and dropping the cask.

- Nodes 5 and 6 are evaluated as pre-transfer (canister) activities. Events for these activities are essentially the same as for Nodes 2, 3, and 4.

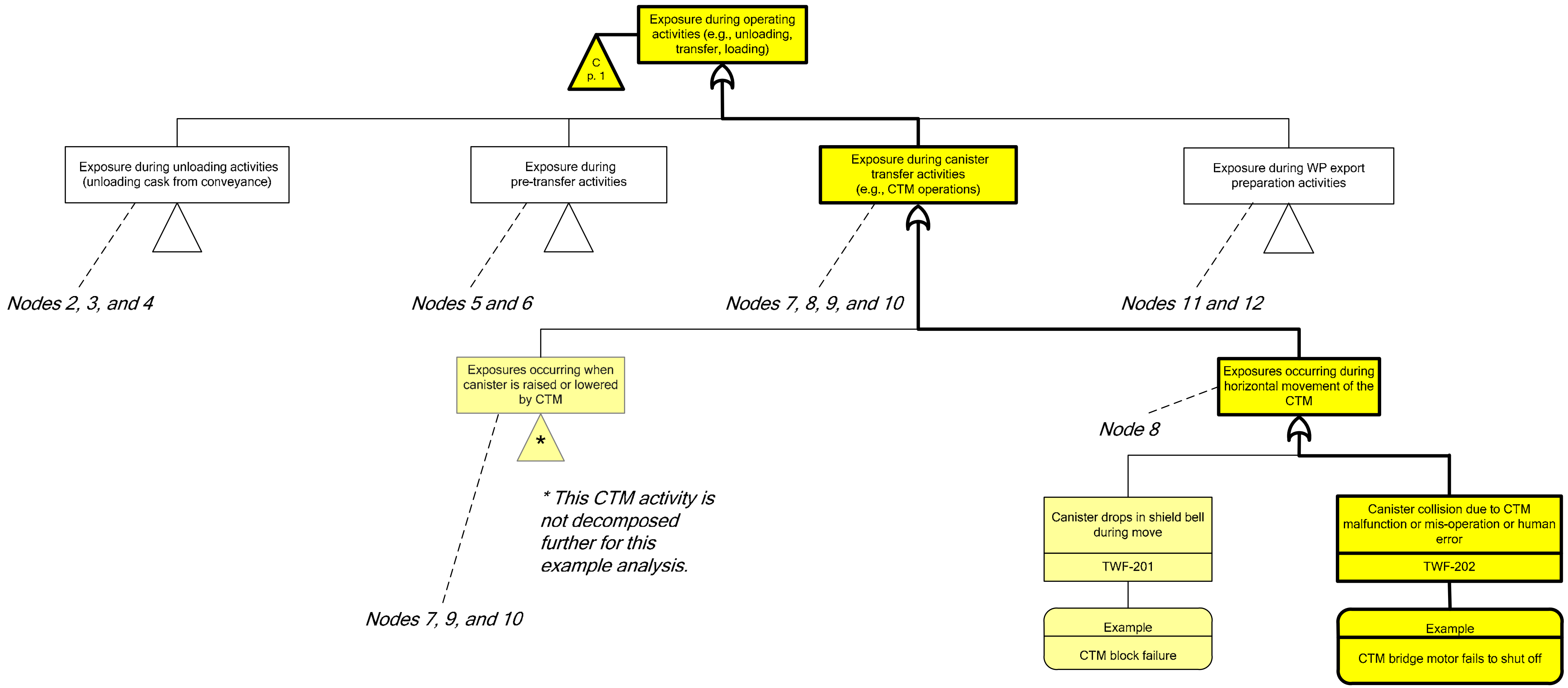
- Nodes 7, 8, 9, and 10 are essentially canister transfer activities relying heavily on the CTM, and are evaluated as such. Events for these activities tend to involve impacting the cask or canister with objects, shearing of the canister, dropping the canister, dropping objects onto the canister, and running the canister into objects.

- Nodes 11 and 12 included activities specific to preparing the waste package on the WPTT for export from the facility, and are evaluated as export activities. Events for these activities tend to involve impacting the waste package with objects, colliding of the waste package into objects, and tipping of the waste package.

For the purpose of this example and as emphasized in Figure 9, only the failure category related to CTM operations (Nodes 7, 8, 9, and 10) is decomposed further.

The CTM is used for transferring canisters containing waste between transportation casks and waste packages in the TWF. The analyst reviews the facility and equipment descriptions and the PFD and determines that, in terms of initiating events, the CTM operations are best analyzed as activities involving either vertical movement of the canister or horizontal movement of the canister. Vertical movement of the canister using the CTM is described in the node descriptions (Table 4) and, briefly, in the previous paragraphs. The focus of the example analysis from this point is the horizontal movement of the canister, identified as Node 8 on the PFD.

Figure 9 shows that the analyst identified two initiating events for horizontal movement of the CTM, and assigned MLD index numbers TWF-201 and TWF-202. The first event, TWF-201, entails a canister in vertical orientation inside the CTM that, while being moved horizontally by the CTM, is dropped inside the shield bell. As detailed in the node description table (Table 4), the CTM extracts a canister from the cask, pulls it up into the shield bell, and closes the bell shield gate. (Note that the canister is enclosed in shielding, but the shield bell provides no containment.) From this point until the CTM operations begin lowering the canister into the waste package, if the CTM prematurely releases the canister, the canister drops inside the shield bell. The analyst will develop a fault tree that includes failure modes that would singly or in combination with other failure modes cause a drop. An example of a failure mode (provided in Figure 9) is a crane malfunction in which the hoist fails to hold the load (e.g., CTM block failure).



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure." CTM = canister transfer machine; RC = railcar; TWP = typical waste-handling facility; WP = waste package.

Source: Original

Figure 9. Master Logic Diagram (Page 2) Typical Waste-Handling Facility (with Emphasis on Initiating Event Branch Relevant to Canister Transfer Machine Operations)

The second event identified, MLD index number TWF-202, relates to unexpected or unusual movement of the CTM (caused by either equipment or human failure) that results in the canister colliding with an object. As in TWF-201, the canister is inside the shield bell, and the CTM is moving horizontally through the Transfer Room. This event differs from TWF-201 in that the insult to the canister is a collision rather than a drop. An example of a failure mode leading to a collision is a motor failure in which the CTM bridge impacts the end stops (e.g., motor fails to shut off).

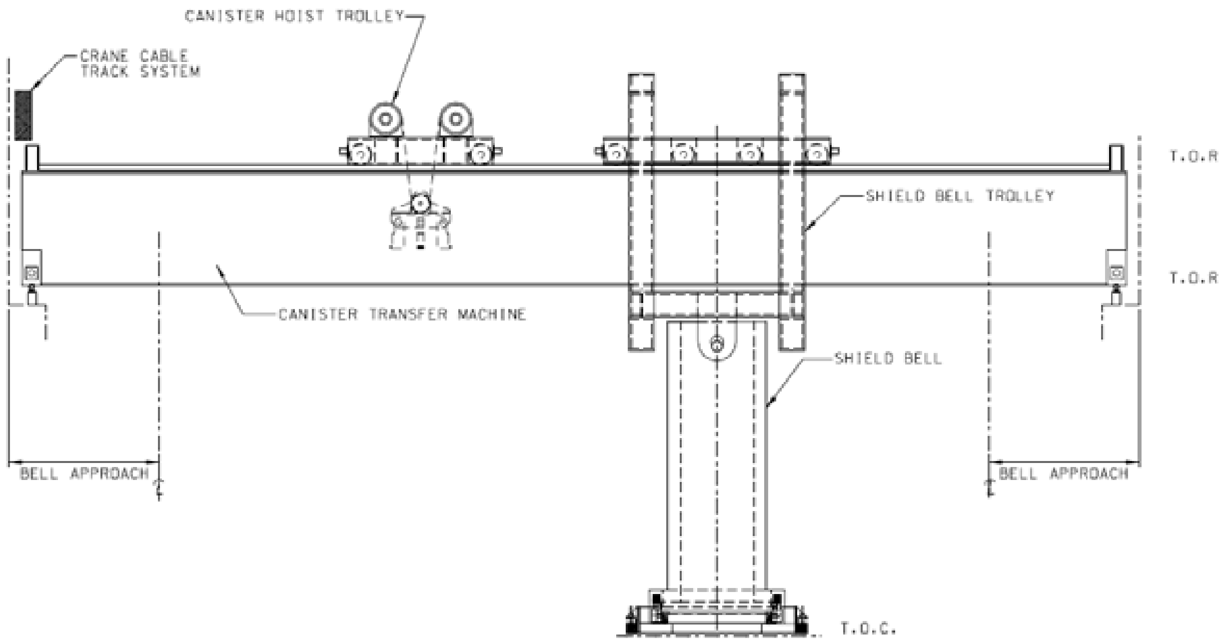
Each set of initiating events and contributors in the MLD is similarly developed and examined. The level at which initiating events are identified is the highest level for which the same system response event tree applies. Lower levels provide failure events associated with the initiating event. The HAZOP is used to verify that an accurate and comprehensive list of initiating events and subsidiary failure events is identified.

4.3.4.3 HAZOP 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 a 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. Any initiating event that is identified in the HAZOP but not already identified in the MLD is added and assigned an MLD index number for traceability. Thus, the MLD becomes the conduit for events identified in the HAZOP to be included in the ESDs. The HAZOP is not used for any other purpose in this analysis. The detailed breakdown of the initiating events from the MLD into contributing failure modes is achieved in fault trees as part of the quantification of the event sequences.

To demonstrate this process for the example facility, TWF, activities involved in the horizontal movement of the CTM are examined (shown on the MLD as “Exposures occurring during horizontal movement of the CTM” (Figure 9). As discussed previously, horizontal movement of the CTM is identified as Node 8 in the PFD and is evaluated discretely from vertical canister movement. The HAZOP results for Node 8 appear as contributors in Figure 9. Speed and direction are the primary parameters of concern for horizontal CTM operations. Deviations from normal operational movement (e.g., movement that is too fast, too slow, wrong direction, gets stuck, two-blocking, or grapple malfunction) are considered, and postulated causes (e.g., human or mechanical failure), consequences (e.g., radioactive release resulting from canister collision), and potential preventive/mitigative design features are identified.

Figure 10 is provided as a conceptual aid showing the equipment and operations analyzed. It depicts the CTM with specific callouts to its individual components. Upon examination of the figure, the initiation of scenarios such as “two-blocking,” as well as other deviations, can be visualized.



Source: *CRCF, IHF, RF, and WHF Canister Transfer Machine Mechanical Equipment Envelope* (Ref. 2.2.6)

Figure 10. Schematic of the Canister Transfer Machine

Referring to Table 6 (Node Item Numbers 8.1, 8.2, and 8.3), the parameter "Speed" signifies the speed of either the CTM crane trolley or the CTM bridge. The deviations studied are based on the HAZOP guidewords, identified for this parameter as "More" (speed is greater than expected); "No" (not moving); and "Less" (speed is less than expected). The conceptual process for each of these deviations is described below. Note that these occurrences and the consequences are only postulated at this point and not yet quantified; however, their inclusion establishes and documents the completeness of the analysis:

- The "More" deviation for this operational parameter could impact safety because, if the machine is moving too fast, it might not be stopped in time and could result in a collision and damage to the canister.

- The deviation "No" means that the loaded CTM does not move when expected, and it is therefore unable to get to the loading port for insertion into the waste package. This would cause additional time of a suspended load and an interruption of operation.

- The deviation "Less" suggests that the CTM is moving at a speed less than expected. This is a variation on No with lesser effects.

As shown in Table 6, the "Direction" parameter is analyzed similarly. However, for operations associated with this node, the HAZOP also presented several deviations that are specific to the CTM and for which no standard HAZOP guidewords exist. One example of a "Miscellaneous" parameter/deviation is "two-blocking" (Node Item Number 8.11).

Table 6. HAZOP for Typical Waste-Handling Facility (with Emphasis on Initiating Event Branch Relevant to Horizontal CTM Operations)

Facility/Operation: Example Facility					**Process**: CTM Operation		
Node 8: Move CTM Laterally					**Process/Equipment**: N/A		
Guidewords: No, More, Less, Other Than, Reverse, As Well As, Part Of					**Consequence Categories**: Radioactive Release, Lack of Shielding, 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 (CTM)	(More) CTM moves faster than allowed by procedures	1 – Human failure 2 – Mechanical failure	Potential collision of canister with internal wall of shield bell leading to radioactive release	1 – CTM design 2 – Procedures and training	N/A	TWF-202
8.2	Speed (CTM)	(No) CTM stuck in middle of room during move	1 – Human failure 2 – Mechanical failure	Operations are interrupted and increased exposure time for possible loss of HVAC while canister in bell.	N/A	Verify cooling is adequate with loss of HVAC	N/A
8.3	Speed (CTM)	(Less) CTM moves too slow	1 – Human failure 2 – Mechanical failure	Operations slow down and increased exposure time for possible loss of HVAC while canister in bell	N/A	N/A	N/A
8.4	Direction (CTM)	(More) CTM moves too far	1 – Human failure 2 – Mechanical failure	Potential collision of canister with internal wall of shield bell leading to radioactive release	1 – CTM design 2 – Procedures and training	N/A	TWF-202
8.5	Direction (CTM)	(Less) CTM does not move enough	1 – Human failure 2 – Mechanical failure	No safety consequences because the move can be completed once the condition is recognized	N/A	N/A	N/A
8.6	Direction (CTM)	(Other Than) Moves in wrong direction	1 – Human failure 2 – Mechanical failure	Potential collision of canister with internal wall of shield bell leading to radioactive release	1 – CTM design 2 – Procedures and training	N/A	TWF-202
8.7	Direction (CTM)	(Other Than) Bridge impacts end stops	1 – Human failure 2 – Mechanical failure	Potential collision of canister with internal wall of shield bell leading to radioactive release	1 – CTM design 2 – Procedures and training	N/A	TWF-202
8.8	Direction (CTM)	(Other Than) Trolley impacts end stops	1 – Human failure 2 – Mechanical failure	Potential collision of canister with internal wall of shield bell leading to radioactive release	1 – CTM design 2 – Procedures and training	N/A	TWF-202
8.9	Direction (CTM)	(Other Than) Canister Bridge impacts other bridge	1 – Human failure 2 – Mechanical failure	Potential collision of canister with internal wall of shield bell leading to radioactive release	1 – CTM design 2 – Procedures and training	N/A	TWF-202
8.10	Miscellaneous (CTM)	(Other Than) Lid not properly stored	Human failure	Potential collision of canister with internal wall of shield bell leading to radioactive release	1 – Facility design 2 – Procedures and training	N/A	TWF-202
8.11	Miscellaneous (CTM Crane)	(No) Two-blocking of CTM Crane	1 – Human failure 2 – Mechanical failure	Potential canister drop leading to radioactive release	1 – CTM design 2 – Procedures and training	N/A	TWF-201
8.12	Miscellaneous (CTM Crane)	(No) Crane malfunction	1 – Human failure 2 – Mechanical failure	Potential canister drop leading to radioactive release	1 – CTM Crane design 2 – Procedures and training	N/A	TWF-201
8.13	Miscellaneous (Canister Grapple)	(No) Grapple malfunction	1 – Human failure 2 – Mechanical failure	Potential canister drop leading to radioactive release	1 – CTM Crane design2 – Procedures and training	N/A	TWF-201

NOTE: Guidewords not used in this node: Reverse, As Well As, and Part Of.
CTM = canister transfer machine; TWF = typical waste-handling facility; MLD = master logic diagram; N/A = not applicable.

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 CTM moving too fast (Node Item Number 8.1) is assigned the MLD index number TWF-202, and the deviation entailing two-blocking (Node Item Number 8.11) is assigned the MLD index number TWF-201. Referring again to the MLD, Figure 9, these MLD index numbers are denoted for two initiating events, and the deviations identified in the HAZOP appear as contributors. "CTM moves too fast" is a contributor identified under TWF-202, and "Two-blocking of CTM crane" is a contributor for TWF-201. Such correlations between the HAZOP and MLD confirm the completeness of the MLD, verifies the thoroughness of the analysis, and provides confidence that other quantification produce reliable outcomes.

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

Table 7. Interfaces between Master Logic Diagram and the Hazard and Operability Study for Typical Waste-Handling Facility (with Emphasis on Initiating Event Relevant to Horizontal Canister Transfer Machine Operations)

MLD Index #	Contributor/ Deviation	Event Cause	Consequence	Originally Included in MLD	Added to MLD from HAZOP
TWF-201	Two-blocking of crane	Human or mechanical failure	Potential canister drop leading to radioactive release	Y	N/A
TWF-201	Crane malfunction	Human or mechanical failure	Potential canister drop leading to radioactive release	Y	N/A
TWF-201	Grapple malfunction	Human or mechanical failure	Potential canister drop leading to radioactive release	Y	N/A
TWF-202	CTM moves too fast	Human or mechanical failure	Potential collision of canister with internal wall of shield bell leading to radioactive release	Y	N/A
TWF-202	CTM stuck	Human or mechanical failure	Potential radioactive release due to heat-up/fire	Y	N/A
N/A	CTM moves too slow	Human or mechanical failure	None	N	N/A
TWF-202	CTM moves too far	Human or mechanical failure	Potential collision of canister with internal wall of shield bell leading to radioactive release	Y	N/A
N/A	CTM does not move enough	Human or mechanical failure	None	N	Y

Table 7. Interfaces between Master Logic Diagram and the Hazard and Operability Study for Typical Waste-Handling Facility (with Emphasis on Initiating Event Relevant to Horizontal Canister Transfer Machine Operations) (Continued)

MLD Index #	Contributor/ Deviation	Event Cause	Consequence	Originally Included in MLD	Added to MLD from HAZOP
TWF-202	CTM moves in wrong direction	Human or mechanical failure	Potential collision of canister with internal wall of shield bell leading to radioactive release	Y	N/A
TWF-202	Canister bridge impacts end stops	Human or mechanical failure	Potential collision of canister with internal wall of shield bell leading to radioactive release	Y	N/A
TWF-202	Trolley impacts end stops	Human or mechanical failure	Potential collision of canister with internal wall of shield bell leading to radioactive release	Y	N/A
TWF-202	Canister bridge impacts other bridge	Human or mechanical failure	Potential collision of canister with internal wall of shield bell leading to radioactive release	Y	N/A
TWF-202	Lid not properly stored	Human failure only	Potential collision of canister with internal wall of shield bell leading to radioactive release	Y	N/A

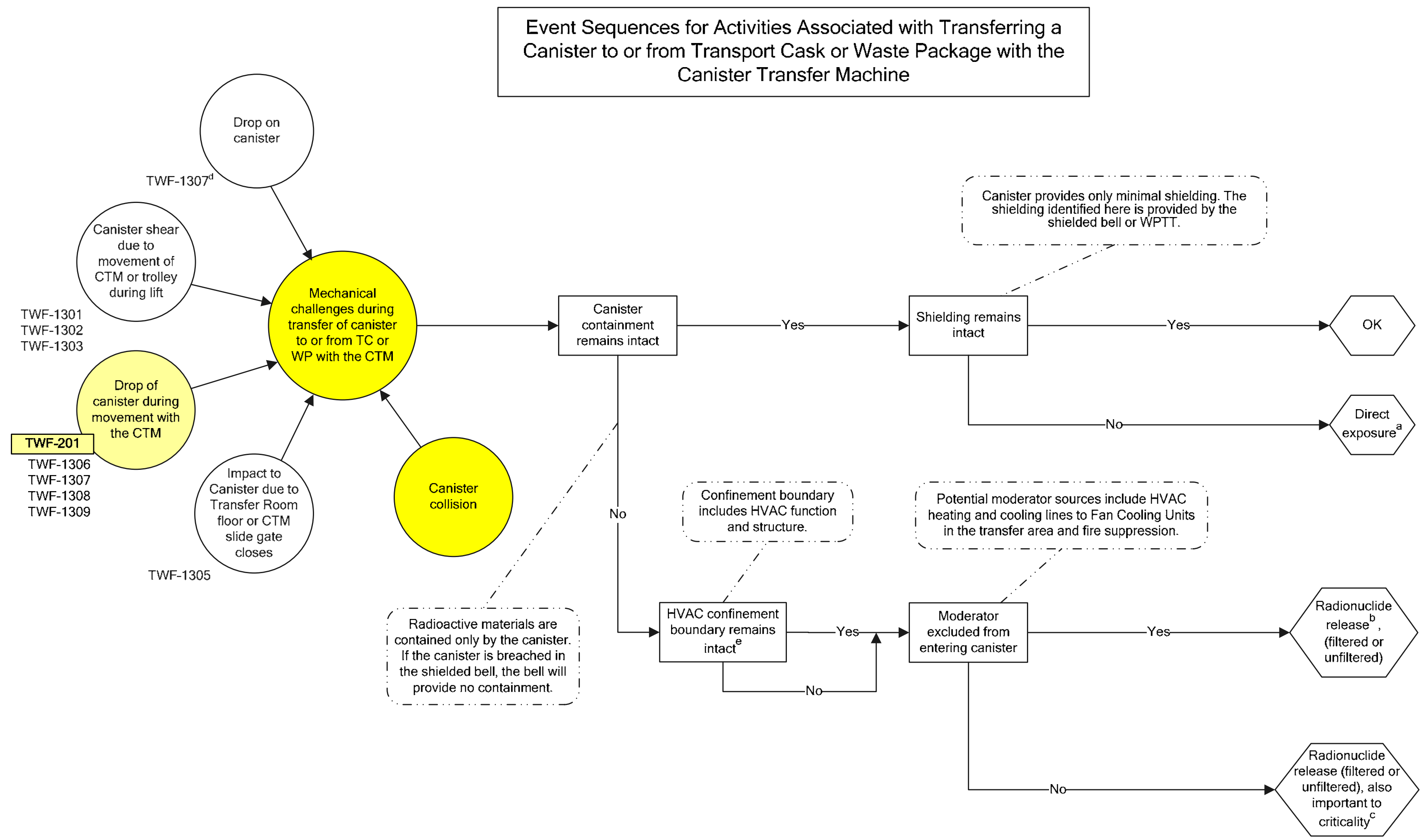
NOTE: CTM = canister transfer machine; HAZOP = hazard and operability; MLD = master logic diagram; TWF = typical waste-handling facility; Y = yes; N = no.

Source: Original

4.3.4.4 Event Sequence Diagram Development

After the HAZOP and MLD results are correlated and the MLD is complete, analysts group initiating events by initiator types, system response, and waste form. 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 on this grouping ESD development can begin.

As detailed in Section 4.3.2.1 and as shown in Figure 11, the ESDs are a graphical communication tool to aid the understanding of the initiating events and the later development of the event trees. An ESD is read left to right: initiating events (bubbles), through pivotal events (success or failure) (rectangles), to end states (hexagons). The small bubbles 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 bubble because events and system responses from different operational nodes are often the same. The set of small bubbles on an ESD shares the same system responses (pivotal events), but each small bubble has a unique set of probabilities for these system responses. (Refer also to Section 4.3.2.2.)



NOTE: [a] "Direct exposure" is that condition where individuals are directly exposed to the radiation beam streaming through areas where shielding has been compromised.

[b] "Radionuclide release" describes a condition where radioactive material has been released from the container creating an inhalation or ingestion hazard that is accompanied by the dose received from emersion in the plume, and direct exposure, as described above.

[c] "Radionuclide release, Also Important to Criticality" describes a condition in which (a) the containment boundaries, such as canister and cask containment, have been compromised, releasing radioactive material and (b). liquid moderator is present and may enter the canister.

[d] TWF numbers next to the smaller bubbles are references to the TWF MLD.

[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

Potential for fire analyzed in fire ESDs.
Canister striking structures results in a drop.
For sequence involving two containers, failure path of pivot event "one canister breached" represents the breach of two canisters.
CTM = canister transfer machine; ESD = event sequence diagram; HVAC = heating, ventilation, and air-conditioning; MLD = master logic diagram, TC = transportation cask; TWF = typical waste-handling facility; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure 11. Event Sequence for Activities Associated with Transferring a Canister to or from Transportation Cask or Waste Package with the Canister Transfer Machine

If events are grouped for a small bubble on an ESD, the relevant MLD index numbers are listed adjacent to the small bubble. For example, for the CTM transfer operations in the TWF, a canister drop can occur during vertical movement or during horizontal movement. These events are reviewed for different operational nodes and therefore appear in different sections of the MLD. However, because both are describing a canister drop, they have the same system responses. Table 8 provides a brief description of the initiating events encompassed in the small bubble "Drop of canister during movement with the CTM" (Figure 11).

Table 8. Initiating Event Descriptions for Event Sequence Diagram for Typical Waste-Handling Facility

MLD Index Number	Initiating Event Text from MLD	Contributors Identified on MLD
TWF-201	Canister drops in shield bell during move	Two-blocking of CTM crane Operator error Crane or grapple malfunction.
TWF-1306	CTM wire cable is cut resulting in dropped canister	CTM shield bell slide gates closes on cable Floor slide gate closes on cable.
TWF-1307	Exposures from dropped or impacted canister due to human failure	WP misaligned with port Load too heavy (e.g., CTM lifting more than canister) Canister lifted too high Grapple improperly attached Canister not lifted high enough to clear floor during lifting Canister not lowered enough to clear second floor during lowering.
TWF-1308	Canister lifting crane motor fails to stop, damaging or dropping canister	Control system malfunction Improper crane maintenance.
TWF-1309	Canister drops in shield bell due to brake, cable, or hook malfunction	Mechanical failure Improper crane maintenance.

NOTE: CTM = canister transfer machine; MLD = master logic diagram; TWP = typical waste-handling facility; WP = waste package.

Source: Original

Following the flow of the ESD to the right, one can see that the small bubbles point to a central, large bubble. The large bubble represents the aggregated initiating event. Each small bubble on an ESD can be considered a subset of the large bubble. Because each small bubble represents an initiating event with a unique frequency, the large bubble is an aggregated initiating event. As is discussed in the *RF Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1), categorization of initiating events is based on the aggregated initiating event (i.e., large bubble).

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 bubbles, however, is necessary because the conditional probability of pivotal events in the system response event tree differs for each small bubble. To obtain the proper event sequence frequency, therefore, it is necessary to quantify the event sequences emanating from each small bubble.

Continuing to the right, the path from the large bubble is the logical progression of an event sequence through each pivotal event (displayed as boxes). For the initiating events in Figure 11, the analyst considers the possible events that might follow. For example, if a structural insult to the canister occurred, what could happen? The canister might breach, or it might remain intact. This is an important distinction, and the analyst identifies this as the first pivotal event.

The analyst looks at the success and failure of this first pivotal event to determine either a next pivotal event or, if no pivotal event is identified, then an end state. Following the success branch for canister containment in the example (Figure 11), assuming the canister does not breach, radioactive material cannot be released. However, the analyst recognizes that the shielding could be compromised even if the canister remains intact and, therefore, determines that the state of the shielding after the insult is the next pivotal event. Either success or failure for the shielding results in an end state as follows. If the shielding remains intact, the end state is “OK.” If the shielding does not remain intact, the identified end state is Direct Exposure.

This process is continued for each pivotal event, considering paths for success and failure for each, leading either to one or more consecutive pivotal events or to an end state. Explanatory annotations on the ESD are included by the analyst to elucidate the meaning of events. As seen in the ESD for the example facility, TWF, the analyst follows this logical progression for each path, identifying canister containment, HVAC confinement, and shielding as system responses. Also identified is a unique pivotal event that represents a condition, moderator ingress, which is used as the basis for the identification of event sequences as important to criticality. These events are described briefly below:

- **Canister Containment**. First opportunity for exposure (radiological release) in normal operating conditions.

- **Shielding**. If the canister successfully contains the radiological material, failure of the shielding presents the next opportunity for exposure (via direct shine to workers).

- **HVAC Confinement**. If the canister containment fails, the success of the HVAC system filters exposure to radionuclides; alternatively, failure leads to unfiltered exposure.

- **Moderator Ingress**. If a condition arises in which a moderator (e.g., water from fire suppression system) is present but is successfully isolated from the waste form by, for example, the canister’s containment barrier or if moderator is not present, then a release that is Also Important to Criticality is avoided. If moderator is present and able to contact the waste form, a potential for criticality exists. Note that failure to prevent moderator ingress does not imply an inevitable criticality event, but rather indicates that further analysis must be done to show either that the event sequence will not result in criticality or that the event sequence is Beyond Category 2.

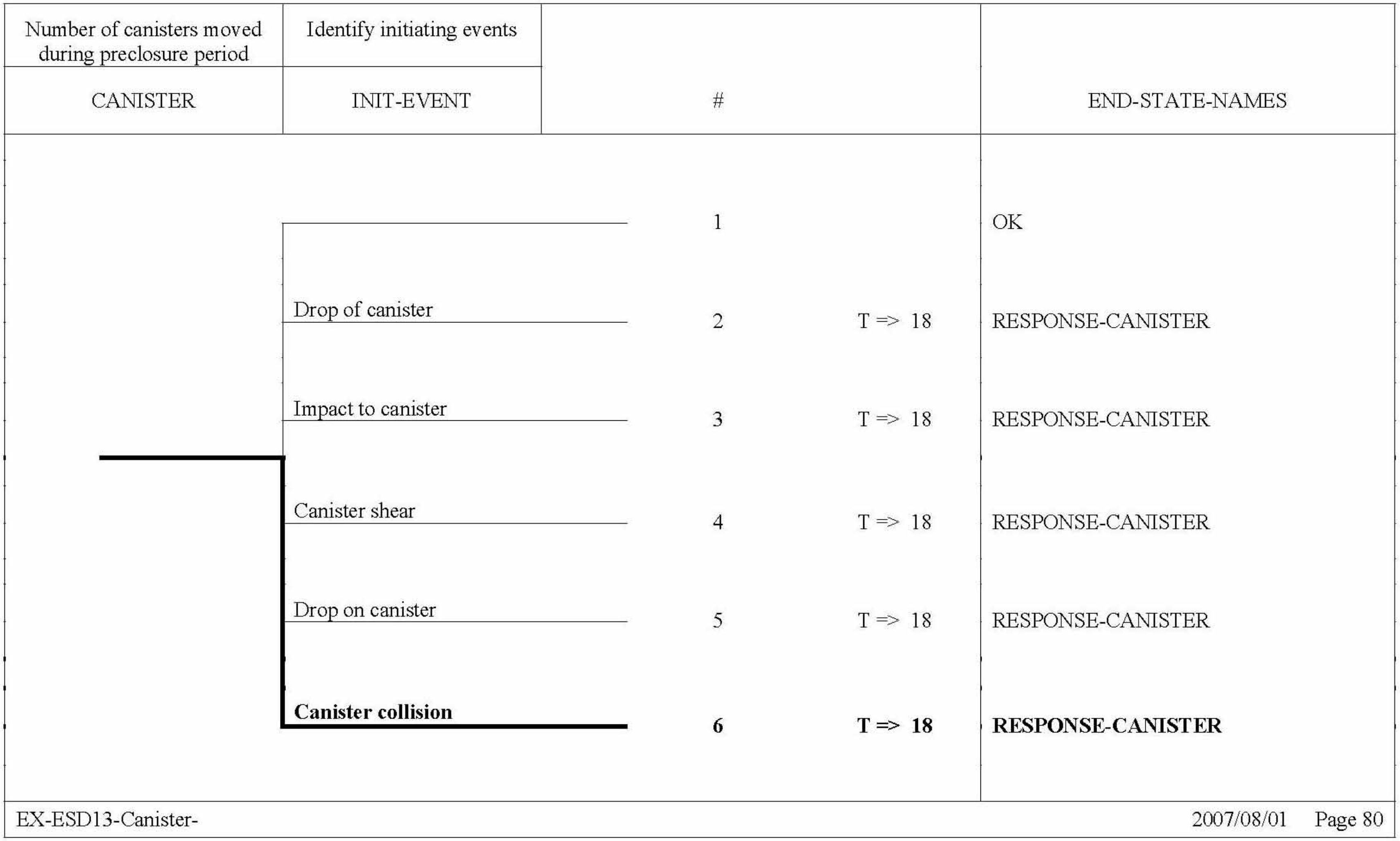
4.3.4.5 Event Tree Development

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

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

Table 8 shows the initiating events for the ESD developed in Figure 11. Each small bubble on the ESD in Figure 11 is represented by a branch on the initiator event tree (Figure 12). The label on a small bubble is in its corresponding branch on the initiator event tree. Each branch is expanded further in the system response event tree, using success/failure criteria for each pivotal event (Figure 13) of the ESD. Note that, as seen in Figure 12, the first branch in an initiator event tree is the branch that represents success for each pivotal event; therefore, the end state for this branch is always "OK." The typical convention used to develop the remaining branches is that the upper branch in a split represents success and the lower branch represents failure. As shown in Figure 11 for the example facility, the analyst expands the "Canister collision" event through each pivotal event until an end state is achieved for each combination of pivotal events.

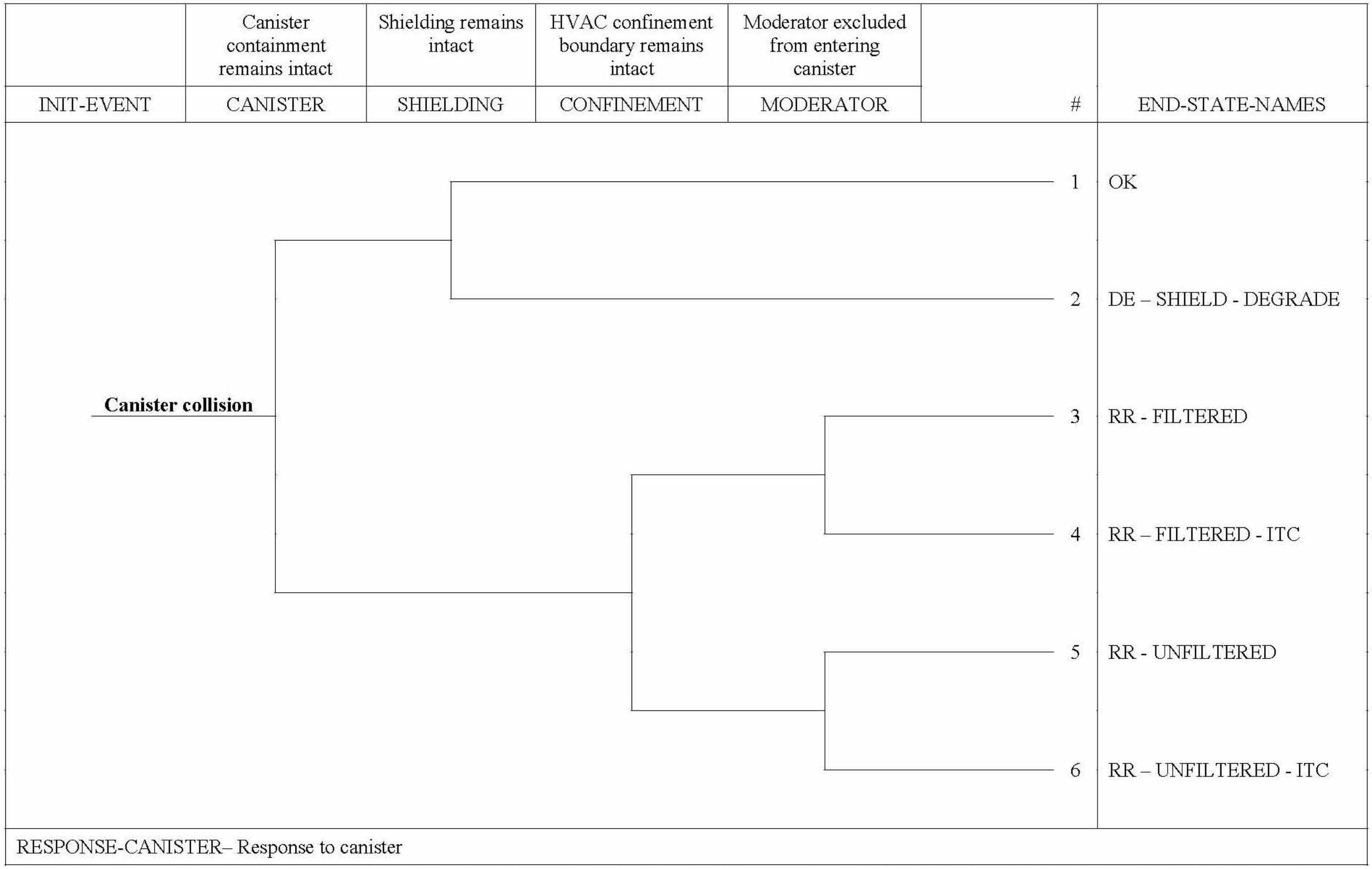
For additional details regarding the development of ESDs and event trees, refer to Section 4.3.2.



NOTE: INIT = initiating

Source: Original

Figure 12. Initiator Event Tree for a Typical Waste-Handling Facility (Canister Collision involving Canister Transfer Machine)



NOTE: INIT = initiating; ITC = Important to Criticality; RAD = radiation; DE = Direct Exposure; RR = Radiation Release; SHIELD = Shielding; DEGRADE = Degraded.

Source: Original

Figure 13. System Response Event Tree for a Typical Waste-Handling Facility (Canister Collision Involving Canister Transfer Machine)

5. LIST OF ATTACHMENTS

6. BODY OF CALCULATION

6.1 INITIATING EVENT ANALYSIS

6.1.1 Introduction

Initiating events are identified for the Yucca Mountain Project (YMP) using MLDs that are verified with a HAZOP as described in Section 4. Each phase of the operations within the RF is analyzed to ensure that a comprehensive list of initiators was identified. These initiators are identified at a level for which historical data exists, 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, which are identified in *Monitored Geologic Repository External Events Hazards Screening Analysis* (Ref. 2.2.5), include natural phenomena such as tornado, earthquakes, flooding, lightning, etc., and activities external to the GROA such as aircraft crash, nearby industrial facilities, etc.; or (b) internal events, which include events that could occur randomly within the facility, 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 due to human failure), and fires or flooding events. These initiating events are depicted in the MLD.

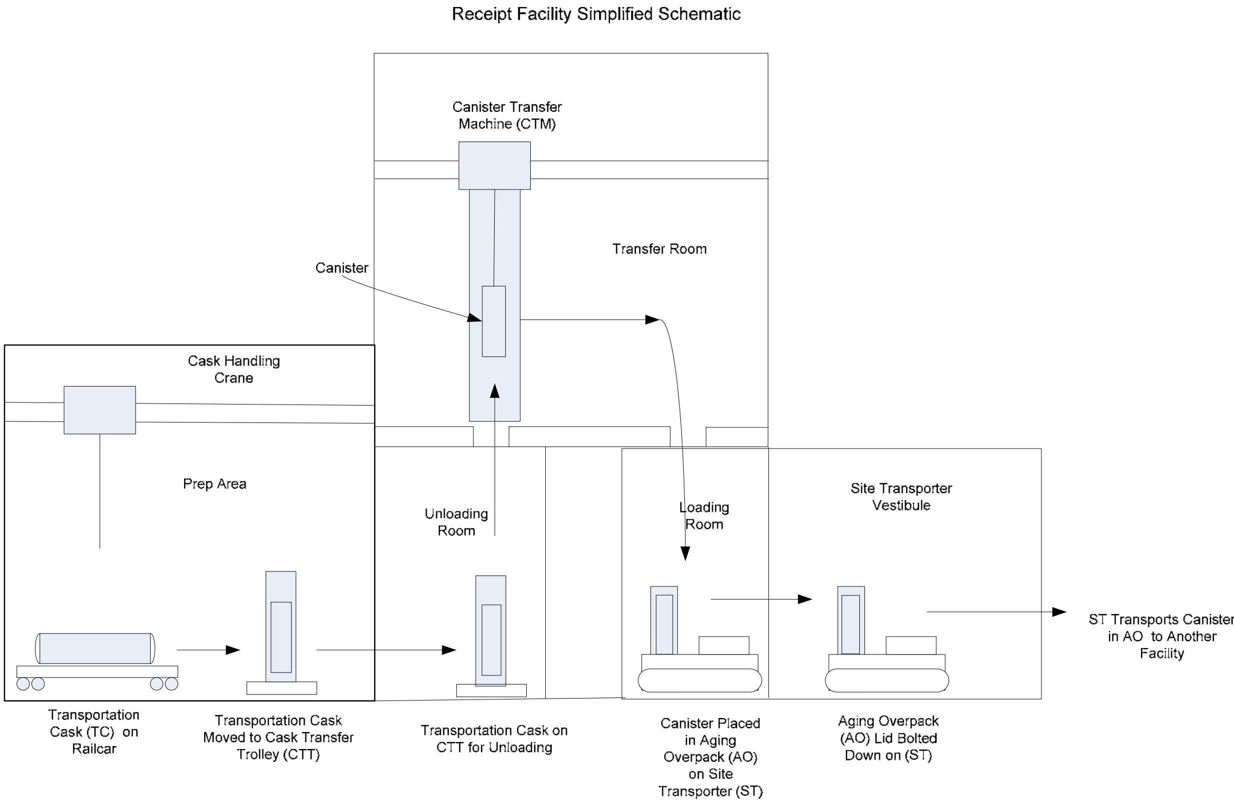
6.1.2 Overview of Receipt Facility and Its Operations

Consistent with the methodology discussed in Sections 4.3.1.1 and 4.3.4.1, this section contains a brief overview of the RF and its operations. The overview 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. The location of the RF within the GROA is shown in Attachment C.

The RF provides handling capability for a portion of the U.S. Department of Energy (DOE) managed waste stream. The waste stream for the RF is limited to TAD canisters and DPCs that contain commercial spent nuclear fuel (CSNF) and arrive in national transportation system transportation casks on railcars. As illustrated in Figure 14, the RF primary function is to receive rail-based transportation casks loaded with TAD canisters or DPCs, open the casks, remove the canisters, and transfer them into aging overpacks for delivery to the WHF, Canister Receipt and Closure Facility (CRCF) or the Aging Facility. It also transfers HTCs to a cask transfer trailer for movement to the Aging Facility for further handling. Once the canisters are removed, the transportation cask is restored and returned to the national transportation system.

The RF will only conduct simple crane and canister transfer machine operations to transfer canisters. The RF will only perform mechanical closure of aging overpacks as no welding is required for closure of these systems.

The RF also provides space for cask tractor and cask trailer to prep and receive transportation casks that are never upended (HTCs) (Ref. 2.2.9).



NOTE: This simplified conceptual depiction is not to scale.

Source: Original

Figure 14. Schematic Diagram of RF Mechanical Handling Operations

The RF is a multilevel reinforced concrete structure with shear walls and shield walls approximately four feet thick. The shield walls protect personnel from exposure during the operations for which a bare canister or waste package may be present in the facility. The roof is also reinforced concrete. The elevated concrete operating floor of the Canister Transfer Room forms the ceiling of a portion of the concrete cell structure. Shield doors in the concrete shield walls and shield gates in the ports that connect the lower rooms to the Canister Transfer Room provide radiation protection when bare canisters are present.

The RF HVAC system is designed to maintain the indoor environmental condition required for the health and safety of the facility workers and to limit the release of radioactive airborne contaminants for the protection of the public, facility workers, and the environment. Areas within the facility with the highest potential for contamination are maintained at the lowest negative pressure to ensure that air flows progressively from the areas of least potential contamination to the areas of highest potential contamination. The exhaust air from confinement areas of the building is passed through a single stage of high efficiency particulate air (HEPA) filters prior to discharging to the atmosphere at an elevated release point.

The operational summary continues with Section 6.1.2.1, and is organized according to the nodes, which are indicated in the PFD (Figure 15). The summary is based primarily on the Level 3 mechanical handling block flow diagram for the RF. The specific pages of the block flow diagram that are used as primary sources for each node are cited at the end of each node's operational description. The general arrangement drawings for the RF and other references have also been used and are cited as needed for information that is not found in the block flow diagram.

Attachment B provides more details on the operation of the RF.

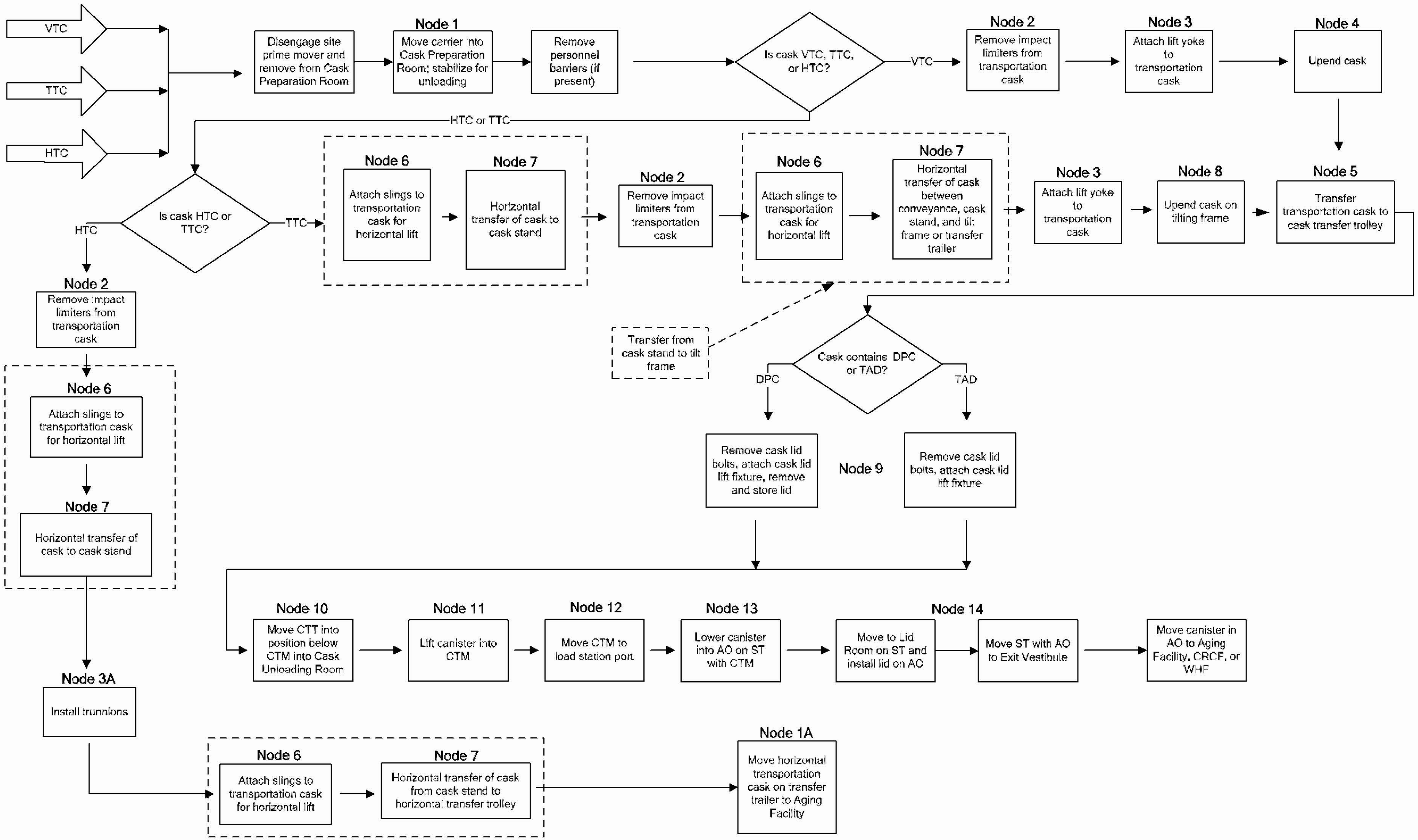
6.1.2.1 Node 1: Receive and Move a Transportation Cask on a Railcar into Preparation Area for Unloading

The RF serves two different objectives. The first is to receive and transfer waste forms consisting entirely of DPCs and TAD canisters from transportation casks to aging overpacks for movement to other waste handling facilities or the Aging Facility (HLW, Naval, CSNF and DOE SNF are not handled in the RF). These casks are referred to as VTCs or TTCs, depending on how they are upended for unloading. The second involves the transfer of a cask from a railcar to a transport vehicle known as the cask transfer trailer that is then transported from the RF to the Aging Facility. These types of casks are referred to as HTCs. Each of these casks is received and prepared for unloading in the same manner as described in this node.

A loaded transportation cask on a railcar is moved by a prime mover from the rail yard to the RF. (The term "prime mover" generically identifies the vehicle that is used to move the railcar from the rail yard to the RF.)

The railcar carrying the cask is brought into the facility through the Transportation Cask Vestibule, the Transportation Cask Vestibule Annex, and the Cask Preparation Annex to the Cask Preparation Room. A door opens to allow passage from the Transportation Cask Vestibule, the Transportation Cask Vestibule Annex, and the Cask Preparation Annex to the Cask Preparation Room. Once the railcar with the cask is parked and secured in the correct position in the preparation area, the prime mover is disconnected and moved to the vestibule and the doors separating these areas are closed (Ref. 2.2.27). If personnel barriers are present on the transportation cask after the cask is received in the RF, they are removed at this point using the auxiliary hook on the cask transfer crane (Ref. 2.2.25).

This node describes blocks 1.1.1 and 1.1.2 on the *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.41).



NOTE: AO = aging overpack; CRCF = Canister Receipt and Closure Facility; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; HTC = a transportation cask that is never upended; ST = site transporter; TAD = transportation, aging, and disposal canister; TTC = a transportation cask that is upended using a tilt frame; VTC = a transportation cask that is upended on a railcar; WHF = Wet Handling Facility.

Source: Original

Figure 15. RF Process Flow Diagram

6.1.2.2 Node 1A: Move Horizontal Transportation Cask on Transfer Trailer Out of Preparation Area

HTCs are moved from the RF to the Aging Facility using the horizontal cask transfer trailer after the cask has been transferred from the railcar to the cask transfer trailer via the cask stand. This is accomplished by lifting the HTC off of the railcar in a horizontal orientation and placing it on the horizontal cask transfer trailer. Once the cask is secured to the trailer it is towed out of the RF to the Aging Facility (Ref. 2.2.7) and (Ref. 2.2.8) This is described in nodes 2, 7, and 3A.

This node describes the transfer arrow “TO AGING FACILITY” on the *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 3* (Ref. 2.2.42).

6.1.2.3 Node 2: Remove Impact Limiters from Transportation Cask

Node 2 on the process flow diagram covers removal of the impact limiters from the cask. This activity occurs at different times in the receipt and unloading process, depending on the cask type. Casks that can be upended on the railcar (VTCs) and the HTC, which must be horizontally transferred off of the railcar with slings, have their impact limiters removed while the cask is still on the railcar. In these instances operators use the mobile access platform (Ref. 2.2.15) and (Ref. 2.2.16) to access the impact limiters for removal. Cask clamps and tie-downs, which secure the cask to the carrier, are removed followed by the removal of the impact limiters using the cask handling crane auxiliary hook and the mobile access platform. The TTC, however, must be horizontally transferred to a cask stand before the impact limiters are removed. Access to the impact limiters on the cask stand will be provided by an industrial scissors lift (Ref. 2.2.27), (Ref. 2.2.31), and (Ref. 2.2.33).

The MAP is a rail-mounted structure that bridges over the cask on the railcar (Ref. 2.2.15) and (Ref. 2.2.16). The MAP includes two adjustable platforms to provide access by personnel to different features on the cask (e.g., personnel barriers, impact limiters, etc.). Both platforms move vertically up the legs of the platform on each side. Each platform includes a platform extension that moves the full length of the platform and can be extended out from the platform to access the centerline of the cask.

This node describes blocks 1.1.4 and 1.1.10 on sheet 2 and block 1.2.1 on sheet 3 of the *Receiving Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.41) and *Sheet 3* (Ref. 2.2.42).

6.1.2.4 Node 3: Attach Lift Yoke to Transportation Cask

For casks upended on the railcar or casks that must be horizontally transferred to the tilting frame for upending (TTC), a yoke is attached to the cask handling crane. It is then lifted into position above the cask and the arms of the yoke are adjusted to engage the lift trunnions on the cask for upending the cask (Ref. 2.2.17).

This node describes equipment supporting block 1.1.7 on the *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.41).

Node 3A: Install Trunnions on HTC Transportation Cask on Cask Stand

HTCs are horizontally transferred to the cask stand as described in nodes 6 and 7. While on the cask stand, trunnions are installed on the cask that will both support the cask on the cask transfer trailer and anchor the cask against the force of the hydraulic ram that is used at the aging pad to horizontally slide the canister out of the HTC and into a horizontal aging module (HAM).

This node describes block 1.2.4 on the *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 3* (Ref. 2.2.42).

6.1.2.5 Node 4: Upend Transportation Cask on Railcar

The cask handling crane is used to upend a cask while it is on the railcar. The cask handling yoke is attached to lift trunnions at one end of the cask. Trunnions on the other end of the cask are released so they can rotate about their support point. The crane is then slowly moved perpendicular to the axis of rotation as the yoke is raised to keep the lift cable vertical.

This node describes block 1.1.7 on the *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.41).

6.1.2.6 Node 5: Transfer Transportation Cask to Cask Transfer Trolley

The cask is transferred by the cask handling crane to the CTT in a vertical orientation and secured to the CTT. The CTT is an air-based carrier that floats on an air film (Ref. 2.2.59).

This node describes block 1.3.1 on the *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 4* (Ref. 2.2.43).

6.1.2.7 Node 6: Attach Slings to Transportation Cask for Horizontal Lift

Both TTCs and HTCs are removed from the railcar with the cask long axis oriented horizontally. This is accomplished using lift slings attached to a horizontal lifting beam suspended from the cask handling crane. The slings are rigged around the cask securing it to the lift beam (Ref. 2.2.36).

This node is covered under standard rigging equipment listed under block 1.1.9 on sheet 2 and block 1.2.3 on sheet 3 of the *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.41) and *Sheet 3* (Ref. 2.2.42).

6.1.2.8 Node 7: Horizontal Transfer of Cask between Conveyance, Cask Stand, and Lift Frame or Transfer Trailer

HTCs and TTCs are lifted off of the railcar in a horizontal orientation and transferred to the cask stand (Ref. 2.2.35) for removal of impact limiters from the TTC or installation of trunnions on the HTC.

Once the impact limiters are removed, the TTC is then horizontally transferred to a tilting frame (Ref. 2.2.14) for upending and movement in a vertical orientation to the CTT as described in Node 5.

After trunnions are installed on the HTC, it is transferred in a horizontal orientation to the horizontal cask transfer trailer for transport to the Aging Facility.

This node describes blocks 1.1.9 and 1.1.11 on sheet 2 and blocks 1.2.3 and 1.2.5 on sheet 3 of *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.41) and *Sheet 3* (Ref. 2.2.42).

6.1.2.9 Node 8: Upend Cask on Tilting Frame

The TTC is transferred to the tilting frame as described in Node 7, where it is upended using the cask handling crane. After the cask is transferred and the lift slings have been removed, the cask is secured to the tilting frame. The lifting slings and the horizontal lifting beam are removed from the cask handling crane and the cask handling yoke is attached. The yoke is then maneuvered into position and connected to the cask trunnions for upending. Once the cask is upright, the cask is released from the tilting frame and transferred to the cask transfer trolley as described in Node 5.

This node describes block 1.1.13 on the *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.41).

6.1.2.10 Node 9: Prepare Cask for Unloading

Casks are prepared for removal of the canister (unloading) in two ways, depending on whether the canister in the cask has a lift fixture as an integral part of the canister top. If the canister does not have an integral lift fixture, one must be attached to the top of the canister before it can be removed from the cask.

For casks containing canisters that do not already have a lift fixture as part of the canister (DPCs), the cask lid must be unbolted, a cask lid lift fixture installed and the lid removed, and the canister lift fixture installed before the cask is moved into the Cask Unloading Room. Shielding of the cask canister annulus while the canister lift fixture is installed is provided by the cask preparation platform and the platform shield plate. After the canister lift fixture is installed, the cask is moved with the cask lid removed on the cask transfer trolley into the Cask Unloading Room.

TAD canisters have a lift fixture as an integral part of the canister, consequently, the lid is only unbolted and a cask lid lift fixture installed prior to movement into the Cask Unloading Room where the cask lid is removed by the canister transfer machine in preparation for transferring the canister to an aging overpack.

This node is describes block 1.3.3 through 1.3.8 on the *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 4* (Ref. 2.2.43).

6.1.2.11 Node 10: Move CTT into Cask Unloading Room

After the cask has been prepared for unloading, the CTT is used to move the loaded transportation cask from the Cask Preparation Room to the Cask Unloading Room. Opening and closing the Cask Unloading Room shield door is required in this node.

This node describes block 1.3.9 on the *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 4* (Ref. 2.2.43).

6.1.2.12 Node 11: Remove Canister from Cask using CTM

For a cask containing a DPC, the cask lid has been removed. For casks containing TAD canisters, the cask lid is still in place, though its bolts have been removed and a cask lid lift fixture installed. In both cases, the CTM is moved into position over the cask, the shield skirt is lowered, and the CTM slide gate and the cask port slide gate are opened (Ref. 2.2.6); (Ref. 2.2.30); (Ref. 2.2.12); (Ref. 2.2.31); and (Ref. 2.2.32).

For removal of either a cask lid or a canister, the appropriate exchangeable grapple must be attached to the CTM (Ref. 2.2.10); (Ref. 2.2.11); and (Ref. 2.2.18).

For a cask containing a TAD canister, when the CTM is correctly positioned the grapple is lowered and engages the cask lid and transfers it to a staging location in the Canister Transfer Room.

At this point both TAD canister and DPC lift fixtures are accessible by the CTM. The CTM grapple is lowered and engages the canister that is then lifted into the CTM shield bell. After the canister is lifted into the shield bell, the CTM slide gate and the cask port slide gate are closed.

The primary function of the CTM is to transfer the canister from a transportation cask to an aging overpack. It also is used to remove cask lids from casks containing TAD canisters and to place the lid on loaded aging overpacks. The CTM is located on the second floor in the Canister Transfer Room. The CTM is mounted on a pair of rails on top of bridge girders. The CTM has an integrated trolley mechanism with a shield compartment (or bell) capable of retaining a canister in place while moving from port to port. The shield-bell trolley consists of a shield bell with an integrated structural frame and trolley mechanism. A sliding shield gate is provided at the bottom of the bell. The trolley mechanism is able to move along the span of the bridge girders to position the shield bell over the floor openings. A skirt on the bottom of the bell can be lowered to provide shielding of the gap between the bell and the floor when the CTM is in position to lift a canister.

This node describes blocks 2.1.2 through 2.1.4 of *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 5* (Ref. 2.2.44) and blocks 2.1.5 through 2.1.11 of *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 6* (Ref. 2.2.45).

6.1.2.13 Node 12: Move CTM Laterally

The horizontal movement of the CTM carries the canister from a position over the cask port to a position above the loading port and an empty aging overpack on a site transporter (Ref. 2.2.31) and (Ref. 2.2.32).

This node describes block 2.1.13 on the *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 6* (Ref. 2.2.45).

6.1.2.14 Node 13: Lower Canister from CTM into Aging Overpack

Once the CTM is in position over the aging overpack port, the CTM skirt is lowered, the CTM slide gate and the aging overpack port slide gate are opened. Next, the canister is lowered into the aging overpack, then the CTM grapple is disengaged and raised, and the port slide gate and the CTM slide gate are closed.

This node describes block 2.1.15 on the *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 6* (Ref. 2.2.45).

6.1.2.15 Node 14: Move Loaded Aging Overpack on Site Transporter Out of Receipt Facility

After the CTM loads the canister into the aging overpack, it retrieves the aging overpack lid from a storage location on the Canister Transfer Room floor and places it on the aging overpack. Next the aging overpack with the unbolted lid in place is moved into the Lid Bolting Room. The aging overpack is then positioned so that workers can access the aging overpack lid from the Lid Bolting Room platform. The aging overpack lid is then bolted to the aging overpack. Once the aging overpack lid is bolted down, the aging overpack is removed from the RF for transfer to the aging pad.

This node describes blocks 1.5.1 through 1.5.3 on the *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 7* (Ref. 2.2.46).

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 RF are provided in Attachment D and E, respectively.

To facilitate ESD development, a unique identification number has been assigned to each initiating event. The numbers consist of “R-” 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, “R-312” means “initiating event 12 on the page 3 of the MLD” and “R-1207” means “initiating event 07 on page 12 of the MLD.” A slightly different convention has been used differentiate internal fire and flood and external events from internal events. A prefix “E” is used to designate external events and a prefix of “I” is used to designate internal fire and flood events. No prefix is used for internal events. Thus, “R-E202” means external initiating event 02 on page 2 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	Initiating Event Description

Identifier	
R-E201	Exposure due to seismic events
R-E202	Non-seismic geologic activity (including landslides, avalanches)
R-E203	Volcanic activity
R-E204	High winds/tornadoes (including wind effects from hurricanes)
R-E205	External floods
R-E206	Lightning
R-E207	Loss of power events
R-E208	Loss of cooling capability event (non-power cause, including biological events)
R-E209	Aircraft crash
R-E210	Nearby industrial/military facility accidents (including transportation accidents)
R-E211	Onsite hazardous materials release
R-E212	External fires (including forest fires, grass fires)
R-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 #
R-101	Exposure due to RC derailment leading to cask drop	D-1	E-2, E-13	F-1
R-102	Exposure due to RC collision leads to impact	D-1	E-2	F-1
R-103	Exposure due to horizontal cask transfer trailer collision with loaded RC, CTT, or suspended cask during movement into facility to receive HTC for transfer to aging pad	D-1		F-1
R-I301	Internal flooding caused by piping failure	D-3		
R-I302	Internal flooding caused by actuation of fire protection system	D-3		
R-I303	Exposure due to large fire affecting the entire facility	D-3	E-2, E-2A, E-3, E-4, E-4A, E-5, E-7, E-8, E-9, E-15	F-12
R-I304	Localized fire threatens TAD/AO in Vestibule/Lid Bolting Room (diesel present)	D-3	E-2, E-2A, E-3, E-4, E-4A, E-5, E-7, E-8, E-9, E-15	F-12
R-I305	Localized fire threatens TAD/AO in Loading Room (diesel present)	D-3	E-2, E-2A, E-3, E-4, E-4A, E-5, E-7, E-8, E-9, E-15	F-12
R-I306	Localized fire threatens TC/TAD or TC/DPC in Vestibule/Preparation Area (diesel present)	D-3	E-2, E-2A, E-3, E-4, E-4A, E-5, E-7, E-8, E-9, E-15	F-12
R-I307	Localized fire threatens TC/TAD or TC/DPC in Preparation Area	D-3	E-2, E-2A, E-3, E-4, E-4A, E-5, E-7, E-8, E-9, E-15	F-12
R-I308	Localized Fire Threatens Waste Form in Preparation Area	D-3	E-2, E-2A, E-3, E-4, E-4A, E-5, E-7, E-8, E-9, E-15	F-12
R-I309	Localized fire threatens waste form in Cask Unloading Room	D-3	E-2, E-2A, E-3, E-4, E-4A, E-5, E-7, E-8, E-9, E-15	F-12
R-I310	Localized fire threatens TAD or DPC in Transfer Room	D-3	E-2, E-2A, E-3, E-4, E-4A, E-5, E-7, E-8, E-9, E-15	F-12
R-I311	Exposure due to excessive temperature (excluding internal fire events)	D-3		
R-401	CTM crane drops object onto canister prior to attachment of grapple	D-4		F-6
R-501	Cask handling crane malfunction causes TC drop	D-5	E-4, E-5	F-2

Table 10. List of Internal Initiating Events (Continued))

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
R-502	Cask handling crane causes unplanned conveyance movement	D-5	E-5	F-2
R-503	Unplanned conveyance movement while crane is attached to TC or conveyance fixtures	D-5	E-5	F-2
R-504	Cask handling crane drops object on TC	D-5	E-4	F-2
R-505	Unplanned conveyance movement prior to cask clearing pedestals	D-5	E-6	F-2
R-506	Cask handling crane drops cask	D-5	E-6	F-2
R-507	Cask handling crane drops object on cask	D-5		F-2
R-508	Cask collides with object while being moved by cask handling crane	D-5	E-6	F-2
R-509	Impact from platform operations	D-5	E-4	F-2
R-510	Cask tips and drops after placed onto CTT	D-5		F-2
R-601	Unplanned conveyance movement prior to clearing pedestals leads to side impact of cask	D-6		F-2
R-602	Cask handling crane drops TC	D-6		F-2
R-603	Cask handling crane drops object on cask	D-6	E-7	F-2
R-604	TC collides with object during movement by cask handling crane leads to a cask drop	D-6		F-2
R-605	Impact due to platform operations	D-6		F-2
R-606	Auxiliary hook drops load on cask	D-6	E-4A	F-2
R-607	Cask handling crane malfunction causes cask stand to roll over	D-6	E-4A	F-2
R-608	Cask handling crane drops cask	D-6	E-7, E-8	F-2
R-609	Cask handling crane drops object on cask	D-6		F-2
R-610	Cask collides with object while being moved by cask handling crane	D-6	E-8	F-2
R-611	Auxiliary hook drops load on TC	D-6	E-3	F-2
R-612	Unplanned conveyance movement while crane is attached to TC or conveyance fixtures leading to a rollover	D-6		F-2
R-613	Cask handling crane malfunction causes cask conveyance to roll over	D-6	E-3	F-2
R-614	Impact from MAP operations	D-6	E-3	F-2
R-701	Unplanned conveyance movement prior to clearing pedestals leads to side impact of cask	D-7	E-7	F-2
R-702	Cask handling crane drops TC	D-7		F-2
R-703	Cask handling crane drops object on cask	D-7	E-7	F-2
R-704	TC collides with object during movement by cask handling crane leads to a cask drop	D-7	E-7	F-2
R-705	Impact due to platform operations	D-7	E-7	F-2
R-706	Auxiliary hook drops load on cask	D-7		F-2

Table 10. List of Internal Initiating Events (Continued))

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
R-707	Cask handling crane malfunction causes cask stand to roll over	D-7		F-2
R-801	Cask handling crane drops cask	D-8	E-8	F-2
R-802	Cask handling crane drops object on cask	D-8	E-8	F-2
R-803	Cask collides with object while being moved by cask handling crane resulting in side impact	D-8	E-8	F-2
R-804	Cask tilting frame failure leads to cask drop	D-8	E-9	F-2
R-805	Cask handling crane drops object on cask	D-8		F-2
R-806	Cask handling crane malfunction leads to cask drop	D-8	E-9	F-2
R-807	Cask handling crane drops cask	D-8	E-6, E-9	F-2
R-808	Cask handling crane drops object on cask	D-8		F-2
R-809	Cask collides with object while being moved by cask handling crane leading to side impact	D-8	E-6, E-9	F-2
R-810	Impact due to platform operations	D-8	E-9	F-2
R-901	Operation of auxiliary crane hook leads to cask tipover	D-9		F-3
R-902	Auxiliary crane hook drops object onto cask	D-9	E-10	F-3
R-903	Cask handling crane causes impact to side of cask	D-9	E-10	F-3
R-904	Failure to close cask preparation platform shield plates	D-9		F-10
R-905	Cask impact resulting from unplanned movement of CTT during installation of cask lid lift fixture	D-9		F-3
R-906	Inadvertent opening of cask preparation platform shield plates	D-9		F-10
R-1001	Heavy load dropped onto the cask or canister	D-10	E-10	F-3
R-1002	Main hook interferes with auxiliary hook resulting in cask tipover	D-10	E-10	F-3
R-1003	Lid binds during removal leads to cask tipover	D-10	E-10	F-3
R-1004	Auxiliary hook malfunction/mis-operation catches and tips over CTT leading to cask impact	D-10	E-10	F-3
R-1005	Auxiliary hook malfunction/mis-operation leads to impact to side of cask	D-10	E-10	F-3
R-1006	Collision between CTT and another moving vehicle, facility structures, or facility equipment leads to cask impact	D-10		F-3
R-1007	Spurious movement of CTT with crane attached to lid leads to cask damage	D-10		F-3
R-1008	Failure to close cask preparation platform shield plates	D-10	E-10	F-10

Table 10. List of Internal Initiating Events (Continued))

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
R-1009	Inadvertent opening of cask preparation platform shield plates	D-10		F-10
R-1101	Cask Unloading Room shield door closes against CTT leads to cask impact	D-11	E-11	F-5
R-1102	Collision with facility structures or equipment during movement leads to cask impact	D-11	E-11	F-4
R-1103	CTT or cask catches crane hook or rigging during movement leads to cask impact	D-11	E-11	F-4
R-1104	CTM drops object onto cask or canister	D-11	E-12	F-6
R-1105	Lid binds during removal leads to dropped cask	D-11	E-12	F-6
R-1201	Temporary loss of shielding while the canister is lifted from the cask into the CTM shield bell or lowered from the CTM shield bell into a container	D-12	E-12, E-14	F-11
R-1202	Canister drops from CTM shield bell during move	D-12	E-12	F-6
R-1203	Canister collision due to CTM malfunction leading to impact	D-12	E-12, E-13	F-6
R-1204	ST moves while loading	D-12	E-14	F-6
R-1205	CTT moves during cask unloading	D-12	E-12	F-6
R-1206	Spurious movement of CTM bridge or trolley	D-12		F-6
R-1207	Canister strikes port edge, CTM slide gate, or wall leading to canister drop	D-12	E-12, E-14	F-6
R-1208	Side impact to canister during lift	D-12	E-12, E-14	F-6
R-1209	CTM wire rope cut resulting in canister drop	D-12	E-12, E-14	F-6
R-1210	Canister drop into CTM shield bell (with CTM slide gate closed) due to CTM malfunction	D-12	E-12, E-14	F-6
R-1211	CTM failure or mis-operation leading to canister impact or drop	D-12	E-12, E-14	F-6
R-1301	CTM drops lid onto loaded AO in Loading Room	D-13	E-14	F-7
R-1302	CTM movement while lid is low enough to catch AO or ST	D-13		F-6
R-1303	Spurious movement of ST with CTM attached to lid	D-13		F-7
R-1304	Shield door shuts against ST carrying AO	D-13		F-5, F-7
R-1305	Collision between ST and facility structures or equipment	D-13	E-15	F-5, F-7
R-1306	Exposure due to collision involving the ST and another vehicle, facility structures, or equipment during movement within facility	D-13	E-15	F-5, F-7
R-1307	Exposure resulting from Lid Bolting Room crane dropping object on AO	D-13		F-7
R-1308	Exposure from crane interference with ST causing AO drop from ST	D-13		F-7

Table 10. List of Internal Initiating Events (Continued))

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
R-1401	Exposure due to dropped AO	D-14		F-8
R-1402	Exposure due to collision involving the ST and another vehicle, facility structures, or equipment	D-14		F-5, F-8
R-1403	Exposure resulting from ST rollover	D-14	E-15	F-8
R-1404	Exposure due to collision involving the cask transfer trailer and another vehicle, facility structures, or equipment	D-14	E-2A	F-5, F-9
R-1405	Exposure due to CT trailer rollover or load drop during loading and export	D-14	E-4A	F-9

NOTE: "Diesel present" denotes the presence of diesel fuel.
AO = aging overpack; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose container; HTC = a transportation cask that is never upended; MAP = mobile access platform; RC = railcar; ST = site transporter; TAD = transportation, aging, and disposal canister; TC = transportation cask; TTC = a transportation cask that is upended using a tilt frame.

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 (Figures F-1 through F-12). Sections 6.2.2 through 6.2.13 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 logic.
- A summary description of each event sequence embodied in the ESD.

6.2.2 RF-ESD-01: Event Sequences for Activities Associated with Receipt of Transportation Cask into Cask Preparation Room

6.2.2.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the transportation cask that occurs in the Cask Preparation Room before removal of the impact limiters from the transportation cask (Figure F-1 and Section 6.1.2.1, Node 1). This includes event sequences that arise during receipt of a transportation cask on a railcar. This ESD applies to the following waste forms:

- Transportation cask containing one DPC received on a railcar.

- Transportation cask containing one TAD canister received on a railcar.

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 two groups (represented as little bubbles), as follows:

1. Railcar derailment
2. Railcar collision.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a structural challenge to the transportation cask that occurs in the Cask Preparation Room before removal of the impact limiters from the transportation cask.

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 (given that the impact limiters are still in place). Determining whether or not the containment boundary of the transportation cask remains intact 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 transportation cask shielding remains intact, as posed by the next pivotal event. Degradation of shielding in lead-shielded casks could occur due to a "slumping effect" as the result of an impact. 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 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. 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 deformation of shielding caused by cask breach. Otherwise, the containment boundary of both the cask and the canister have been breached and a Radionuclide Release occurs. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion.

First, a pivotal event asks whether the HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility, exclusive of any areas designated as a vestibule or vestibule annex, along with the HVAC ducting, exhaust fans, and filter plenums. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule are closed. When these doors are closed, flow paths within the facility ensure any release exhausts through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release. If HVAC confinement is not maintained, the release is considered unfiltered.

The remaining pivotal 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 filtered or unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or 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 entry of moderator to the canister internals in the dry handling facilities as the means of criticality prevention. 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. 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 (little bubble), the ESD in Figure F-1 delineates seven event sequences. The ESD shows five end states (not all of them different):

1. "OK"
2 Direct exposure
3 Direct exposure
4. Radionuclide Release
5. Radionuclide Release, Also Important to Criticality.

The end states that correspond to radioactive release are further developed to indicate whether HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered). Therefore, the ESD traces seven event sequences as follows:

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 deformation of cask shielding results in Direct Exposure.

4. Cask containment fails, canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a Filtered Radionuclide Release.

5. Cask containment fails, canister containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an Unfiltered Radionuclide Release.

6. Cask containment fails, canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a Filtered Radionuclide Release, Also Important to Criticality.

7. Cask containment fails, canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an Unfiltered Radionuclide Release, Also Important to Criticality.

6.2.3 RF-ESD-02: Event Sequences for Activities Associated with Removal of Impact Limiters, Cask Upending, and Transfer to CTT or Cask Transfer Trailer

6.2.3.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the transportation cask that occurs in the Cask Preparation Room during removal of impact limiters, upending, and transfer of the cask to the CTT or cask transfer trailer (Figure F-2 and Sections 6.1.2.3, Node 2; 6.1.2.4, Node 3; 6.1.2.5, Node 4; 6.1.2.6, Node 5; 6.1.2.7, Node 6; 6.1.2.8, Node 7; and 6.1.2.9, Node 8). This ESD applies to the following waste forms:

- Transportation cask containing one DPC received on a railcar.
- Transportation cask containing one TAD canister received on a railcar.

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 six groups (represented as little bubbles), as follows:

1. Transportation cask dropped at operational height.
2. Transportation cask dropped above operational height.
3. Unplanned conveyance movement causes drop.
4. Heavy load dropped on transportation cask.
5. Collision involving side impact.
6. Cask tip over or drop while on cask tilting frame or in CTT.

The groups are summarized by a generic initiating event, which is represented by the big bubble in the ESD. The big bubble represents a structural challenge to the transportation cask that occurs in the Cask Preparation Room during removal of impact limiters, upending and transfer of the cask to the CTT.

6.2.3.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the containment boundary of the transportation cask remains intact (given that the impact limiters have been removed). Determining whether or not the containment boundary of the transportation cask remains intact 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 transportation cask shielding remains intact, as posed by the next pivotal event. Degradation of shielding in lead-shielded casks could occur due to a "slumping effect" as the result of an impact. 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 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. 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 deformation of shielding caused by cask breach. Otherwise, the containment boundary of both the cask and the canister have been breached and a Radionuclide Release occurs. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion.

First, a pivotal event asks whether the HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility, exclusive of any areas designated as a vestibule or vestibule annex, along with the HVAC ducting, exhaust fans, and filter plenums. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule are closed. When these doors are closed, flow paths within the facility ensure any release exhausts through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release. If HVAC confinement is not maintained, the release is considered unfiltered.

The remaining pivotal 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 filtered or unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or 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 in the dry handling facilities as the means of criticality prevention. 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. 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 (little bubble), the ESD in Figure F-2 delineates seven event sequences. The ESD shows five end states (not all of them different):

1. "OK"
2 Direct exposure

3 Direct exposure
4. Radionuclide Release
5. Radionuclide Release, Also Important to Criticality.

The end states that correspond to radioactive release are further developed to indicate whether HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered). Therefore, the ESD traces seven event sequences as follows:

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

2. Cask containment remains intact, but deformation of cask shielding results in Direct Exposure.

3. Cask containment fails, canister containment remains intact, but implied deformation of cask shielding results in Direct Exposure.

4. Cask containment fails, canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a Filtered Radionuclide Release.

5. Cask containment fails, canister containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an Unfiltered Radionuclide Release.

6. Cask containment fails, canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a Filtered Radionuclide Release, Also Important to Criticality.

7. Cask containment fails, canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an Unfiltered Radionuclide Release, Also Important to Criticality.

6.2.4 RF-ESD-03: Event Sequences Associated with Unbolting and Lid Adapter Installation)

6.2.4.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to a transportation cask that occurs in the Cask Preparation Room during cask preparation activities involving the auxiliary hook on the cask handling crane (Figure F-3 and Section 6.1.2.10, Node 9). This ESD applies to the following waste forms:

- Transportation cask containing one DPC.
- Transportation cask containing one TAD canister

6.2.4.2 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 little bubbles), as follows:

1. Transportation cask dropped.
2. Side impact to transportation cask.
3. Drop of heavy load onto transportation cask.
4. Transportation cask tipover.

The groups are summarized by an aggregated initiating event, which is represented by the big bubble in the ESD. The big bubble represents a structural challenge to the transportation cask that occurs in the Cask Preparation Room during cask preparation activities involving the cask handling crane.

6.2.4.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the containment boundary of the transportation cask remains intact (given that the impact limiters have been removed). If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the transportation cask shielding remains intact, as posed by the next pivotal event. Degradation of shielding in lead-shielded casks could occur due to a "slumping effect" as the result of an impact. 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 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. 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 deformation of shielding caused by cask breach. Otherwise, the containment boundary of both the cask and the canister have been breached and a Radionuclide Release occurs. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion.

First, a pivotal event asks whether the HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility, exclusive of any areas designated as a vestibule or vestibule annex, along with the HVAC ducting, exhaust fans, and filter plenums. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule are closed. When these doors are closed, flow paths within the facility ensure any release exhausts through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release. If HVAC confinement is not maintained, the release is considered unfiltered.

The remaining pivotal 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 filtered or unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or an Unfiltered Radionuclide Release that must be further evaluated with respect to criticality (which is indicated as Also Important to Criticality).

In summary, for each waste form and each initiating event group (little bubble), the ESD in Figure F-3 delineates seven event sequences. The ESD shows five end states (not all of them different):

1. "OK"
2 Direct exposure
3 Direct exposure
4. Radionuclide Release
5. Radionuclide Release, Also Important to Criticality.

The end states that correspond to radioactive release are further developed to indicate whether HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered). Therefore, the ESD traces seven event sequences as follows:

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

2. Cask containment remains intact, but deformation of cask shielding results in Direct Exposure.

3. Cask containment fails, canister containment remains intact, but implied deformation of cask shielding results in Direct Exposure.

4. Cask containment fails, canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a Filtered Radionuclide Release.

5. Cask containment fails, canister containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an Unfiltered Radionuclide Release.

6. Cask containment fails, canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a Filtered Radionuclide Release, Also Important to Criticality.

7. Cask containment fails, canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an Unfiltered Radionuclide Release, Also Important to Criticality.

6.2.5 RF-ESD-04: Event Sequences Associated with Transfer of a Cask on CTT from Cask Preparation Room to Cask Unloading Room

6.2.5.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to a loaded cask transfer trolley that occurs during a transfer from the Cask Preparation Room to the Cask Unloading Room (Figure F-4 and Section 6.1.2.11, Node 10). This ESD applies to the following waste forms:

- Transportation cask containing one DPC on a cask transfer trolley.
- Transportation cask containing one TAD canister on a cask transfer trolley.

6.2.5.2 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 little bubbles), as follows:

1. CTT or cask catches crane hook or rigging resulting in impact to cask.
2. CTT collision with another vehicle, facility structures, or equipment (excluding shield door).

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a structural challenge during movement of a loaded CTT from the Cask Preparation Room to the Cask Unloading Room. The cask lid has been unbolted and the cask does not provide containment.

6.2.5.3 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 transportation cask remains intact 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. 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. For a cask, slumping of the shield wall could occur from the structural challenge. 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 subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion.

First, a pivotal event asks whether the HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility, exclusive of any areas designated as a vestibule or vestibule annex, along with the HVAC ducting, exhaust fans, and filter plenums. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure any release exhausts through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release. If HVAC confinement is not maintained, then the release is considered unfiltered.

The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or 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 in the dry handling facilities as the means of criticality prevention. 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. 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 (little bubble), the ESD in Figure F-4 delineates six event sequences. The ESD shows five end states (not all of them different):

1. “OK”
2 Direct exposure
3 Direct exposure
4. Radionuclide Release
5. Radionuclide Release, Also Important to Criticality.

The end states that correspond to radioactive release are further developed to indicate whether HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered). Therefore, the ESD traces six event sequences as follows:

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

2. Canister containment remains intact, but deformation of cask or aging overpack shielding results in Direct Exposure.

3. Canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented resulting in a Filtered Radionuclide Release.

4. Canister containment fails, HVAC confinement fails, and moderator intrusion is prevented resulting in an Unfiltered Radionuclide Release.

5. Canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented resulting in a Filtered Radionuclide Release, Also Important to Criticality.

6. Canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented resulting in an Unfiltered Radionuclide Release, Also Important to Criticality.

6.2.6 RF-ESD-05: Event Sequences Involving CTT or Site Transporter Collisions with Shield Doors

6.2.6.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to a cask or aging overpack resulting from a collision with a shield door. Collisions of this nature can occur when a transportation cask is transferred from the Cask Preparation Room to the Cask Unloading Room on a CTT or an aging overpack is transferred from the Loading Room to the Lid Bolting room on an aging overpack. These activities are depicted in Figure F-5 of Attachment F and are described in Section 6.1.2.11 (Node 10) and 6.1.2.15 (Node 14) of this document. This ESD applies to the following waste forms:

- Transportation cask containing one DPC on a cask transfer trolley.
- Transportation cask containing one TAD canister on a cask transfer trolley.
- Aging overpack containing one DPC on a site transporter.
- Aging overpack containing one TAD canister on a site transporter.

6.2.6.2 Initiating Events

The initiating events identified in the MLD are shown on the ESD as collisions involving either the CTT carrying a cask and the Cask Unloading Room shield door or a site transporter carrying an aging overpack and the Loading Room door.

These collisions could result from the vehicle hitting a shield door or the shield door closing on the vehicle while it is transiting a door opening. This initiating event is represented by the big bubble on the ESD.

6.2.6.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the shield door remains on its tracks and does not fall onto the CTT or site transporter. Determining whether or not the door remains on its track involves uncertainties in both the load imposed on the shield door and the strength of the shield door anchoring design. If the shield door comes off its track and falls onto the CTT or site transporter, the impact to the waste form could be large. If the shield door remains on its track there is still an impact to the waste form from the collision. In either case, whether the canister containment boundary remains intact is questioned to determine if there is a release of radioactive materials. Determining whether or not the containment boundary of the canister remains intact 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 shielding provided by the cask or aging overpack remains intact, as posed by the next pivotal event. Degradation of shielding in lead-shielded casks could occur due to a "slumping effect" as the result of an impact. Loss of shielding in aging overpacks could occur if the aging overpack is cracked open 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 (i.e., for a negative answer to the question posed by the second pivotal event), a Radionuclide Release is postulated. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion.

First, a pivotal event asks whether the HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility, exclusive of any areas designated as a vestibule or vestibule annex, along with the HVAC ducting, exhaust fans, and filter plenums. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule are closed. When these doors are closed, flow paths within the facility ensure any release exhausts through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release. If HVAC confinement is not maintained, the release is considered unfiltered.

The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or 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 in the dry handling facilities as the means of criticality prevention. 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. 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 (little bubble), the ESD in Figure F-5 delineates twelve event sequences. The ESD shows five end states (not all of them different):

1. "OK"
2 Direct exposure
3 Direct exposure
4. Radionuclide Release
5. Radionuclide Release, Also Important to Criticality.

The end states that correspond to radioactive release are further developed to indicate whether HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered). This would make six end states, except that, they are all further categorized depending upon whether the door remains on its tracks. Therefore, the ESD traces twelve event sequences as follows:

1. Shield door remains on its track, canister containment boundary and transportation cask or aging overpack shielding remain intact (no radiation exposure).

2. Shield door falls off its track and crashes on CTT, canister containment boundary and transportation cask or aging overpack shielding remain intact (no radiation exposure).

3. Shield door remains on its track, canister containment remains intact, but deformation of cask or aging overpack shielding causes Direct Exposure.

4. Shield door falls off its track and crashes on CTT, canister containment remains intact, but degradation of cask or aging overpack shielding causes Direct Exposure.

5. Shield door remains on its track, canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented resulting in a Filtered Radionuclide Release.

6. Shield door falls off its track and crashes on cask or aging overpack, canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented resulting in a Filtered Radionuclide Release.

7. Shield door remains on its track, canister containment fails, HVAC confinement fails, and moderator intrusion is prevented resulting in an Unfiltered Radionuclide Release.

8. Shield door falls off its track and crashes on cask or aging overpack, canister containment fails, HVAC confinement fails, and moderator intrusion is prevented resulting in an Unfiltered Radionuclide Release.

9. Shield door remains on its track, canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented resulting in a Filtered Radionuclide Release, Also Important to Criticality.

10. Shield door falls off its track and crashes on cask or aging overpack, canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented resulting in a Filtered Radionuclide Release, Also Important to Criticality.

11. Shield door remains on its track, canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented resulting in an Unfiltered Radionuclide Release, Also Important to Criticality.

12. Shield door falls off its track and crashes on cask or aging overpack, canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented resulting in an Unfiltered Radionuclide Release, Also Important to Criticality.

6.2.7 RF-ESD-06: Event Sequences for Activities Associated with the Transfer of a Canister from Transportation Cask to Aging Overpack with CTM

6.2.7.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the canister that occurs during a transfer with the CTM. This includes event sequences that arise during lifting canisters into the CTM, moving the loaded CTM to the Loading Room port, and lowering the canister into an aging overpack (Figure F-6 and Sections 6.1.2.12, Node 11; 6.1.2.13, Node 12; and 6.1.2.14, Node 13). This ESD applies to the following waste forms:

- DPC being handled by the CTM.
- TAD canister being handled by the CTM.

6.2.7.2 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 seven groups (represented as little bubbles), as follows:

1. Transportation cask impact associated with lid removal.
2. Drop of an object onto canister.
3. Canister impact due to movement of the CTM, CTT, or site transporter during lift.
4. Canister dropped at an operational height.
5. Canister dropped above operational height.
6. Canister dropped inside the CTM.
7. Collision or impact to canister.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. This big bubble represents a structural challenge to the canister that occurs during transfer to or from a transportation cask or aging overpack with the CTM.

6.2.7.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the containment boundary of the canister remains intact. Determining whether or not the containment boundary of the transportation cask remains intact 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. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the shielding provided by the CTM shield bell 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 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 subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion.

First, a pivotal event asks whether the HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility, exclusive of any areas designated as a vestibule or vestibule annex, along with the HVAC ducting, exhaust fans, and filter plenums. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure any release exhausts through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release. If HVAC confinement is not maintained, then the release is considered unfiltered.

The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or 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 in the dry handling facilities as the means of criticality prevention. 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. 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 (little bubble), the ESD in Figure F-6 delineates six event sequences. The ESD shows five end states (not all of them different):

1. “OK”
2 Direct exposure
3 Direct exposure
4. Radionuclide Release
5. Radionuclide Release, Also Important to Criticality.

The end states that correspond to radioactive release are further developed to indicate whether HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered). Therefore, the ESD traces six event sequences as follows:

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

2. Canister containment remains intact, but loss of CTM shielding results in Direct Exposure.

3. Canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented resulting in a Filtered Radionuclide Release.

4. Canister containment fails, HVAC confinement fails, and moderator intrusion is prevented resulting in an Unfiltered Radionuclide Release.

5. Canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented resulting in a Filtered Radionuclide Release, Also Important to Criticality.

6. Canister Containment fails, HVAC confinement fails, and moderator intrusion is not prevented resulting in an Unfiltered Radionuclide Release, Also Important to Criticality.

6.2.8 RF-ESD-07: Event Sequences for Activities Associated with Assembly and Closure of an Aging Overpack

6.2.8.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the aging overpack that occurs during assembly and closure. This includes events associated with movement of the aging overpack from the Loading Room to the Lid Bolting Room (Figure F-7 and Section 6.1.2.15, Node 14). This ESD applies to the following waste forms:

- Aging overpack containing a DPC.
- Aging overpack containing a TAD canister.

6.2.8.2 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 little bubbles), as follows:

1. Collision between the site transporter and facility structures or equipment.
2. Object dropped on aging overpack.
3. Aging overpack impact.
4. Crane mishap results in aging overpack tipover.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a structural challenge to the aging overpack during assembly and closure.

6.2.8.3 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 transportation cask remains intact 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. 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 cracked open 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 subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion.

First, a pivotal event asks whether the HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility, exclusive of any areas designated as a vestibule or vestibule annex, along with the HVAC ducting, exhaust fans, and filter plenums. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure any release exhausts through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release. If HVAC confinement is not maintained, then the release is considered unfiltered.

The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or 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 in the dry handling facilities as the means of criticality prevention. 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. 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 (little bubble), the ESD in Figure F-7 delineates six event sequences. The ESD shows five end states (not all of them different):

1. "OK"
2 Direct exposure
3 Direct exposure
4. Radionuclide Release
5. Radionuclide Release, Also Important to Criticality.

The end states that correspond to radioactive release are further developed to indicate whether HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered). Therefore, the ESD traces six event sequences as follows:

1. Canister containment and shielding remain intact (no radiation exposure).
2. Canister containment remains intact, but loss of aging overpack shielding results in Direct Exposure.
3. Canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented resulting in a Filtered Radionuclide Release.
4. Canister containment fails, HVAC confinement fails, and moderator intrusion is prevented resulting in an Unfiltered Radionuclide Release.
5. Canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented resulting in a Filtered Radionuclide Release, Also Important to Criticality.
6. Canister Containment fails, HVAC confinement fails, and moderator intrusion is not prevented resulting in an Unfiltered Radionuclide Release, Also Important to Criticality.

6.2.9 RF-ESD-08: Event Sequences for Activities Associated with the Exporting of an Aging Overpack from the RF

6.2.9.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the aging overpack that occurs while it is being exported from the RF (Figure F-8 and Section 6.1.2.15, Node 14. This ESD applies to the following waste forms:

- Aging overpack containing a DPC.
- Aging overpack containing a TAD canister.

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 three groups (represented as little bubbles), as follows:

1. Aging overpack dropped from the site transporter.
2. Collision involving the site transporter and another vehicle, facility structures, or facility equipment excluding shield doors, which is covered in ESD-05.
3. Site transporter rollover.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a structural challenge during exporting of aging overpacks from the RF.

6.2.9.3 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 transportation cask remains intact 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. 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 cracked open 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 subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion.

First, a pivotal event asks whether the HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility, exclusive of any areas designated as a vestibule or vestibule annex, along with the HVAC ducting, exhaust fans, and filter plenums. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure any release exhausts through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release. If HVAC confinement is not maintained, then the release is considered unfiltered.

The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or 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 in the dry handling facilities as the means of criticality prevention. 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. 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 (little bubble), the ESD in Figure F-8 delineates six event sequences. The ESD shows five end states (not all of them different):

1. "OK"
2 Direct exposure
3 Direct exposure
4. Radionuclide Release
5. Radionuclide Release, Also Important to Criticality.

The end states that correspond to radioactive release are further developed to indicate whether HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered). Therefore, the ESD traces six event sequences as follows:

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

2. Canister containment remains intact, but loss of aging overpack shielding results in Direct Exposure.

3. Canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented resulting in a Filtered Radionuclide Release.

4. Canister containment fails, HVAC confinement fails, and moderator intrusion is prevented resulting in an Unfiltered Radionuclide Release.

5. Canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented resulting in a Filtered Radionuclide Release, Also Important to Criticality.

6. Canister Containment fails, HVAC confinement fails, and moderator intrusion is not prevented resulting in an Unfiltered Radionuclide Release, Also Important to Criticality.

6.2.10 RF-ESD-09: Event Sequences for Activities Associated with Export of Horizontal Cask on Cask Transfer Trailer

6.2.10.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to a HTC during movement out of the RF on the cask transfer trailer (Figure F-9 and Section 6.1.2.2, Node1A).

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 two groups (represented as little bubbles), as follows:

- Cask transfer trailer rollover.
- Cask transfer trailer collision.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a structural challenge to the cask that occurs during movement of the cask out of the RF on the cask transfer trailer.

6.2.10.3 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 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 transportation cask shielding remains intact, as posed by the next pivotal event. Degradation of shielding in lead-shielded casks could occur due to a "slumping effect" as the result of an impact. 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 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. 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 deformation of shielding caused by cask breach. Otherwise, the containment boundary of both the cask and the canister have been breached and a Radionuclide Release occurs. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion.

First, a pivotal event asks whether the HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility, exclusive of any areas designated as a vestibule or vestibule annex, along with the HVAC ducting, exhaust fans, and filter plenums. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure any release exhausts through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release. If HVAC confinement is not maintained, the release is considered unfiltered.

The remaining pivotal 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 filtered or unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or 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 in the dry handling facilities as the means of criticality prevention. 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. 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 (little bubble), the ESD in Figure F-9 delineates seven event sequences. The ESD shows five end states (not all of them different):

1. "OK"
2 Direct exposure
3 Direct exposure
4. Radionuclide Release
5. Radionuclide Release, Also Important to Criticality.

The end states that correspond to radioactive release are further developed to indicate whether HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered). Therefore, the ESD traces seven event sequences as follows:

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

2. Cask containment remains intact, but deformation of cask shielding results in Direct Exposure.

3. Cask containment fails, canister containment remains intact, but implied deformation of cask shielding causes Direct Exposure.

4. Cask containment fails, canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a Filtered Radionuclide Release.

5. Cask containment fails, canister containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an Unfiltered Radionuclide Release.

6. Cask containment fails, canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a Filtered Radionuclide Release, Also Important to Criticality.

7. Cask containment fails, canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an Unfiltered Radionuclide Release, Also Important to Criticality.

6.2.11 RF-ESD-10: Event Sequences for Activities Associated with Direct Exposure during DPC Handling Activities

6.2.11.1 Overall Description

This ESD delineates the event sequence that arises after a loss of shielding challenge during cask preparation activities (Figure F-10 and Section 6.1.2.10, Node 9) that would lead to Direct Exposure. This ESD applies to a transportation cask containing a DPC.

6.2.11.2 Initiating Events

The initiating event identified in the MLD is indicated in the big bubble on the ESD as deformation of shielding during cask preparation operations. This ESD only applies to DPC waste forms that require removal of the cask lid, allowing radiation streaming from the cask canister annulus.

6.2.11.3 System Response

No pivotal events identified; the initiator (deformation of shielding) results in a Direct Exposure to radiation.

6.2.12 RF-ESD-11: Event Sequences for Activities Associated with Direct Exposure During CTM Activities

6.2.12.1 Overall Description

The initiating event that is identified in the MLD is presented on the ESD as temporary loss of shielding of CTM shield bell while the canister is being lifted from the cask. This initiating event represents the big bubble on the ESD (Figure F-11 and Sections 6.1.2.12, 6.1.2.13, and 6.1.2.14, Nodes 11, 12, and 13). This ESD applies to all RF waste forms.

6.2.12.2 Initiating Events

The initiating event identified in the MLD is presented on the ESD as temporary loss of shielding of CTM shield bell while the canister is being lifted from the cask. This initiating event represents the big bubble on the ESD.

6.2.12.3 System Response

No pivotal events identified; the initiator (loss of shielding) results in a Direct Exposure to radiation.

6.2.13 RF-ESD-12: Event Sequences for Fire Occurring in Receipt Facility

6.2.13.1 Overall Description

This ESD delineates the event sequences that occur when a fire threatens waste forms in the RF. This includes event sequences that are associated with localized fires that are specific to certain areas of the facility and large fires that affect the entire facility (Figure F-12). There are no specific node associations between this event sequence and the PFD because fire event sequences might occur in any location. This ESD applies to all waste forms in the RF.

6.2.13.2 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 eight groups (represented as little bubbles), as follows:

1. Localized fire threatens TAD canister/aging overpack in Vestibule/Lid Bolting Room (diesel present).
2. Localized fire threatens TAD canister/aging overpack in Loading Room (diesel present).
3. Localized fire threatens transportation cask/aging overpack or transportation cask/DPC in Vestibule/Preparation Area (diesel present).
4. Localized fire threatens transportation cask/aging overpack or transportation cask/DPC in Preparation Area.
5. Localized fire threatens waste form in Preparation Area.
6. Localized fire threatens waste form in Cask Unloading Room.
7. Localized fire threatens TAD canister or DPC (including TTCs) in Transfer Room.
8. Large fires threaten waste forms in RF.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a thermal challenge to a waste form due to fire in the RF.

6.2.13.3 System Response

After a localized or large fire has occurred and the waste form has been thermally challenged, 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 involves uncertainties in both the heat load imposed on the canister and the ability of the canister to resist thermal failure. For each waste form considered (canister in a cask, canister in an aging overpack, bare canister), the thermal analysis considers the configuration of that waste form. For example, even though the pivotal event only specifically addresses the failure of the canister, if a canister is in a transportation cask, the ability of the cask to resist thermal failure and protect the canister contained within is considered in the analysis. If the canister remains intact, Radionuclide Release is avoided; the end state is "OK." Otherwise, the containment boundaries the canister has been breached and a Radionuclide Release is inevitable. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion.

First, a pivotal event asks whether the HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility, exclusive of any areas designated as a vestibule or vestibule annex, along with the HVAC ducting, exhaust fans, and filter plenums. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure any release exhausts through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. An impediment to the ability of the HVAC system to maintain confinement in this instance is the damage that the excessive particulates and hot gases could inflict on the HEPA filters and other components of the HVAC system. If, despite the difficulties inherent in the case of a fire severe enough to cause a Radionuclide Release, HVAC confinement is maintained over the mission time, the release is considered a filtered release. If HVAC confinement is not maintained, the release is considered unfiltered.

The remaining pivotal event provides further delineation by asking 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 would be in abundant supply. In the affirmative case, that is, the absence of moderator intrusion, the filtered or 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 either a filtered or 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 in the dry handling facilities as the means of criticality prevention. 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. Demonstration of subcriticality is not required for event sequences that are beyond Category 2.

No Direct Exposure scenarios are identified for fire events because the fire would normally lead to personnel evacuation. In an extreme case of a fire severe enough to destroy radiation shielding, any personnel that were not evacuated would be injured, possibly severely, by the fire and any need to consider the effects of radiation would be secondary.

In summary, for each waste form and each initiating event group (little bubble), the ESD in Figure F-12 delineates five event sequences. The ESD shows five end states (not all of them different):

1. "OK"
2 Direct exposure
3 Direct exposure
4. Radionuclide Release
5. Radionuclide Release, Also Important to Criticality.

The end states that correspond to radioactive release are further developed to indicate whether HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered). Therefore, the ESD traces five event sequences as follows:

1. Canister containment remains intact (no radiation exposure).

2. Canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented resulting in a Filtered Radionuclide Release.

3. Canister containment fails, HVAC confinement fails, and moderator intrusion is prevented resulting in an Unfiltered Radionuclide Release.

4. Canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented resulting in a Filtered Radionuclide Release, Also Important to Criticality.

5. Canister containment fails, HVAC confinement 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 (little bubble), 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 number of waste forms is different for different waste form types. 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 RF and identifies and develops potential event sequences that could occur in the RF during the preclosure period. The results of this analysis are:

- An MLD for the RF (Attachment D) that identifies potential initiating events for event sequences.
- A set of ESDs for the RF (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
RECEIPT FACILITY 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

As shown in the general arrangement drawings cited in Section A3, the Receipt Facility (RF) is a multistory structure approximately 315 ft wide by 318 ft long and 100 ft high. The waste handling operations take place in the central area of the building covering an area about 74 ft by 196 ft within the confines of the facility. The second floor elevation is 32 ft above grade. The roof of the facility varies in height to accommodate lift heights required by the various cranes inside the facility. Over the Canister Transfer Room, the roof is approximately 100 ft above grade. The roof covering the receipt and preparation area is approximately 75 ft above grade, with the remainder of the second roof at about 67 ft above grade. Figure 14 in Section 6.1.2 provides a schematic representation of the facility and its operations, and Figure 15 provides a simplified process flow diagram.

A3 ROOM AND EQUIPMENT DESCRIPTIONS

Room descriptions for rooms and 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 facility. Important pieces of equipment are covered in the description of the room where the equipment is located or first encountered by the waste form in transit. The descriptions are synthesized, in part, from the following general arrangement drawings:

- *Receipt Facility General Arrangement Legend and General Notes* (Ref. 2.2.28)
- *Receipt Facility General Arrangement Ground Floor Plan* (Ref. 2.2.27*)*
- *Receipt Facility General Arrangement Second Floor Plan* (Ref. 2.2.30)
- *Receipt Facility General Arrangement Third Floor Plan* (Ref. 2.2.34)
- *Receipt Facility General Arrangement Roof Plan* (Ref. 2.2.29)
- *Receipt Facility General Arrangement Plan Sections A and B* (Ref. 2.2.31)
- *Receipt Facility General Arrangement Sections C and D* (Ref. 2.2.32)
- *Receipt Facility General Arrangement Sections E and F* (Ref. 2.2.33).

The RF Level 3 mechanical handling block flow diagram, which occupies several sheets as follows, is also used to synthesize the room and equipment descriptions:

- *Receipt Facility Mechanical Handling System Block Flow Diagram Level 3 Sheet 1 of 10* (Ref. 2.2.40)
- *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.41)
- *Receipt Facility Mechanical Handling System Block Flow Diagram Level 3 Sheet* 3 (Ref. 2.2.42)
- *Receipt Facility Mechanical Handling System Block Flow Diagram Level 3 Sheet* 4 (Ref. 2.2.43)
- *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 5* (Ref. 2.2.44)
- *Receipt Facility Mechanical Handling System Block Flow Diagram Level 3 Sheet 6* (Ref. 2.2.45)
- *Receipt Facility Mechanical Handling System Block Flow Diagram Level 3 Sheet 7* (Ref. 2.2.46)
- *Receipt Facility Mechanical Handling System Block Flow Diagram Level 3 Sheet 8* (Ref. 2.2.47)
- *Receipt Facility Mechanical Handling System Block Flow Diagram Level 3 Sheet 9* (Ref. 2.2.48)
- *Receipt Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 10* (Ref. 2.2.49).

A3.1 CASK PREPARATION ROOM

The Cask Preparation Room (Room 1017) is used to receive by rail, transfer, and prepare loaded transportation casks for unloading, and to export HTCs transferred to a cask transfer trailer to the Aging Facility. Other materials and equipment associated with RF operations are also received by rail or truck in this area. Cask preparation activities, such as removal of impact limiters, transfer of the cask to the CTT or cask transfer trailer, and removal of the cask lid for casks containing DPCs, take place in this room as well. This generally open area occupies the east end of the structure. Crane rails in this area are supported by 4 ft thick reinforced concrete bearing walls surrounding the room.

The following equipment is used in operations performed in the Cask Preparation Room:

Mobile Access Platform

The MAP is a rail-mounted structure that bridges over the cask on the railcar. The MAP includes two adjustable platforms to provide access by personnel to different features on the cask (e.g., personnel barriers, impact limiters, etc.). Both platforms move vertically up the legs of the platform on each side. Each platform includes a platform extension that moves the full length of the platform and can be extended out from the platform to access the centerline of the cask.

This equipment is shown in *CRCF, RF AND WHF Mobile Access Platform Mechanical Equipment Envelope Sheet 1 of 2* (Ref. 2.2.15) and *Sheet 2* (Ref. 2.2.16).

Cask Handling Crane

The function of the cask handling crane is to transfer the transportation cask from the railcar to the CTT. The cask handling crane is a top-running double girder type with a top-running trolley. The cask handling crane has the following design features:

- The main hoist is rated at 200 tons.
- The crane rails are supported by the walls of the Cask Preparation Room.
- The bridge is about 70 ft long spanning the distance between the rails.
- The bridge rails clearance envelope is approximately 81 ft east to west
- The elevation of the rail for the bridge is 45 ft above the floor of the building.

This equipment is shown in *Receipt Facility Cask Handling Crane Mechanical Equipment Envelope* (Ref. 2.2.25).

Cask Handling Yoke

The cask handling yoke is used by the cask handling crane to transfer casks between the railcar and the CTT. The cask handling yoke has an estimated weight of 7.5 tons, and can accommodate a hook load of 200 tons. The yoke has two lifting arms that connect to the trunnions on a cask. The arm positions are adjustable to accommodate different cask diameters.

This equipment is shown in *CRCF, RF, WHF and IHF Cask Handling Yoke Mechanical Equipment Envelope* (Ref. 2.2.17).

Horizontal Lifting Beam

The horizontal lifting beam is used to attach slings to HTCs and VTCs that are lifted with the long axis oriented horizontal instead of vertical as is the case for casks lifted using the cask handling yoke. Slings attached to the beam are placed around the circumference of the cask to support the weight of the cask during the lift.

This equipment is shown in *Receipt Facility Horizontal Lifting Beam Mechanical Equipment Envelope* (Ref. 2.2.36).

Cask Preparation Platform

The cask preparation platform is a stationary steel structure located inside the Cask Preparation Room. The platform is an open rectangular structure that allows the CTT to be moved inside and beneath the top of the platform for processing. The interior side walls, top, and bottom of the structure are shielded to attenuate radiation. The cask lid is accessed through a circular opening through the top of the platform. Shielding for this opening is provided by a sliding shield gate that can be slid back to uncover the opening for placing grapples. Access to lid and grapple bolts during preparations operations is provided by means of a rotating plate in the middle of the slide gate with openings that are lined up with the bolt being accessed. These openings are closed with shield plugs when not in use.

This equipment is shown in *Receipt Facility Cask Preparation Platform Mechanical Equipment Envelope* (Ref. 2.2.26).

Cask Transfer Trolley

The CTT is used for moving the transportation cask in vertical orientation between the Cask Preparation Room and the Cask Unloading Room. The CTT is an air-based conveyance that floats on an air film when activated for movement. The CTT has the following design features:

- Trolley dimensional envelope is approximately 16 ft by 16 ft by 22 ft tall.
- The trolley features a structural metal frame on a platform. Restraining brackets secure the transportation cask within the frame.
- The rated capacity of the trolley is 240 tons.
- To elevate the top of the cask to a height just below the ceiling height of the Cask Unloading Room, an exchangeable pedestal is placed in the bottom of the CTT. Different pedestals are used to accommodate the different cask types.

The equipment is shown in *Cask Transfer Trolley MEE* (Ref. 2.2.59).

Rail-Cask Lid Adapter

The rail cask lid adapter is used to allow the CTM to grapple and remove rail cask lids prior to canister transfer.

This equipment is described in *Nuclear Facilities Rail Cask Lid Adapter Mechanical Equipment Envelope* (Ref. 2.2.23).

A3.2 CASK UNLOADING ROOM

The Cask Unloading Room (Room 1015) provides a shielded location for removal of the canister from the cask. The easternmost room of the concrete cell structure within the RF is the Cask Unloading Room. The room measures approximately 21 ft by 37 ft in plan, with a ceiling height of 33 ft. The walls and roof are 4 ft thick reinforced concrete. The floor is the RF base mat. The south wall is a shield door.

The following equipment is used in operations performed in the Cask Unloading Room:

Cask Port Slide Gate

The cask port, which is the opening through which the canister passes from the cask into the CTM shield bell, is located in the operating deck between the Cask Unloading Room below and Canister Transfer Room above. The cask port slide gate assembly consists of two opposing sliding shield gates mounted on heavy duty bearing blocks and single edge V-slides, a cover plate, and two linear actuator drives (one for each gate). The concrete floor and cover plate are flush and level to allow proper contact of the retractable shield skirt of the CTM, described in Section A3.3. When closed, the gate provides sufficient shielding to allow operators to be in the Canister Transfer Room when loaded casks are located in the Cask Unloading Room. The shielding thickness may be up to 9 in. of steel.

The equipment is shown in *CRCF, IHF, RF, & WHF Port Slide Gate Mechanical Equipment Envelope* (Ref. 2.2.12).

Cask Unloading Room Shield Door

The Cask Unloading Room shield door provides equipment and personnel access to the Cask Unloading Room and radiation shielding for personnel in the Cask Preparation Room. The Cask Unloading Room shield door is a slide-open door made of steel plate. The door is operated by an electric motor turning a screw.

This equipment is described in *Nuclear Facilities Equipment Shield Door-Type 1 Mechanical Equipment Envelope* (Ref. 2.2.21).

A3.3 CANISTER TRANSFER ROOM

The Canister Transfer Room (Room 2007) is the area above both the Cask Unloading Room and the Loading Room. The CTM operates in this area, carrying the canister from the cask port to the loading port. The concrete roof slab of the Loading Room and the Cask Unloading Room forms the Canister Transfer Room floor. The area footprint is approximately 75 ft long east to west and 52 ft wide.

The following equipment is used in operations performed in the Canister Transfer Room:

Canister Transfer Machine

The primary function of the CTM is to transfer the canister from the transportation cask to the aging overpack. The CTM is a specialized bridge crane that runs on rails and is mounted on a pair of bridge girders supported by the building walls. The CTM features a shielded compartment (the shield bell), which houses the canister while moving from port to port. The CTM has two trolleys: the canister-hoist trolley and the shield-bell trolley. Although the two trolleys can move independently when required, they are mechanically locked together when performing a canister transfer operation. The bridge moves along its rails and the trolley moves along the bridge to position the shield bell over the ports to the rooms below. The CTM hoist is designed to allow the grapple to be changed out to match the canister lift fixture. A motorized slide gate (the CTM slide gate) is provided at the bottom of the shield bell to provide shielding for the bottom of the canister once it is inside the shield bell. The CTM slide gate is part of the CTM and is distinct from the port slide gates, which are located within the floor of the Canister Transfer Room. The CTM also features a motorized shield skirt to close the gap between the CTM bottom plate and floor surface to prevent any lateral radiation shine during canister transfer.

This equipment is shown in *CRCF, IHF, RF, and WHF Canister Transfer Machine Mechanical Equipment Envelope* (Ref. 2.2.6).

A3.4 LOADING ROOM

The Loading Room (Room 1013) provides a shielded location for placement of the canister into an aging overpack. The interior dimensions of the room are 46 ft east to west by 41 ft north to south, with a ceiling height of 28 ft. The walls and roof are 4 ft thick reinforced concrete. The north wall has a shield door for the site transporter.

The following equipment is used in operations performed in the Loading Room:

Aging Overpack Port Slide Gate

The aging overpack port, which is the opening through which the canister passes from the CTM shield bell into the aging overpack, is located in the operating deck between the Canister Transfer Room above and the Loading Room below. The gate assembly consists of two opposing sliding shield gates mounted on heavy duty bearing blocks and single edge V-slides, a cover plate, and two linear actuator drives (one for each gate). The concrete floor and cover plate are flush and level to allow proper contact of the retractable shield skirt of the CTM. When closed, the gate provides sufficient shielding to allow operators to be in the Canister Transfer Room when loaded waste packages are located in the Loading Room.

The equipment is shown in *CRCF, IHF, RF, & WHF Port Slide Gate Mechanical Equipment Envelope* (Ref. 2.2.12).

A3.5 LID BOLTING ROOM

The Lid Bolting Room (Room 1002) provides a shielded location where the aging overpack lid can be accessed and bolted down. The room measures approximately 46 ft by 43 ft in plan with a ceiling height of approximately 62 ft. The walls are 4 ft thick reinforced concrete. Shield doors on the north and south sides of the room allow site transporter access. The following equipment is used in operations performed in the Lid Bolting Room:

Lid Bolting Room Shield Door

The Lid Bolting Room shield door provides personnel shielding and equipment and personnel access to the Unloading Room. The door is operated by an electric motor with a worm-gear assembly attached to the door hinges. This equipment is shown in *Nuclear Facilities Equipment Shield Door-Type 3 Mechanical Equipment Envelope* (Ref. 2.2.22).

Each door is operated by an electric motor with a worm-gear assembly attached to the door hinges.

This equipment is shown in *Nuclear Facilities Equipment Shield Door-Type 3 Mechanical Equipment Envelope* (Ref. 2.2.22).

Lid Bolting Room Platform

The Lid Bolting Room platform provides personnel and tool access to the top of the aging overpack while on the site transporter for aging overpack lid bolting operations. The platform is essentially a 19 ft wide bridge spanning the east west dimensions of the Lid Bolting Room. The aging overpack is driven underneath the platform on a site transporter and parked below the access opening, which is approximately an 8 ft diameter opening in the center of the platform.

This equipment is shown in *Receipt Facility Lid Bolting Room Platform Mechanical Equipment Envelope Sheet 1of 2* (Ref. 2.2.38) and *Sheet 2* (Ref. 2.2.39).

Lid Bolting Room Crane

The Lid Bolting Room crane is a 10-ton overhead crane located in the Lid Bolting Room that the operators use to assist them in handling heavy loads encountered during Lid Bolting Room operations.

The crane dimensional envelope is approximately 41 ft by 34 ft 6 in., on a 5 ft 3 in. clearance envelope elevation. It has a hook elevation of between 48 and 49 ft. The Lid Bolting Room bridge crane girders transverse in the north-south direction; the crane trolley travels in the east-west direction. Crane rail stops and bumpers are provided.

This equipment is shown in *Receipt Facility Lid Bolting Room Crane Mechanical Equipment Envelope* (Ref. 2.2.37).

A3.6 SITE TRANSPORTER VESTIBULE

The Site Transporter Vestibule (Room 1001) is located on the north side of the RF. Empty aging overpacks are moved into the Site Transporter Vestibule from the outside, and loaded aging overpacks are moved in from the Lid Bolting Room and transported out to their destinations. The room is 35 ft by 42 ft in plan, and 30 ft high. The walls are all 4 ft thick concrete, and the ceiling is the 18 in. floor slab of the room above.

The Site Transporter Vestibule is the interface point between the facility and the outside. The aging overpack moves through the Site Transporter Vestibule, no other operations are performed in this area. The overhead door between the Site Transporter Vestibule and the outside is a standard industrial overhead door. The door between the Site Transporter Vestibule and the Lid Bolting Room is a shield door, as described above.

ATTACHMENT B
RECEIPT FACILITY OPERATIONAL SUMMARY

B1 INTRODUCTION

The description of operations in Section 6.1 and this attachment emerged from a cooperative effort involving preclosure safety analysis facility leads, human reliability analysts, nuclear operations personnel, equipment reliability personnel and other engineering personnel. The PFD was developed while preparing the HAZOP because this is a precondition for conducting the HAZOP. 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 multi-disciplinary effort was led by the Preclosure Safety Analysis group and is documented herein.

B2 FACILITY OVERVIEW

This attachment describes the mechanical handling operation in the RF. There are two separate sets of operations in the RF: the first encompasses the receipt and transfer of waste forms from a national transportation system transportation cask to an aging overpack for movement to other on-site waste handling facilities or the Aging Facility. The second involves the transfer of a cask from a railcar to an onsite specific transport vehicle known as the cask transfer trailer.

The first of these operations involves handling transportation casks that must be removed from the railcar and upended for unloading in two different manners. One type of cask can be upended directly on the railcar to a vertical orientation for unloading. Casks handled in this manner are referred to as VTCs for this analysis. The other type of cask must be transferred from the railcar in a horizontal orientation to a tilting frame that is used to upend the cask into a vertical orientation for unloading. These casks are referred to as TTCs for this analysis.

The second set of operations involves transferring national transportation system casks that remain in a horizontal orientation to a trailer for movement to the Aging Facility where the canister inside the cask is unloaded into a horizontal aging module (HAM). For this analysis, these casks are referred to as HTCs.

For both types of operations, the empty casks are returned to the national transportation system.

These operations are presented according to the nodes of the RF PFD, Figure 15. The major pieces of mechanical handling equipment, including overhead bridge cranes, CTTs, CTM, and associated lifting fixtures and devices, are described in Attachment A.

All operations in this facility involving a canister are overseen by a radiation protection worker who monitors the radiation level within the facility. Furthermore, all personnel involved in handling transportation casks or aging overpacks and their contents receive proper training commensurate with nuclear industry standards. This training is followed by a period of observation until it is deemed that the operator is proficient in performing their assigned duties.

B3 NODE 1: RECEIVE AND MOVE TRANSPORTATION CASKS FROM RAILCAR INTO PREPARATION ROOM FOR TRANSFER OFF THE RAILCAR (ALL CASKS)

Pre-Job Plan

Before the cask on the railcar reaches the RF, a crew member is notified of the type of cask to expect and how to process it.

Movement of Loaded Transportation Cask into Preparation Room

Crew members are at the entrance of the RF to facilitate movement of the transportation cask into the RF. The transportation cask is conveyed to the RF by the SPM. (The SPM runs on either rail or road).

Once the RC is in the Transportation Cask Vestibule Annex, the Cask Preparation Room Annex door will be opened and the railcar will proceed to the Cask Preparation Room and stop. A crew member will then set the railcar brakes and chock the wheels.

Remove Site Prime Mover from the Cask Preparation Room

The SPM will detach from the railcar and proceed back to the Transportation Cask Vestibule. The Cask Preparation Room Annex door will then be closed by a crew member. A checklist will be used to ensure that all doors have been closed and the brakes set.

Interlocks assure that the door to the Transportation Cask Vestibule is closed when the door to the Cask Preparation Annex is open, and vice versa.

Remove Site Prime Mover from Cask Preparation Area

- After the Cask Preparation Room door is closed, the SPM may be moved out of the facility.

Remove and Store Personnel Barrier (If Required)

Personnel barriers for all casks except the HTCs are expected to be removed when the cask is received from the national transportation system at the B36 gate, as described in the Intra-Site Operations analysis prior to movement to the RF. The tie-downs on HTCs are integral to the personnel barrier and cannot be removed before transferring the cask to the RF on the railcar. The steps associated with this operation are described in Section B11.

B4 NODES 2-8: CASK UPENDING AND TRANSFER TO CASK TRANSPORT TROLLEY (VTC AND TTC ONLY)

Nodes 6 and 7: Move Transportation Cask to Cask Stand (TTC only)

Once the railcar carrying the TTC is parked and secured, the cask is ready to be transferred to the cask stand for removal of the impact limiters. In order to move a TTC to the cask stand, the tie-downs must first be removed. The mobile access platform, cask handling crane, and cask handling slings are then used to move a TTC to the cask stand where the following activities are performed:

- Crew attaches horizontal lift beam to the cask handling crane.
- Crane operator moves cask handling crane to transportation cask.
- Crew aligns horizontal lift beam with cask and attaches slings.
- Crane operator lifts the cask in a horizontal orientation, ensuring load is level.
- Crane operator moves cask over cask stand for lowering.
- Crane operator lowers cask and removes slings.

Node 2: Remove Impact Limiters

Before the cask can be upended, the impact limiters must be removed. For VTCs, this is accomplished while the cask is still on the railcar. For TTCs, this is done while the cask is on the cask stand. Impact limiters are removed and stored using the cask handling crane auxiliary hook. Access to the impact limiters is provided by the mobile access platform for VTCs and by a scissors lift for TTCs while in the cask stand. This procedure is performed twice on each cask because each cask has two impact limiters.

In preparation for removal of the impact limiters, the crew attaches the impact limiter lifting device to the cask handling crane auxiliary hook and unbolts the restraining bolts on the impact limiters.[1] The crew then removes and stores the impact limiters as follows:

- Crane operator moves crane to impact limiter position.
- Crane operator aligns crane to impact limiter and crew attaches rigging.
- Crane operator removes the impact limiter.
- Crane operator moves impact limiter to position for lowering.
- Crane operator lowers impact limiter and disengages.

Once the impact limiters have been removed, the crew installs trunnions on the cask, if needed (some casks are shipped with the trunnions removed).

Variation for TTCs: Prior to upending a TTC, it must be moved from the cask stand to the tilting frame using the lift slings as follows:

- Crew attaches horizontal lift beam to the cask handling crane.
- Crane operator moves cask handling crane to transportation cask.
- Crew aligns horizontal lift beam with cask and attaches slings.
- Crane operator lifts the cask in a horizontal orientation, ensuring load is level.
- Crane operator moves cask over tilting frame for lowering.
- Crane operator lowers cask and removes slings.

Once this is accomplished, the lift yoke can be installed and the TTC upended as described in the following paragraphs.

[1] All operations that involve bolt removal or emplacement and tightening involve check and verification.

Node 3: Attach Lift Yoke to Transportation Cask

Access to the cask for these steps will be provided by the mobile access platform for VTCs and by a scissors lift for TTCs. With the trunnions in place, the crew then attaches the cask handling crane to the cask, using the cask handling yoke as follows:

- Crew attaches cask handling yoke to cask handling crane.
- Crane operator moves cask handling crane to transportation cask.
- Crane operator aligns crane to cask.
- Crane operator engages yoke arms on trunnions.

Nodes 4 and 8: Upend Transportation Cask

Once the cask handling yoke is installed, the crane operator will upend the transportation cask using the 200-ton cask handling crane. The TTCs are upended on a tilting frame and VTCs are upended directly on the conveyance. The crew will then use common tools to free the cask from the pivot point or tilting frame.

Node 5: Move Transportation Cask to Cask Transfer Trolley

The crane operator will use the cask handling crane, which is already attached to the cask, to move the cask from the railcar or tilting frame to the CTT. The CTT is stationed alongside the railcar where it can be freely moved under the cask preparation platform. Once the cask is properly loaded in the CTT, a crewmember will secure the cask to the CTT. After the cask is secure in the CTT, the crew will disengage the cask from the crane and close the cask preparation platform.

B5 NODE 9: CASK PREPARATION ACTIVITIES

Gas Sampling and Equalization (if required)

To determine the nature and concentration of any gas that may have built up in the cask, the crew connects a hose to the sampling port, takes a reading (in the gas sampling room) of gas that is being removed, and verifies that the cask is safe for opening. After the sample is taken, the remainder of the gas is vented.

Lid Preparation

The crew will use the preparation platform to remove all the cask lid bolts. Then the crew will use the auxiliary hook with lid lifting fixture lifting device to retrieve and emplace the proper lid lifting fixture. The following specific steps are involved in lid preparation:

- Crane operator selects and retrieves the appropriate lid lift fixture with the cask preparation crane.

- Crane operator moves lid lift fixture to cask.

- Crew opens cask preparation platform shield plate.

- Crane operator lowers lid lift fixture and disengages.
- Crew closes cask preparation platform shield plate.
- Crew bolts lid lift fixture to cask lid.

Variation for DPCs

In order to lift a DPC with the CTM, a canister lift fixture must be installed on the DPC. To prepare the DPC for installation of the lift fixture, the cask lid is removed and a canister lift fixture is installed as follows:

- Crew opens cask preparation platform shield plate.
- Crane operator positions the auxiliary hook over the cask lid and engages the lid lift fixture to the crane.
- Crane operator lifts cask lid.
- Crew closes cask preparation platform shield plate.
- Crane operator moves cask lid to staging area and stages lid.
- Crane operator retrieves canister lift fixture and moves it over the cask.
- Crew opens cask preparation platform shield plate.
- Crane operator lowers canister lift fixture onto DPC and disengages the crane.
- Crew closes cask preparation platform shield plate.
- Crew bolts canister lift fixture to DPC.

B6 NODE 10: CASK TRANSPORT TROLLEY MOVES CASK INTO POSITION BELOW CANISTER TRANSFER MACHINE IN CASK UNLOADING ROOM

Using the CTT, the crew member will move the transportation cask to the Cask Unloading Room and position the cask under the cask port and secure. To do this, the crew will move the CTT to the Cask Unloading Room shield door, open the door, move the CTT through the door into position under the cask port, disconnect the air hose providing lift air to the CTT and close the door.

B7 NODE 11: LIFT CANISTER INTO CTM

Using the CTM, the crew moves a canister from the transportation cask and places it into an aging overpack. The first operation in this sequence is to lift the canister out of the transportation cask into the CTM shielded bell. The steps in removing the canister from the transportation cask are as follows:

- Install appropriate canister grapple – The CTM operator moves the CTM from the lid station to the CTM Maintenance Room where a crew member manually takes off and stores the lid grapple and attaches the appropriate canister grapple, depending on the waste form.
- Move CTM to cask port.
- Lower shield skirt.
- Open CTM slide gate and cask port slide gate.
- Lower hoist, engage grapple and lift canister into CTM.
- Close CTM slide gate and cask port slide gate.

B8 NODE 12: MOVE CANISTER TRANSFER MACHINE TO AGING OVERPACK LOAD STATION PORT

With the canister in the CTM shield bell, the crew moves the CTM from over the cask port to the aging overpack loading port. The steps in moving the CTM are as follows:

- Lift shield skirt and move CTM to the aging overpack loading port.
- Lower shield skirt.
- Open CTM slide gate and aging overpack loading port slide gate.

B9 NODE 13: LOWER CANISTER INTO AGING OVERPACK ON SITE TRANSPORTER WITH CTM

With the canister in the CTM shield above the aging overpack loading port with the slide gates open, the canister is lowered into the aging overpack. The steps in lowering the canister into the aging overpack are as follows:

- Lower canister into aging overpack.
- Release the grapple.
- Retract the grapple into the CTM shield bell.
- Change grapple.
- Retrieve the aging overpack lid.

- Place lid on the aging overpack.
- Close CTM slide gate and aging overpack loading port slide gate.

The canister transfer to the aging overpack is now complete.

B10 NODE 14: MOVE AGING OVERPACK TO LID BOLTING ROOM, BOLT LID THEN MOVE TO SITE TRANSPORTER VESTIBULE

Move Aging Overpack to Lid Bolting Room

The crewmember will open the Cask Unloading Room shield door and the loaded aging overpack will move out of the Cask Unloading Room to Lid Bolting Room on a site transporter. The site transporter operator will follow the indicated safe path marked on the floor. The operator will do this visually, and also receive confirmation from another crew member. After the site transporter is cleared out of the Cask Unloading Room, the crew member will close the shield door.

Install Aging Overpack Lid Bolts

Using the Lid Bolting Room platform, crew member(s) will emplace and tighten all the aging overpack lid bolts.

Move Aging Overpack from Lid Bolting Room to Site Transporter Vestibule

Once the aging overpack lid is bolted down, the overhead door to the vestibule will be opened and the site transporter will proceed to the Site Transporter Vestibule and stop. The inside overhead door will then be closed by a crew member.

Movement of Loaded Site Transporter to Out of Facility

After the door to the Lid Bolting Room has been closed, a crew member will open the outside door of the Site Transporter Vestibule and the site transporter operator will proceed to move the site transporter to the outside. Once the site transporter has cleared the outside overhead door, a crew member will close the door.

B11 TRANSFER HTC TO CASK TRANSFER TRAILER AND EXPORT (HTC ONLY)

HTCs are never upended while being handled within the GROA. In the RF they are simply transferred from the railcar to a horizontal transfer trailer that is used to move these types of casks to the Aging Facility for unloading. The steps necessary to accomplish this are similar to those described above with some differences that are described below. The first step in preparation for the transfer is to remove the impact limiters. Subsequent steps transfer the cask to the cask stand for installation of trunnions followed by transfer to the cask transfer trailer. Each of these nodes is described below.

Remove and Store Personnel Barrier (If Required)

Personnel barriers for all casks except the HTCs will be removed when received from the national transportation system at the B36 gate. The tie-downs on HTCs are integral to the personnel barrier and cannot be removed before transferring the cask to the RF on the railcar. The personnel barrier is removed and stored using the auxiliary hook on the cask handling crane with the personnel barrier lifting device and the mobile access platform. In order to remove the personnel barrier from the cask conveyance, the crew members must first unbolt the barrier from the cask. The crane operator retrieves the crane and removes the personnel barriers as follows:

- Crane operator aligns crane to personnel barrier and the crew attaches rigging.
- Crane operator lifts the personnel barrier clear of the cask.
- Crane operator moves personnel barrier to position for lowering.
- Crane operator lowers personnel barrier and the crew detaches rigging.

Node 2: Remove Impact Limiters from Transportation Cask

For HTCs, the impact limiters are removed while the cask is still on the railcar before it is transferred to the cask transfer trailer while remaining in a horizontal orientation. Impact limiters are removed and stored using the cask handling crane auxiliary hook. Access to the impact limiters is provided by the mobile access platform. This procedure is performed twice on each cask because each cask has two impact limiters.

In preparation for removal of the impact limiters, the crew attaches the impact limiter lifting device to the cask handling crane auxiliary hook and unbolts the restraining bolts on the impact limiters. The crew then removes and stores the impact limiters as follows:

- Crane operator moves crane to impact limiter position.
- Crane operator aligns crane to impact limiter and crew attaches rigging.
- Crane operator lifts the impact limiter clear of the cask.
- Crane operator moves impact limiter to position for lowering.
- Crane operator lowers impact limiter and disengages.

Nodes 6 and 7: Move Transportation Cask to Transportation Cask Stand

After the impact limiters have been removed, the HTC is ready to be transferred to the cask stand for installation of the trunnions. The crew then uses the mobile access platform, cask handling crane, and cask handling slings to move an HTC to the cask stand:

- Crew attaches horizontal lift beam to the cask handling crane.
- Crane operator moves cask handling crane to transportation cask.
- Crew aligns horizontal lift beam with cask and attaches slings.
- Crane operator lifts the cask in a horizontal orientation ensuring load is level.
- Crane operator moves cask over cask stand for lowering.
- Crane operator lowers cask and removes slings.

Node 3A: Install trunnions

Once the cask has been transferred to the cask stand, access to the cask is provided using a scissors lift. First, the lift slings are removed and stored. Next, crew members will retrieve the trunnions to be installed. These trunnions are located in a package on the railcar. This operation may require a crane, in which case the 20-ton auxiliary hoist will be used. The trunnions are placed in the proper position using common tools, standard rigging, cask handling crane (auxiliary hook), and a scissors lift.

Nodes 6 and 7: Move Transportation Cask to Transportation Cask Trailer

After the trunnions have been installed, the crew then uses the scissors lift, cask handling crane, and cask handling slings to move the cask to the cask transfer trailer:

- Crew attaches horizontal lift beam to the cask handling crane.
- Crane operator moves cask handling crane to cask stand.
- Crew aligns horizontal lift beam with cask and attaches slings.
- Crane operator lifts the cask in a horizontal orientation ensuring load is level.
- Crane operator moves cask over cask transfer trailer for lowering.
- Crane operator lowers cask and removes slings.

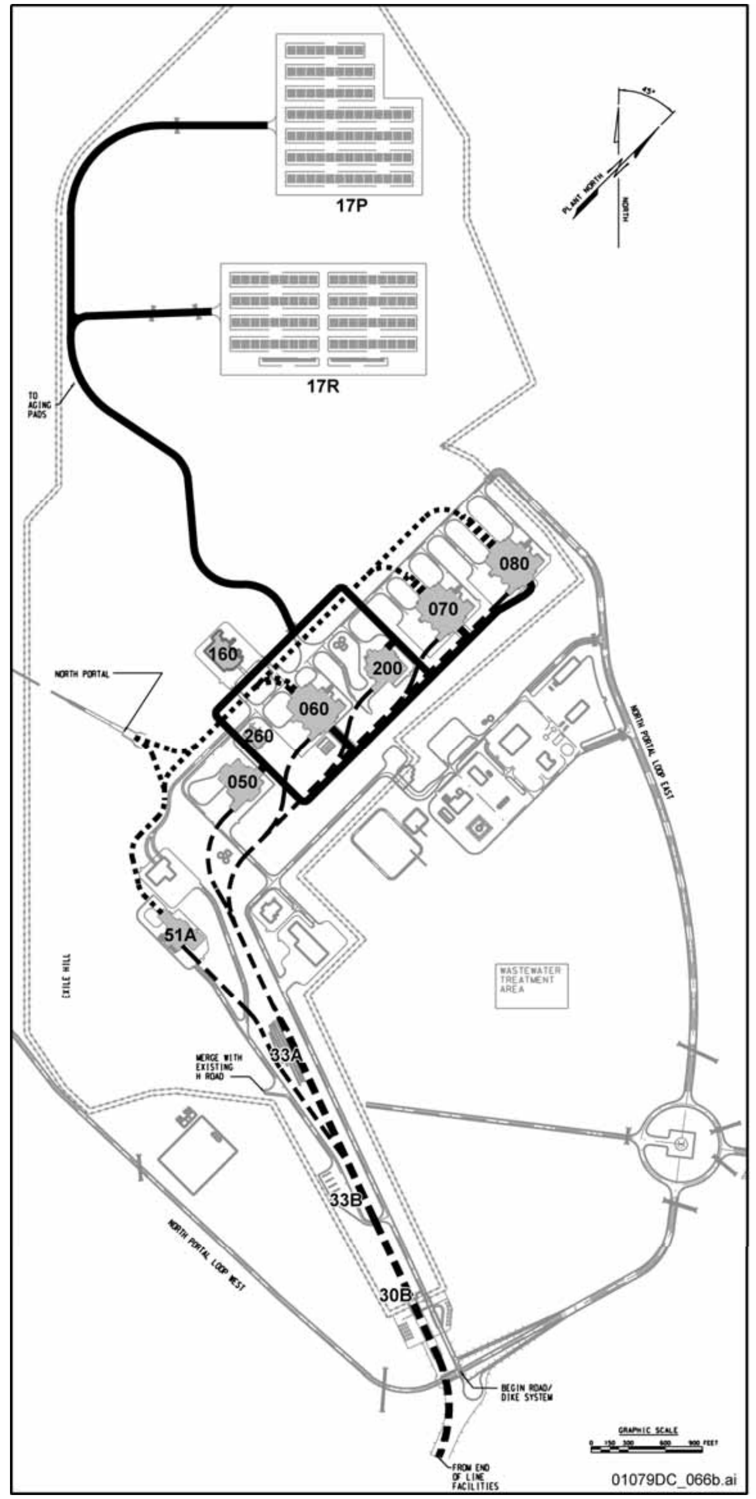
Node 1A: Move HTC on Transfer Trailer out of Cask Preparation Room

Once the cask transfer trailer has been loaded in the Cask Preparation Room, the door to the Transportation Cask Vestibule and the Transportation Cask Vestibule Annex is opened and the cask transfer trailer proceeds to the Transportation Vestibule/Annex and stops. The Cask Preparation Room door is closed by a crew member.

Once the door to the Cask Preparation Room has been closed, a crew member opens the outer door of the Transportation Cask Vestibule and the cask transfer trailer operator moves the cask transfer trailer to the outside. Once the cask transfer trailer has cleared the outside overhead door, a crew member closes the door.

ATTACHMENT C
RECEIPT FACILITY LOCATION WITHIN THE GROA

The RF is one of four waste-handling building types (Ref. 2.2.50). Figure C-1 displays the location of the RF and other major facilities within the GROA. The RF accomplishes two functions: the first is to receive rail-based transportation casks loaded with TAD canisters or DPCs, open the casks, remove the canisters, and transfer them into aging overpacks for delivery to the WHF, Canister Receipt and Closure Facility (CRCF) or the Aging Facility. The second function is to transfer HTCs to a cask transfer trailer for movement to the Aging Facility for further handling. Once the canisters are removed, the transportation casks are restored and returned to the national transportation system.



FACILITIES

17P	AGING PAD P
17R	AGING PAD R
050	WET HANDLING FACILITY
060/070/080	CANISTER RECEIPT AND CLOSURE FACILITY (1, 2, 3)
51A	INITIAL HANDLING FACILITY
200	RECEIPT FACILITY
30B	CASK RECEIPT SECURITY STATION
33A	RAILCAR BUFFER AREA
33B	TRUCK BUFFER AREA
160	LOW-LEVEL WASTE FACILITY
260	EMERGENCY DIESEL GENERATOR FACILITY

TRANSPORTATION ROUTES

- – – APPROXIMATE TRANSPORTATION CASK CONVEYANCE ROUTES
- ······ TEV TRANSPORTATION ROUTES
- ▬ APPROXIMATE SITE TRANSPORTER AND CASK TRANSFER TRAILER ROUTES

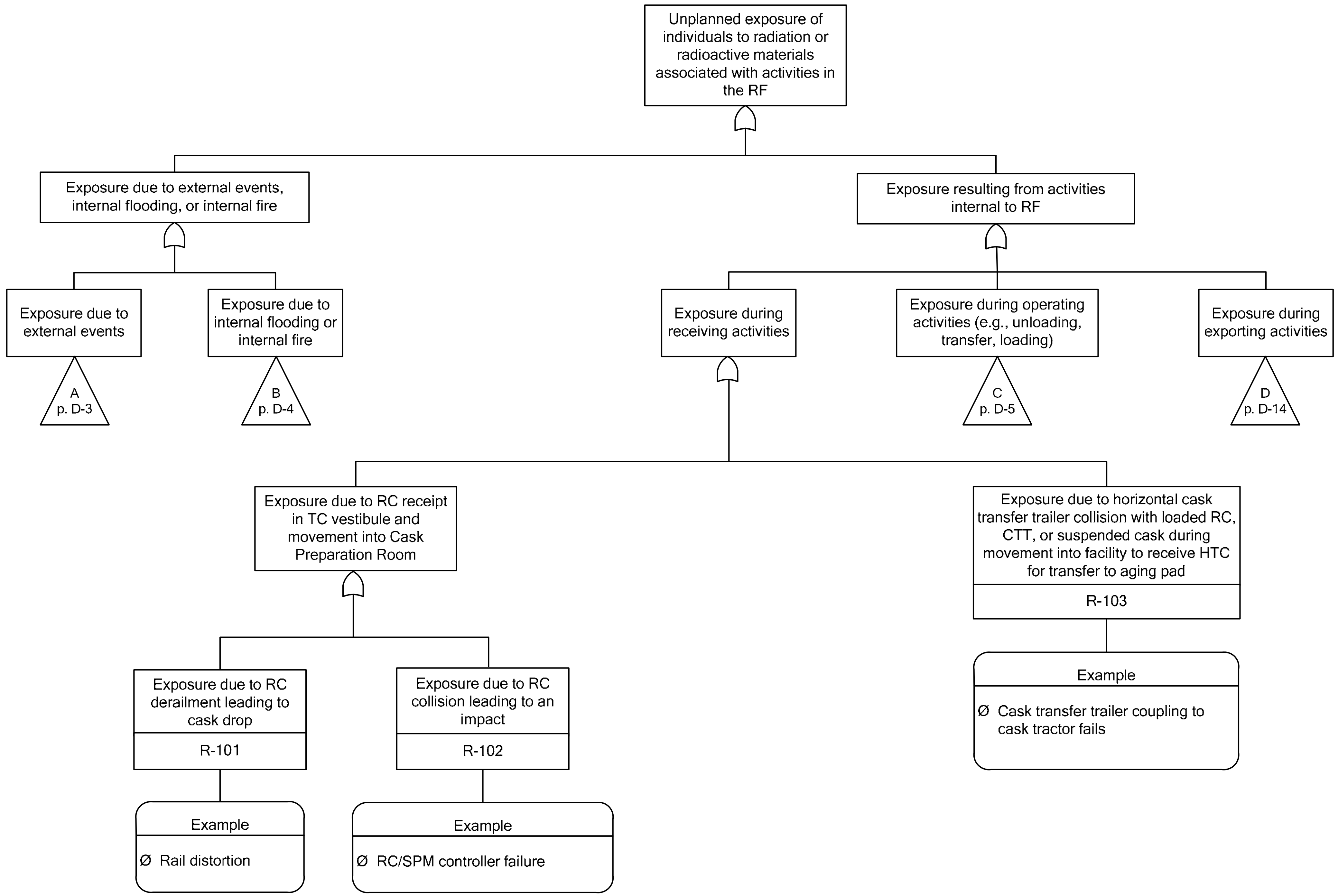
NOTE: TEV = transport and emplacement vehicle.

Source: Modified from Ref. 2.2.50 and Ref. 2.2.51.

Figure C-1 Geologic Repository Operations Area Overall Site Plan

ATTACHMENT D
RECEIPT FACILITY MASTER LOGIC DIAGRAM

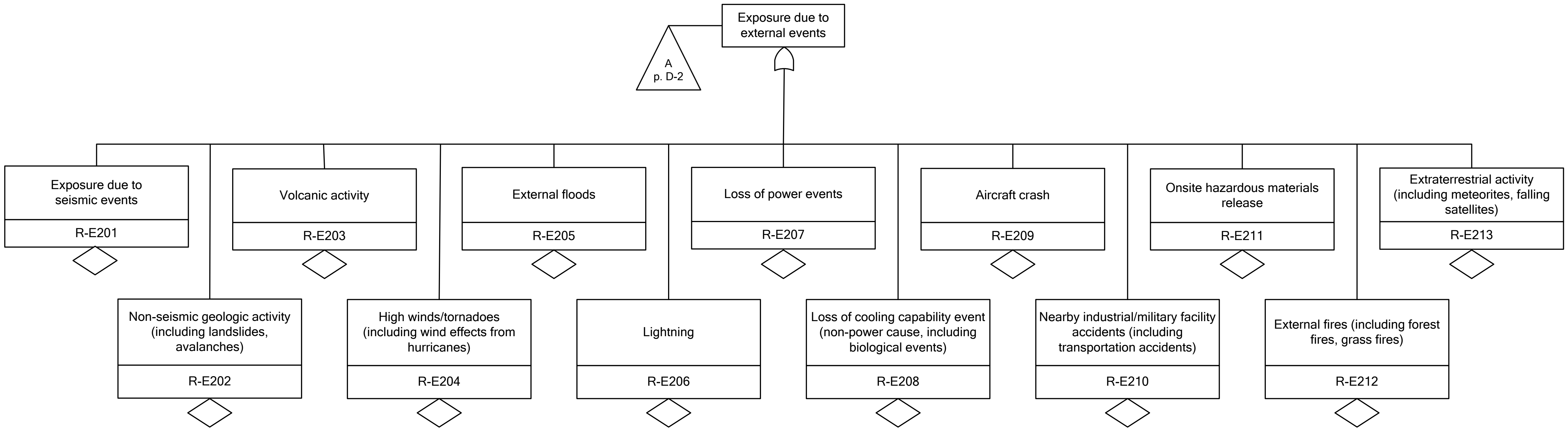
This attachment and Figures D-1 through D-14 presents the results of applying the MLD process to the design and operations of the Receipt Facility.



NOTES: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
CTT = cask transfer trolley; HTC = a transportation cask that is never upended; RC = railcar; RF = Receipt Facility; SPM = site prime mover; TC = transportation cask.

Source: Original

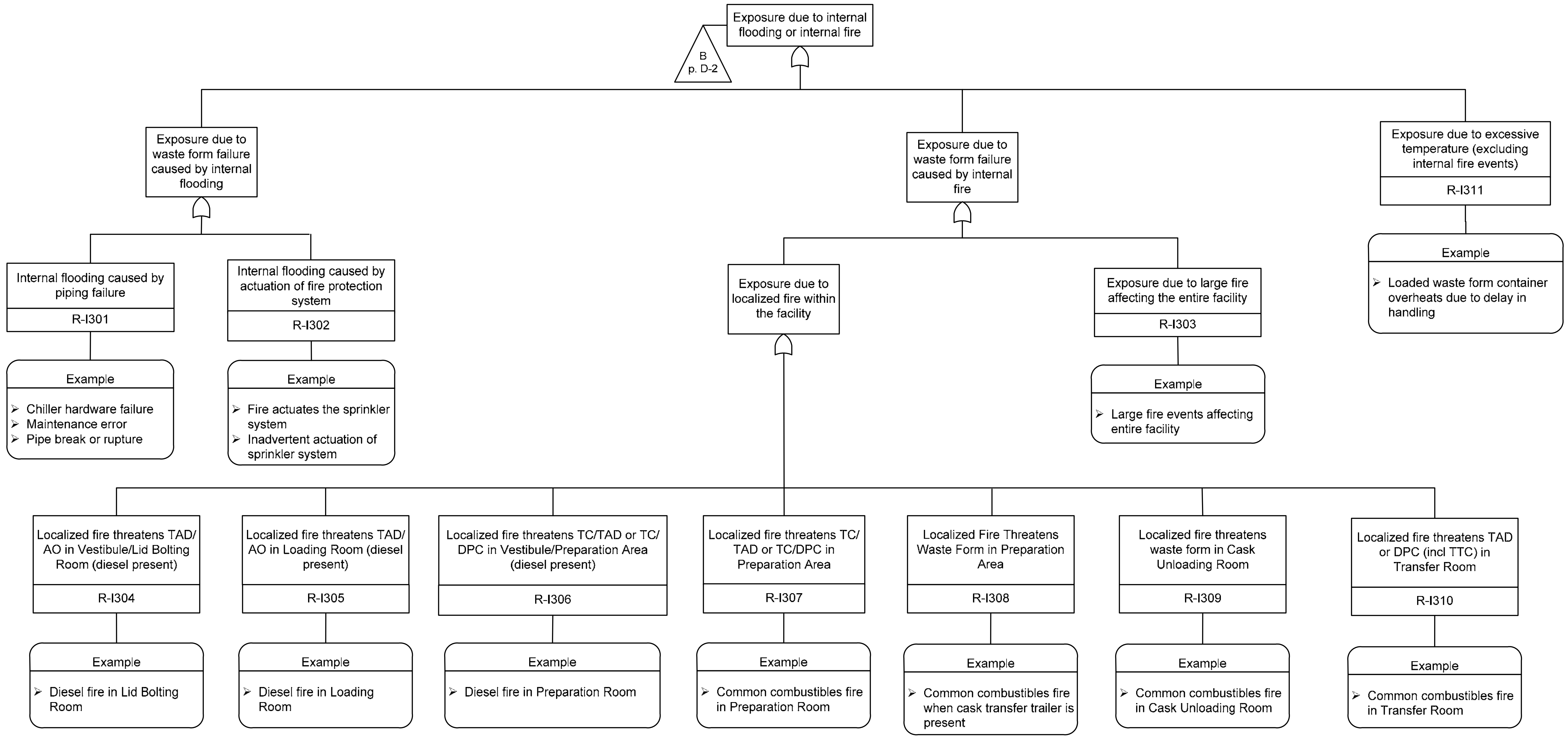
Figure D-1. Unplanned Exposure of Individuals to Radiation or Radioactive Materials Associated With Activities in the RF



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."

Source: Original

Figure D-2. Exposure Due to External Events

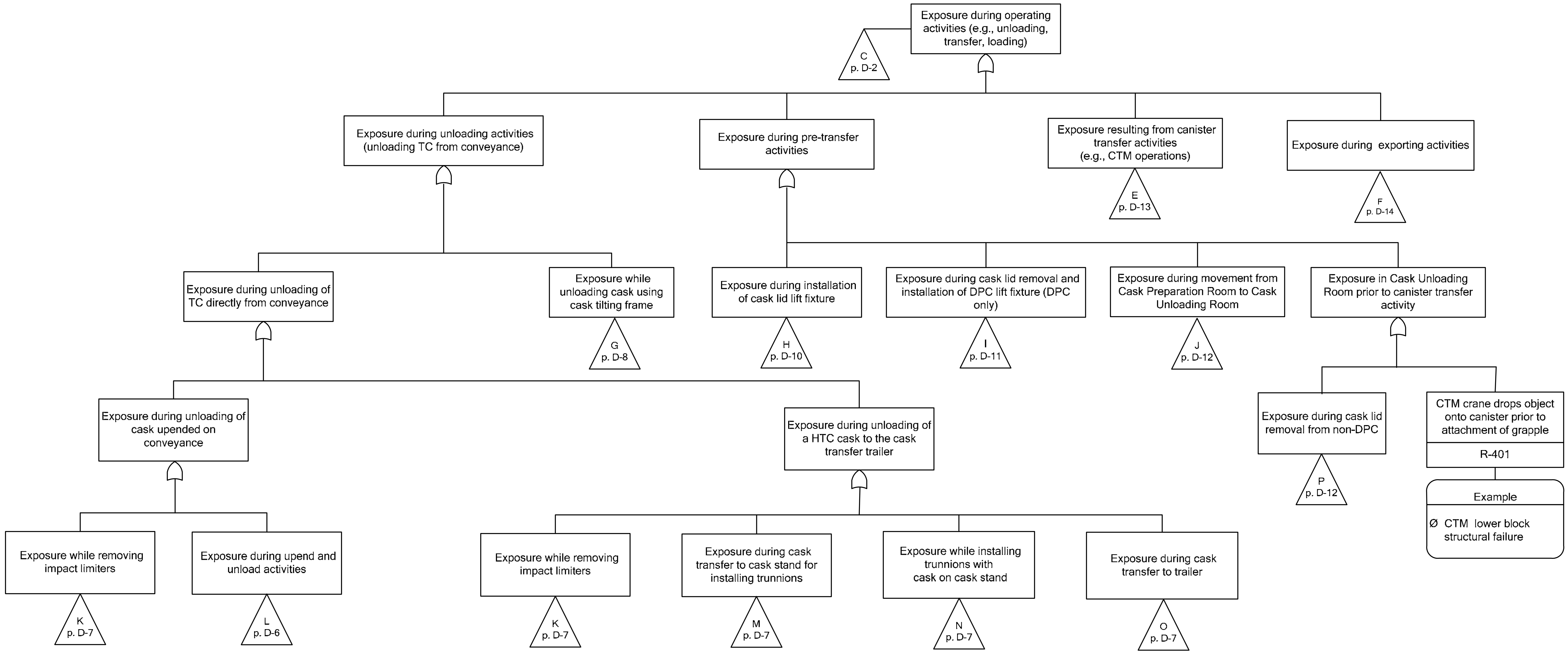


NOTES: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."

AO = aging overpack; CTM = canister transfer machine; DPC = dual-purpose container; TAD = transportation, aging, and disposal canister; TC = transportation cask; TTC = a transportation cask that is upended using a tilt frame.

Source: Original

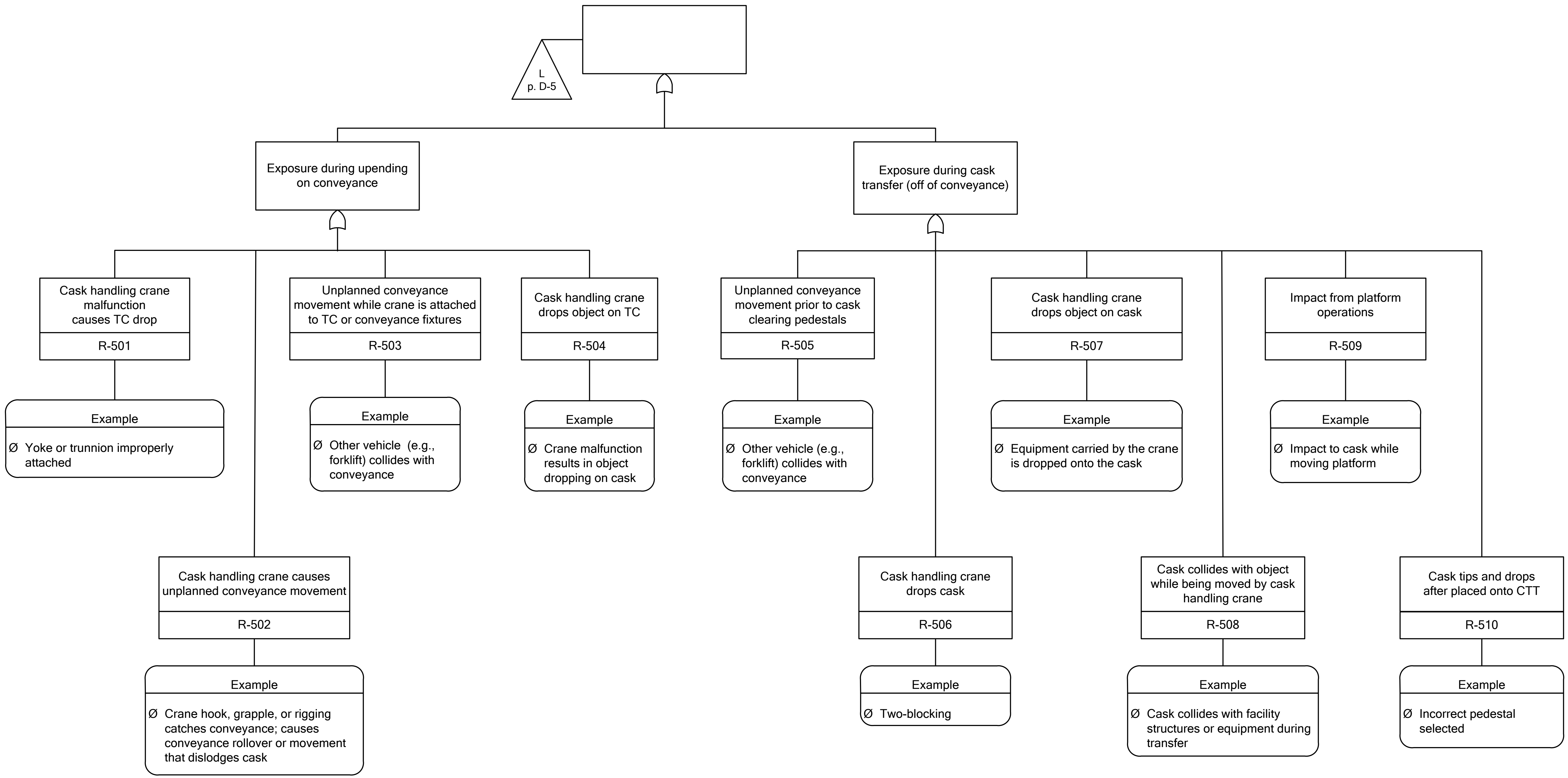
Figure D-3. Exposure Due to Internal Flooding or Internal Fire



NOTES: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
CTM = canister transfer machine; DPC = dual-purpose canisters; HTC = a transportation cask that is never upended; TC = transportation cask.

Source: Original

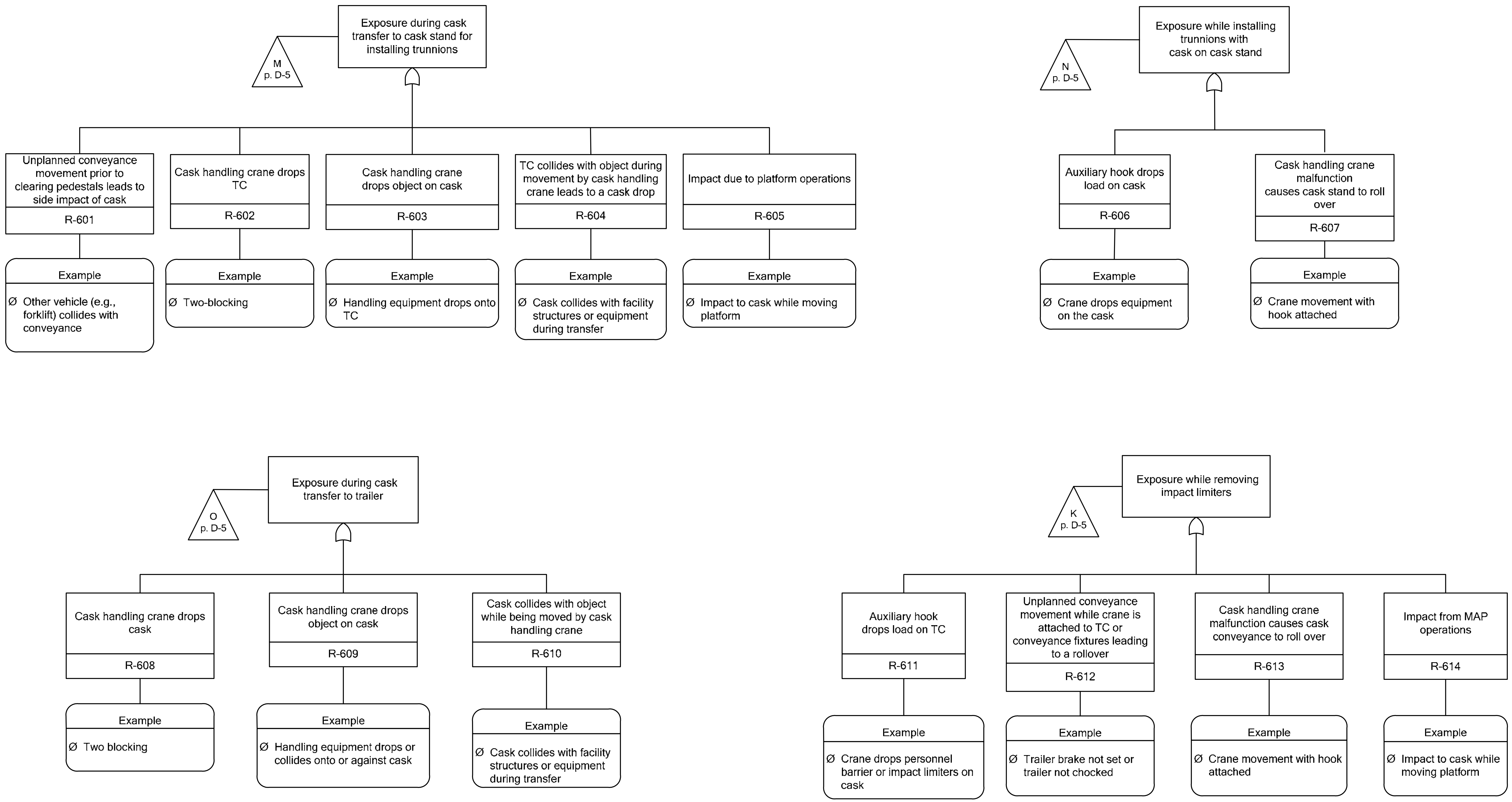
Figure D-4. Exposure During Operating Activities (e.g., Unloading, Transfer, Loading)



NOTES: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
CTT = cask transfer trolley; TC = transportation cask.

Source: Original

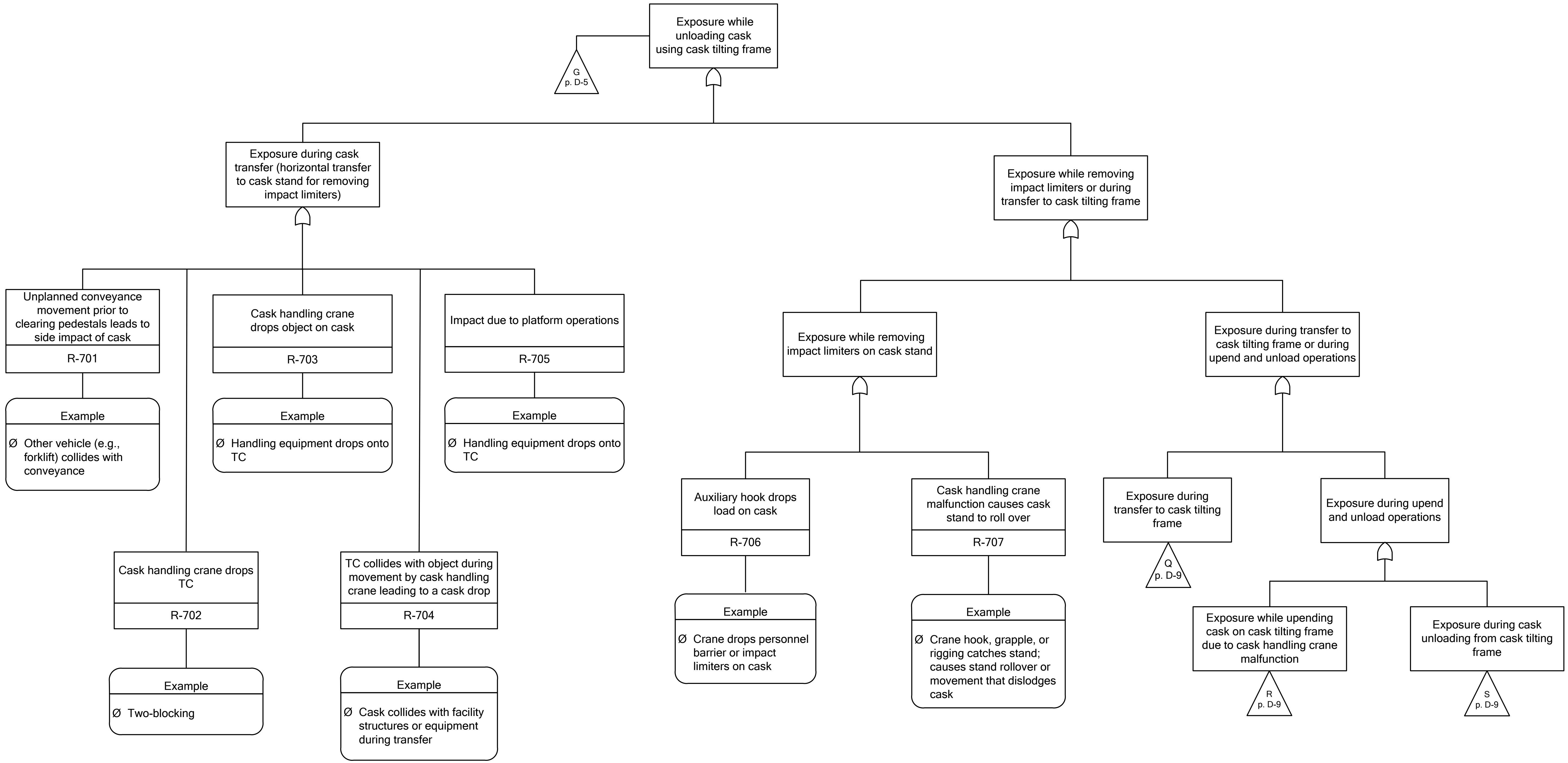
Figure D-5. Exposure During Upend and Unload Activities



NOTES: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
MAP = mobile access platform; TC = transportation cask.

Source: Original

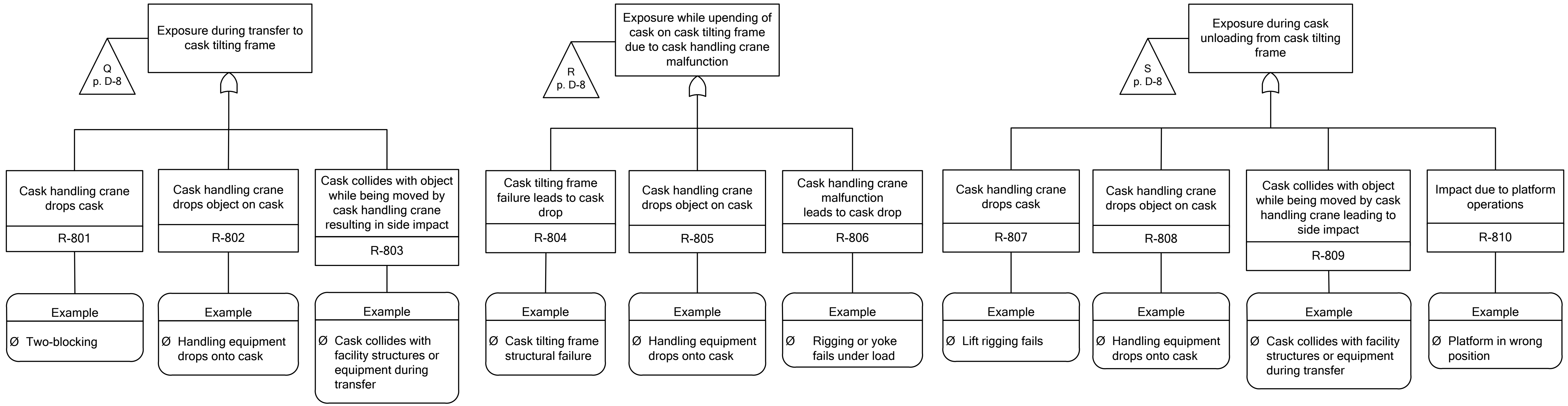
Figure D-6. Exposure During Cask Transfer to Cask Stand for Installing Trunnions – Exposure While Installing Trunnions with Cask on Cask Stand – Exposure During Cask Transfer to Trailer – Exposure While Removing Impact Limiters



NOTES: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
TC = transportation cask.

Source: Original

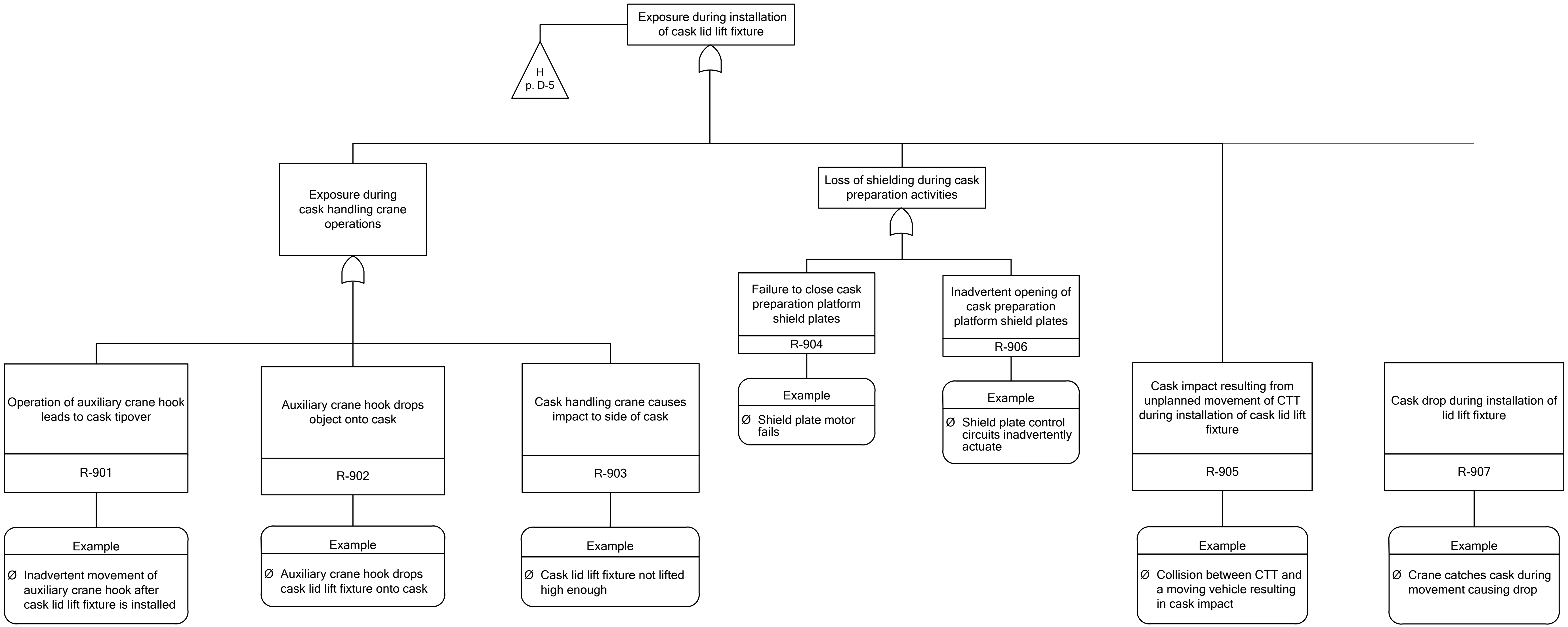
Figure D-7. Exposure While Unloading Cask Using Cask Tilting Frame



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."

Source: Original

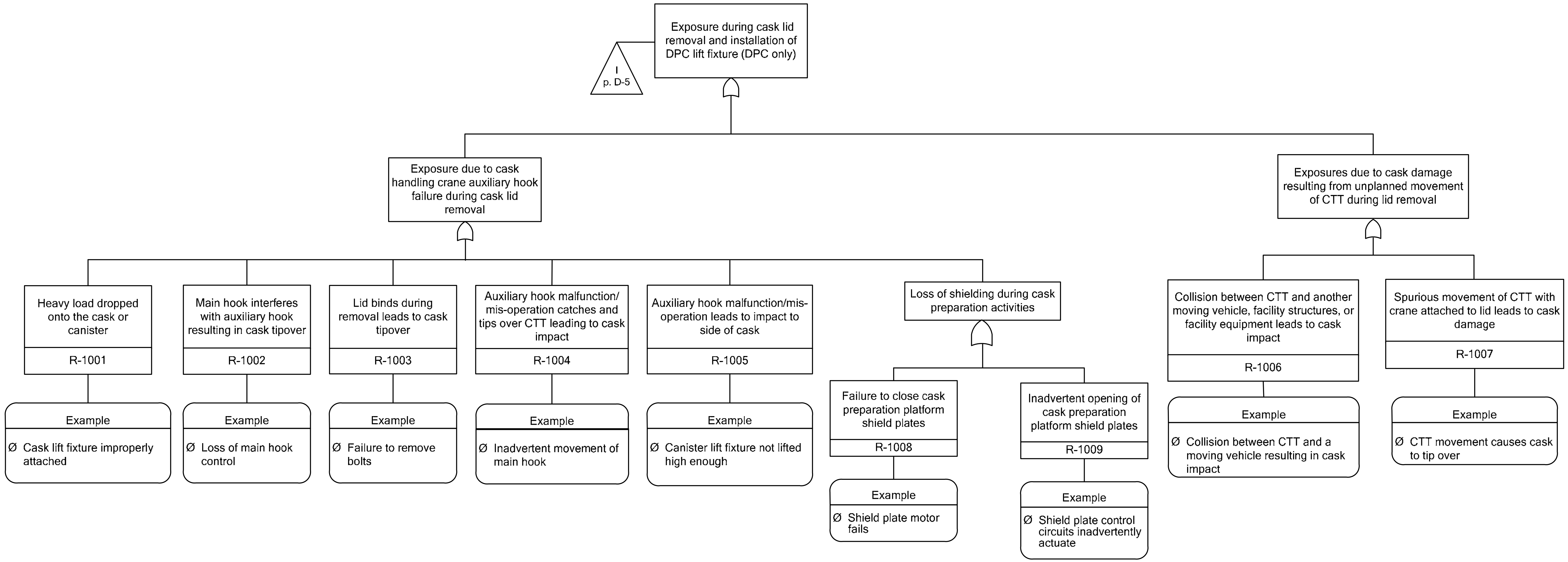
Figure D-8. Exposure During Transfer to Cask Tilting Frame – Exposure While Upending of Cask in Cask Tilting Frame Due to Cask Handling Crane Malfunction – Exposure During Cask Unloading from Cask Tilting Frame



NOTES: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
CTT = cask transfer trolley.

Source: Original

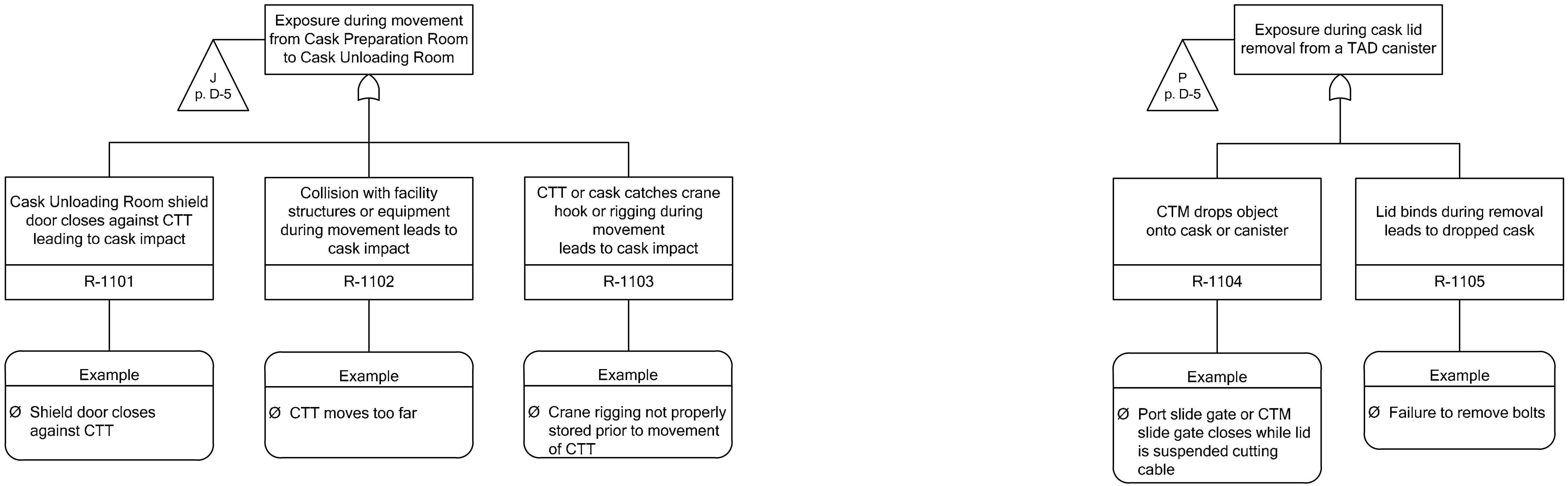
Figure D-9. Exposure During Installation of Cask Lid Lift Fixture



NOTES: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
CTT = cask transfer trolley; DPC = dual-purpose canister.

Source: Original

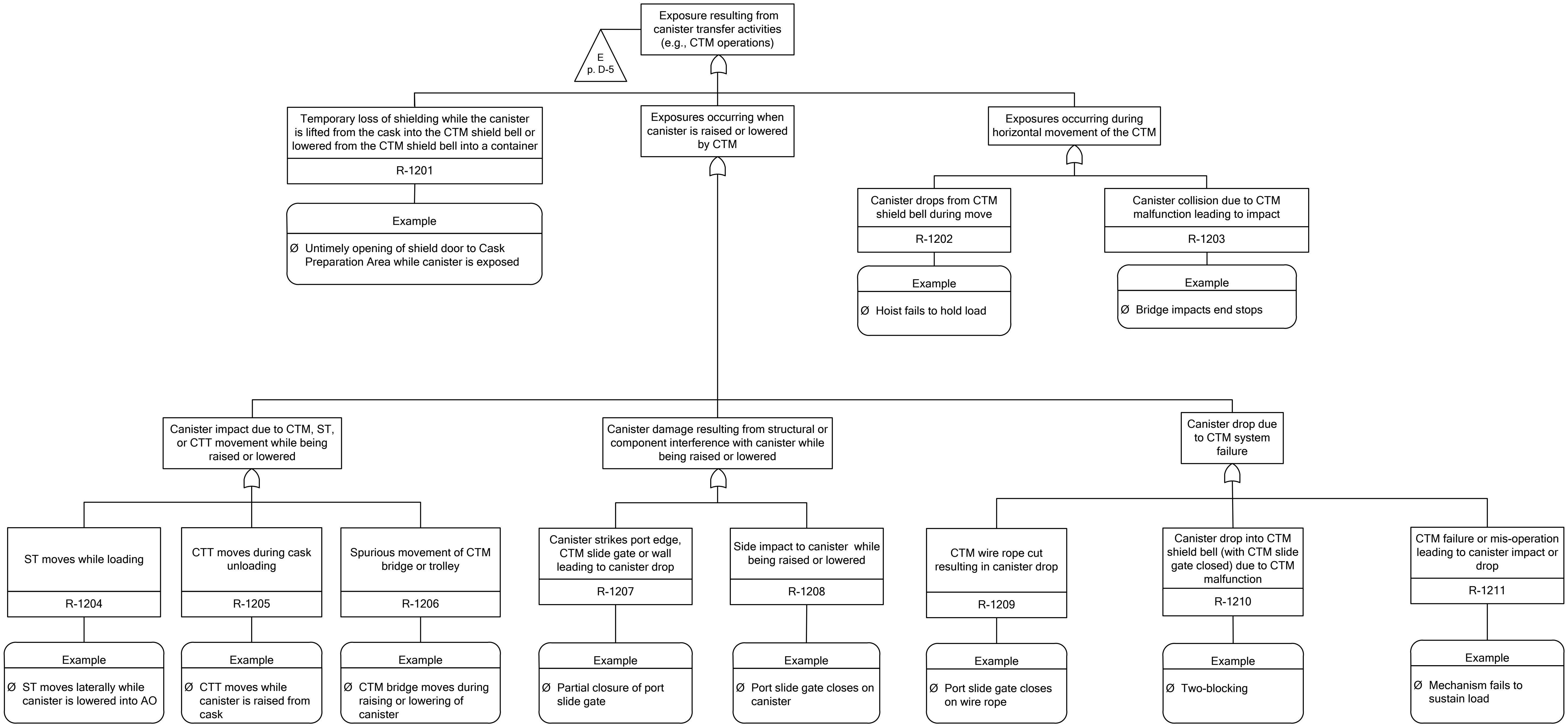
Figure D-10. Exposure During Cask Lid Removal and Installation of DPC Lift Fixture (DPC Only)



NOTES: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister.

Source: Original

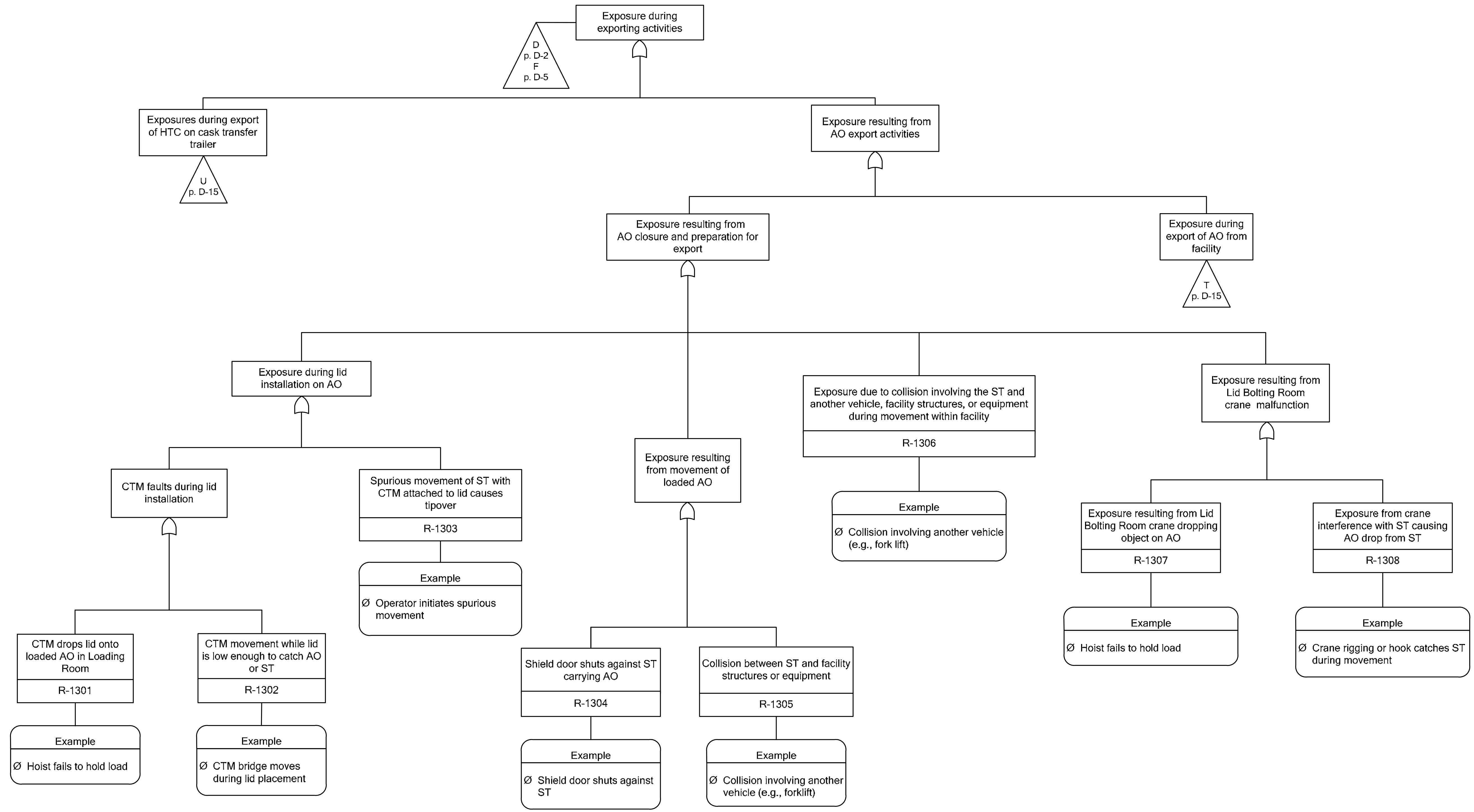
Figure D-11. Exposure During Movement from Cask Preparation Room to Cask Unloading Room – Exposure During Cask Lid Removal from Non-DPC



NOTES: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
AO = aging overpack; CTM = canister transfer machine; CTT = cask transfer trolley; ST = site transporter; WP = waste package.

Source: Original

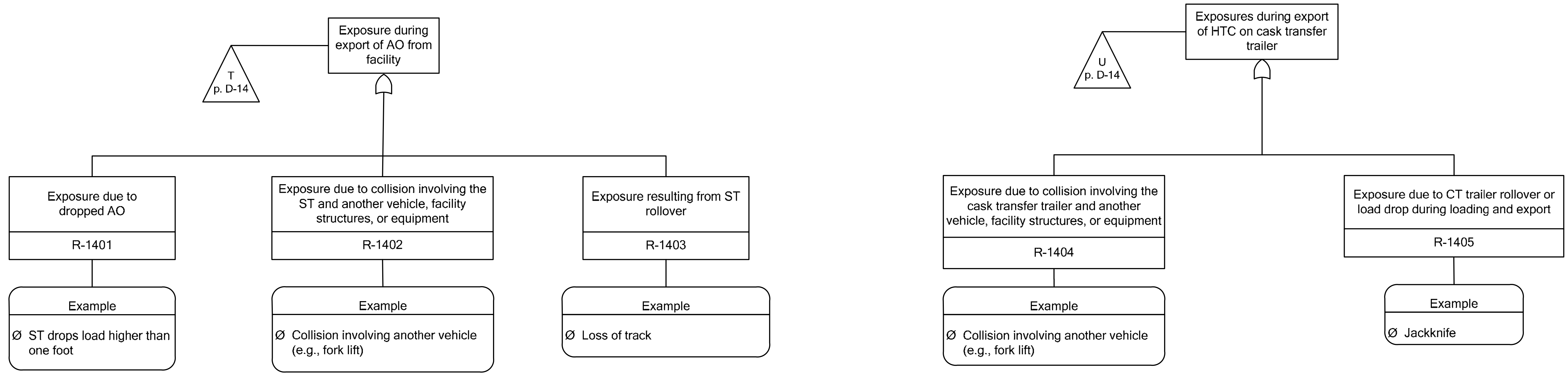
Figure D-12. Exposure Resulting from Canister Transfer Activities (e.g., CTM Operations)



NOTES: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
AO = aging overpack; CTM = canister transfer machine; HTC = a transportation cask that is never upended; ST = site transporter.

Source: Original

Figure D-13. Exposure During Exporting Activities of Aging Overpack



NOTES: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
AO = aging overpack; CT = cask transfer; HTC = a transportation cask that is never upended; ST = site transporter.

Source: Original

Figure D-14. Exposure During Export of Aging Overpack from Facility - Exposure During Export of HTC on Cask Transfer Trailer

ATTACHMENT E
RECEIPT FACILITY HAZARD AND OPPERABILITY

A hazard operations study for the RF is provided in this attachment. The HAZOP was conducted in accordance with the process described in Section 4.3.1.3. The HAZOP was conducted in a series of meetings that lasted from 4 to 8 hours for each facility. A list of attendees and biographies of the team members 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 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

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

HAZOP Meetings		
Name	**Telephone Number**	**Organization**
Mary Presley	505-272-7102	ARES
Guy Ragan	702-821-7637	BSC
Daniel Reny	505-272-7102	ARES
Clarence Smith	702-821-7126	BSC
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

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

HAZOP Meetings		
Name	**Telephone Number**	**Organization**
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
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 the 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 CRCF 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, Systematic Human Action Reliability Procedure) 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 CRCF 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

Facility/Operation: RF					Process: Receipt and Transfer into Preparation Area		
Node 1: Receive and Move TC Railcar into Preparation Area for Unloading					Process/Equipment: SPM Railcar		
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of					Consequence Categories: Radioactive Release, Lack of Shielding, Criticality		
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
1.1	Speed	(More) SPM moves too fast	Driver drives SPM too fast	Potential loss of control or collision leading to radioactive release	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training	Creeping speed	R-102
1.2	Speed	(More) SPM moves too fast	Mechanical failure of SPM	Potential loss of control or collision leading to radioactive release	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training	Creeping speed	R-102
1.3	Speed	(Less) SPM moves too slow	Mechanical failure of SPM	No safety consequences			
1.4	Speed	(No) SPM does not move	1 – Human failure 2 – Mechanical failure	No safety consequences		Always at least one-door boundary for HVAC if conveyance is stuck in doorway	
1.5	Direction	(Reverse) SPM backs up instead of going forward	1 – Human failure 2 – Mechanical failure	Potential loss of control or collision leading to radioactive release	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training	Potential loss of HVAC boundary if collision with door	R-102
1.6	Direction	(Other Than) SPM derailment	1 – Human failure 2 – Mechanical failure	Potential derailment leading to radioactive release	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training		R-101
1.7	Direction	(Other Than) SPM derailment	Rail distortion due to structural failure	Potential drop leading to radioactive release	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training 3 – Rail design		R-101
1.8	Direction	(Other Than) SPM does not follow designated route and goes to wrong location or problem area	1 – Human failure 2 – Mechanical failure	Potential loss of control or collision leading to radioactive release	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training	Faulty track or switch indicator	R-101, R-102
1.9	Parking	(Other Than) Improper positioning and constraint of cask conveyance	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training 3 – Brakes, chocks, and rail stops	Collision caused by unconstrained cask conveyance	R-102
1.10	Temperature	(More) Exceeds 10 CFR 71 temperature design basis	Fire	1 – Radioactive release 2 – Potential criticality	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training 3 – Combustible materials control	1–10 CFR 71 temperature design basis 2–Combustible materials control includes removing SPM prior to cask handling operations	R-I303 thru R-I310
1.11	Temperature	(Less) Below 10 CFR 71 temperature design basis	Normal condition	No safety consequences			
1.12	Shielding	(Less) Displacement of TC shielding	Impact or fire	Direct exposure	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training 3 – Combustible materials control	Includes reduction or complete loss of shielding	R-102, R-I303 thru R-I310

NOTE: Guidewords not used in this node: As Well As and Part Of.
HVAC = heating, ventilation, and air conditioning; RF = Receipt Facility; SPM = site prime mover; TC = transportation cask
Events that have no direct safety consequences but may be precursors to events that occur in other nodes are noted as “No safety consequences.” .

Source: Original; Ref. 2.3.3.

Table E-2A. HAZOP Worksheet

Facility/Operation: RF							Process: Export of Horizontal Cask with DPC from Preparation and Receipt Area
Node 1A: Move Horizontal TC on Transfer Trailer Out of Preparation Area							Process/Equipment: Cask Transfer Trailer with Tractor
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
1A.1	Speed	(More) Tractor moves too fast	Driver drives too fast	Potential loss of control or collision leading to radioactive release	1 – Tractor design 2 – Procedures and training		R-1404
1A.2	Speed	(More) Tractor moves too fast	Mechanical failure of SPM	Potential loss of control or collision leading to radioactive release	1 – Tractor design 2 – Procedures and training		R-1404
1A.3	Speed	(Less) Tractor moves too slow	Mechanical failure of SPM	No safety consequences			
1A.4	Speed	(No) Tractor or trailer does not move	1 – Human failure 2 – Mechanical failure	No safety consequences		Always at least one-door boundary for HVAC if conveyance is stuck in doorway	
1A.5	Direction	(Reverse) Backs up instead of going forward	1 – Human failure 2 – Mechanical failure	Potential loss of control or collision leading to radioactive release	1 – Tractor design 2 – Procedures and training	Potential loss of HVAC boundary if collision with door	R-1404
1A.6	Direction	(Other Than) Does not follow designated route and goes to wrong location or problem area	1 – Human failure 2 – Mechanical failure	Potential loss of control or collision leading to radioactive release	Procedures and training		R-1404
1A.7	Temperature	(More) Exceeds 10 CFR 71 temperature design basis	Fire	1 – Radioactive release 2 – Potential criticality	1 – Procedures and training 2 – Combustible materials control	Combustible materials control includes removing SPM prior to cask handling operations	R-I303 thru R-I310
1A.8	Temperature	(Less) Below 10 CFR 71 temperature design basis	Normal condition	No safety consequences			
1A.9	Shielding	(Less) Displacement of horizontal TC shielding	Impact or fire	Direct exposure	1 – Procedures and training 2 – Combustible materials control	Includes reduction or complete loss of shielding	R-1404 R-I303 thru R-I310

NOTE: Guidewords not used in this node: As Well As and Part Of.
DPC = dual-purpose canister; HVAC = heating, ventilation, and air conditioning; RF = Receipt Facility; SPM = site prime mover; TC = transportation cask.
Events that have no direct safety consequences but may be precursors to events that occur in other nodes are noted as “No safety consequences.”

Source: Original; Ref. 2.3.3.

Table E-3. HAZOP Worksheet

Facility/Operation: RF							Process: TC Unloading
Node 2: Remove Impact Limiters from TC							Process/Equipment: Railcar, Cask Handling Crane (Auxiliary Hook), Cask Access Platform
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
2.1	Load	(More) Load lifted too heavy for crane	Failure to remove restraining bolt on impact limiters	Drop of load leading to radioactive release	1 – TC design 2 – Procedures and training 3 – Crane design and below-the-hook devices	20-ton hoist	R-611
2.2	Load	(Less) Load lifted too light		No safety consequences			
2.3	Speed (Crane)	(More) Hook lowers too fast	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – TC design 2 – Procedures and training 3 – Crane design		R-611
2.4	Speed (Crane)	(Less) Hook lowers too slow		No safety consequences			
2.5	Travel (Crane)	(Other Than) Crane moves with hook lowered	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – TC design 2 – Procedures and training 3 – Crane design		R-613
2.6	Travel (Crane)	(More) Crane moves past desired position for activity	1 – Human failure 2 – Mechanical failure	No safety consequences			
2.7	Travel (Crane)	(Less) Crane does not move into desired position for activity	1 – Human failure 2 – Mechanical failure	No safety consequences			
2.8	Travel (Crane)	(Reverse) Travels in wrong direction	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – TC design 2 – Procedures and training 3 – Crane design		R-613
2.9	Motor	(More) Motor temperature too high	1 – Human failure 2 – Mechanical malfunction	No safety consequences		Potential fire scenario	R-I303 thru R-I310
2.10	Maintenance	(No) Improper maintenance of crane	Human failure	No safety consequences	Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	
2.11	Controls (PLC)	(Other Than)		No safety consequences		Considered in event sequence development (event tree/FTA/HRA)	
2.12	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment	No safety consequences	1 – Crane operator training program 2 – Human factor evaluation 3 – Industrial hygiene standards	Considered in HRA	
2.13	Alignment	(Other Than)	See 2.5 through 2.8 above	No safety consequences			
2.14	Mobile Access Platform Operations	(Other Than) Impact from operational activities	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – TC design 2 – Procedures and training 3 – Platform and tool design		R-614

NOTE: Guidewords not used in this node: As Well As and Part Of.
FTA = fault-tree analysis; HRA = human-reliability analysis; PLC = programmable logic controller; RF = Receipt Facility; TC = transportation cask.
Events that have no direct safety consequences but may be precursors to events that occur in other nodes are noted as “No safety consequences.”

Source: Original

Table E-4. HAZOP Worksheet

Facility/Operation: RF							Process: TC Unloading
Node 3: Attach Lift Yoke to TC on Railcar							Process/Equipment: Railcar, 200-Ton Crane, Lift Yoke, Trunnions (as required)
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, 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 (Crane)	(More) Yoke lowers too fast	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – Procedures and training 2 – Crane design	TC design may mitigate event, depending on passive equipment failure analysis	R-504
3.2	Speed (Crane)	(Less) Yoke lowers too slow		No safety consequences			
3.3	Travel (Crane)	(Other Than) Crane moves with yoke lowered	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – Procedures and training 2 – Crane design	TC design may mitigate event, depending on passive equipment failure analysis	R-504
3.4	Motor	(More) Motor temperature too high	1 – Human failure 2 – Mechanical malfunction	No safety consequences		Potential fire scenario	R-I303 thru R-I310
3.5	Maintenance	(No) Improper maintenance of crane	Human failure	No safety consequences	Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	
3.6	Controls (PLC)	(Other Than)		No safety consequences		Considered in event sequence development (event tree/FTA/HRA)	
3.7	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment	No safety consequences	1 – Crane operator training program 2 – Human factor evaluation 3 – Industrial hygiene standards	Considered in HRA	
3.8	Mobile Access Platform Operations	(Other Than) Impact from operational activities	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – TC design 2 – Procedures and training 3 – Platform and tool design		R-509
3.9	Engagement (Yoke)	(More) Over-travel on yoke arm positioning	1 – Human failure 2 – Mechanical failure	Potential drop of TC leading to radioactive release	1 – Positioning interlocks 2 – Yoke adjustment motor design 3 – Pin alignment 4 – Procedures and training		R-501
3.10	Engagement (Yoke)	(Less) Under-travel on yoke arm positioning	1 – Human failure 2 – Mechanical failure	Potential drop of TC leading to radioactive release	1 – Positioning interlocks 2 – Yoke adjustment motor design 3 – Pin alignment 4 – Procedures and training	Potential partial yoke engagement	R-501
3.11	Engagement	(No) Yoke fails to engage		No safety consequence			
3.12	Yoke	(Other Than) Trunnion installed incorrectly	1 – Human failure 2 – Mechanical failure	Potential drop of TC leading to radioactive release	1 – Procedures and training 2 – Trunnion design	As required for certain casks	R-501

NOTE: Guidewords not used in this node: Reverse, As Well As, and Part Of.
FTA = fault-tree analysis; HRA = human-reliability analysis; PLC = programmable logic controller; RF = Receipt Facility; TC = transportation cask.
[a]Events that have no direct safety consequences but may be precursors to events that occur in other nodes are noted as “No safety consequences.”

Source: Original

Table E-4A. HAZOP Worksheet

Facility/Operation: RF							Process: TC Unloading
Node 3A: Install Trunnions on Horizontal Storage TC on Cask Stand							Process/Equipment: Cask Stand, 200-Ton Crane, Trunnions
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
3A.1	Speed	(More) Trunnions lowered too fast	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – Procedures and training 2 – Crane design	TC design may mitigate event, depending on passive equipment failure analysis	R-606
3A.2	Speed (Crane)	(Less) Trunnions lowered too slow		No safety consequences			
3A.3	Travel (Crane)	(Other Than) Crane moves with yoke lowered	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – Procedures and training 2 – Crane design	TC design may mitigate event, depending on passive equipment failure analysis	R-607
3A.4	Motor	(More) Motor temperature too high	1 – Human failure 2 – Mechanical malfunction	No safety consequences		Potential fire scenario	R-I303 thru R-I310
3A.5	Maintenance	(No) Improper maintenance of crane	Human failure	No safety consequences	Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	
3A.6	Controls (PLC)	(Other Than)		No safety consequences		Considered in event sequence development (event tree/FTA/HRA)	
3A.7	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment	No safety consequences	1 – Crane operator training program 2 – Human factor evaluation 3 – Industrial hygiene standards	Considered in HRA	
3A.8	Trunnions	(Other Than) Trunnion installed incorrectly	1 – Human failure 2 – Mechanical failure	Potential drop of TC leading to radioactive release	1 – Procedures and training 2 – Trunnion design	As required for certain casks	R-1405

NOTE: Guidewords not used in this node: Reverse, As Well As, and Part Of.
FTA = fault-tree analysis; HRA = human-reliability analysis; PLC = programmable logic controller; RF = Receipt Facility; TC = transportation cask.
Events that have no direct safety consequences but may be precursors to events that occur in other nodes are noted as “No safety consequences.”

Source: Original

Table E-5. HAZOP Worksheet

Facility/Operation: RF					Process: TC Unloading		
Node 4: Upright TC on Railcar					Process/Equipment: Railcar, 200-Ton Crane		
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of					Consequence Categories: Radioactive Release, Lack of Shielding, Criticality		
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
4.1	Load	(More) Load lifted too heavy for crane	Failure to remove tie-downs	Drop of load leading to radioactive release	1 – Procedures and training 2 – Crane design	1 – 200-ton hoist 2 – TC may mitigate event, depending on passive equipment failure analysis	R-501
4.2	Load	(Less) Load lifted too light		No safety consequences			
4.3	Speed (Crane and Hook)	(More or Less) Hook and crane speed not matched during lifting motion	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – Procedures and training 2 – Crane design and below-the-hook design	TC may mitigate event, depending on passive equipment failure analysis	R-501
4.4	Travel (Crane)	(Reverse) Travels in wrong direction	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – Procedures and training 2 – Crane design and below-the-hook design	1 – TC may mitigate event, depending on passive equipment failure analysis 2 – Crane feature to prevent rapid rundown needs to be subjected to FTA	R-502
4.5	Motor	(More) Motor temperature too high	1 – Human failure 2 – Mechanical malfunction	Potential radioactive release		Potential fire scenario	R-I303 thru R-I310
4.6	Motor Motive Force	(Less or No) Loss of motive force allows rapid rundown	1 – Human failure 2 – Mechanical malfunction	Potential radioactive release	Crane design and below-the-hook design	1 – TC may mitigate event, depending on passive equipment failure analysis 2 – Crane feature to prevent rapid rundown needs to be subjected to FTA	R-501
4.7	Maintenance	(No) Improper maintenance of crane	Human failure	Potential radioactive release	Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	R-501
4.8	Controls (PLC)	(Other Than) Control system failures	1 – Human failure 2 – Mechanical malfunction	Potential radioactive release	Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	R-501, R-502, R-503
4.9	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment	Potential radioactive release resulting from slap-down	1 – Crane operator training program 2 – Human factor evaluation 3 – Industrial hygiene standards	Considered in HRA	R-501
4.10	Alignment	(Other Than)	See 4.3 above				R-501
4.11	Pivot Point	(Other Than) Pivot point constraint fails	Cover brackets fail or are removed out of sequence	Potential radioactive release resulting from slap-down	1 – Transportation skid pedestal design 2 – Procedures and training		R-501

NOTE: Guidewords not used in this node: As Well As and Part Of.
FTA = fault-tree analysis; HRA = human-reliability analysis; PLC = programmable logic controller; RF = Receipt Facility; TC = transportation cask.
Events that have no direct safety consequences but may be precursors to events that occur in other nodes are noted as “No safety consequences.”

Source: Original

Table E-6. HAZOP Worksheet

Facility/Operation: RF				Process: TC Unloading			
Node 5: Transfer TC to CTT (Air Pallet)				Process/Equipment: Railcar, 200-Ton Crane, CTT			
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of				Consequence Categories: Radioactive Release, Lack of Shielding, Criticality			
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
5.1	Pedestal	(Other Than) Chooses wrong cask pedestal	Human failure	Cask tip-over resulting in release	1 – Procedures and training 2 – Pedestal design	1 – Human factors 2 – Scheduling by campaigns may minimize occurrence	R-508, R-809
5.2	Lift	(More) Two-blocking	1 – Human failure 2 – Mechanical malfunction	Potential radioactive release resulting from drop	1 – Crane design 2 – Procedures and training	1 – TC may mitigate event, depending on passive equipment failure analysis 2 – 20 ft or greater drop considered	R-506, R-807
5.3	Lift	(Less) Not lifted high enough to clear other structures or equipment	1 – Human failure 2 – Mechanical malfunction	Potential radioactive release resulting from drop or impact	Procedures and training		R-505, R-508, R-809
5.4	Lift	(No)		No safety consequences			N/A
5.5	Lift	(Reverse) Rapid rundown	1 – Human failure 2 – Mechanical malfunction	Potential radioactive release resulting from drop or impact	1 – Crane design 2 – Procedures and training	TC may mitigate event, depending on passive equipment failure analysis	R-506, R-807
5.6	Speed (Crane)	(More) Crane moves faster than allowed by procedures	1 – Human failure 2 – Mechanical failure	Potential radioactive release resulting from collision with structures or equipment	1 – Crane design 2 – Procedures and training	TC design may mitigate event, depending on passive equipment failure analysis	R-508, R-809
5.7	Speed (Crane)	(Less) Crane moves too slow	1 – Human failure 2 – Mechanical failure	Potential radioactive release resulting from drop	Procedures and training	Prolonged exposure time for sequence initiation	R-508, R-809
5.8	Speed (Crane)	(Other Than) Abrupt stop	1 – Human failure 2 – Mechanical failure	Potential radioactive release resulting from collision with structures or equipment	1 – Crane design 2 – Procedures and training	TC design may mitigate event, depending on passive equipment failure analysis	R-506, R-807
5.9	Alignment (Trolley)	(No) Improper alignment	Human failure	Potential radioactive release resulting from collision with structures or equipment	Procedures and training	Check for self-aligning features or electronic-aligning features	R-508, R-809

NOTE: Guidewords not used in this node: As Well As and Part Of.
CTT = cask transfer trolley; ft = feet; RF = Receipt Facility; TC = transportation cask.
Events that have no direct safety consequences but may be precursors to events that occur in other nodes are noted as "No safety consequences."

Source: Original

Table E-7. HAZOP Worksheet

Facility/Operation: RF						Process: TC Unloading	
Node 6: Attach Slings to TC on Railcar for Horizontal Lift						Process/Equipment: Railcar, 200-Ton Crane, Lift Slings	
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of						Consequence Categories: Radioactive Release, Lack of Shielding, 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 (Crane)	(More) Slings lowered too fast	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – Procedures and training 2 – Crane design	TC design may mitigate event, depending on passive equipment failure analysis	R-603, R-703
6.2	Speed (Crane)	(Less) Slings lowered too slow		No safety consequences			
6.3	Travel (Crane)	(Other Than) Crane moves with slings lowered	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – Procedures and training 2 – Crane design	TC design may mitigate event, depending on passive equipment failure analysis	R-603, R-704
6.4	Motor	(More) Motor temperature too high	1 – Human failure 2 – Mechanical malfunction	No safety consequences		Potential fire scenario	R-I303 thru R-I310
6.5	Maintenance	(No) Improper maintenance of crane	Human failure	No safety consequences	Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	
6.6	Controls (PLC)	(Other Than)		No safety consequences		Considered in event sequence development (event tree/FTA/HRA)	
6.7	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment	No safety consequences	1 – Crane operator training program 2 – Human factor evaluation 3 – Industrial hygiene standards	Considered in HRA	
6.8	Mobile Access Platform Operations	(Other Than) Impact from operational activities	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – TC design 2 – Procedures and training 3 – Platform and tool design		R-705
6.9	Engagement (Slings)	(More) Over-travel on sling arm positioning	1 – Human failure 2 – Mechanical failure	Potential drop of TC leading to radioactive release	1 – Positioning interlocks 2 – Sling adjustment motor design 3 – Pin alignment 4 – Procedures and training		R-608, R-701
6.10	Engagement (Slings)	(Less) Under-travel on sling arm positioning	1 – Human failure 2 – Mechanical failure	Potential drop of TC leading to radioactive release	1 – Positioning interlocks 2 – Sling adjustment motor design 3 – Pin alignment 4 – Procedures and training	Potential partial sling engagement	R-608, R-701
6.11	Engagement (Slings)	(No) Failed to engage		No safety consequences			

NOTE: Guidewords not used in this node: Reverse, As Well As, and Part Of.
FTA = fault-tree analysis; HRA = human-reliability analysis; PLC = programmable logic controller; RF = Receipt Facility; TC = transportation cask.
Events that have no direct safety consequences but may be precursors to events that occur in other nodes are noted as “No safety consequences.”

Source: Original

Table E-8. HAZOP Worksheet

Facility/Operation: RF							Process: TC Unloading
Node 7: Horizontal Transfer of Cask Between Rail Car, Cask Stand and Lift Fixture or Cask Transfer Trailer							Process/Equipment: Railcar, 200-Ton Crane, Cask Stand
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, 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 (Crane)	(More) Cask lowers too fast	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – Procedures and training 2 – Crane design	TC design may mitigate event, depending on passive equipment failure analysis	R-608, R-801
7.2	Speed (Crane)	(Less) Cask lowers too slow		No safety consequences			N/A
7.3	Travel (Crane)	(Other Than) Crane moves with cask lowered	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – Procedures and training 2 – Crane design	TC design may mitigate event, depending on passive equipment failure analysis	R-610, R-803
7.4	Motor	(More) Motor temperature too high	1 – Human failure 2 – Mechanical malfunction	No safety consequences		Potential fire scenario	R-I303 thru R-I310
7.5	Maintenance	(No) Improper maintenance of crane	Human failure	No safety consequences	Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	N/A
7.6	Controls (PLC)	(Other Than)		No safety consequences		Considered in event sequence development (event tree/FTA/HRA)	N/A
7.7	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment	No safety consequences	1 – Crane operator training program 2 – Human factor evaluation 3 – Industrial hygiene standards	Considered in HRA	N/A
7.8	Lift	(More) Two-blocking	1 – Human failure 2 – Mechanical malfunction	Potential radioactive release resulting from drop	1 – Crane design 2 – Procedures and training	1 – TC design may mitigate event, depending on passive equipment failure analysis 2 – 20 ft or greater drop considered	R-608, R-801
7.9	Lift	(Less) Not lifted high enough to clear other structures or equipment	1 – Human failure 2 – Mechanical malfunction	Potential radioactive release resulting from drop or impact	Procedures and training		R-610, R-803
7.10	Lift	(No)		No safety consequences			N/A
7.11	Lift	(Reverse) Rapid rundown	1 – Human failure 2 – Mechanical malfunction	Potential radioactive release resulting from drop or impact	1 – Crane design 2 – Procedures and training	TC design may mitigate event, depending on passive equipment failure analysis	R-608, R-801, R-802
7.12	Speed (Crane)	(More) Crane moves faster than allowed by procedures	1 – Human failure 2 – Mechanical failure	Potential radioactive release resulting from collision with structures or equipment	1 – Crane design 2 – Procedures and training	TC design may mitigate event, depending on passive equipment failure analysis	R-610, R-803
7.13	Speed (Crane)	(Less) Crane moves too slow	1 – Human failure 2 – Mechanical failure	Potential radioactive release resulting from drop	Procedures and training	Prolonged exposure time for sequence initiation	R-801
7.14	Speed (Crane)	(Other Than) Abrupt stop	1 – Human failure 2 – Mechanical failure	Potential radioactive release resulting from collision with structures or equipment	1 – Crane design 2 – Procedures and training	TC design may mitigate event, depending on passive equipment failure analysis	R-801
7.15	Lift	(Other Than) 200-ton crane used instead of 20-ton entrance vestibule crane to remove impact limiters	Human failure	Drop of cask resulting in release	1 – Procedures and training 2 – Hook design		R-801

NOTE: Guidewords not used in this node: As Well As and Part Of.
ft = feet; FTA = fault-tree analysis; HRA = human-reliability analysis; PLC = programmable logic controller; RF = Receipt Facility; TC = transportation cask.
Events that have no direct safety consequences but may be precursors to events that occur in other nodes are noted as “No safety consequences.”

Source: Original

Table E-9. HAZOP Worksheet

Facility/Operation: RF							Process: TC Unloading
Node 8: Move Horizontal TC from Cask Stand onto Cask Tilting Frame and Upend							Process/Equipment: 200-Ton Crane, Tilting Frame
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
8.1	Load	(More) Load lifted too heavy for crane	Human failure	Drop of load leading to radioactive release	1 – Procedures and training 2 – Crane design	1 – 200-ton hoist 2 – TC design may mitigate event, depending on passive equipment failure analysis	R-806, R-807
8.2	Load	(Less) Load lifted too light		No safety consequences			N/A
8.3	Speed (Crane and Hook)	(More/Less) Hook and crane speed not matched during lifting motion	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – Procedures and training 2 – Crane design and below-the-hook design	TC design may mitigate event, depending on passive equipment failure analysis	R-806, R-807
8.4	Travel (Crane)	(Reverse) Travels in wrong direction	1 – Human failure 2 – Mechanical failure	Potential radioactive release	1 – Procedures and training 2 – Crane design and below-the-hook design	1 – TC design may mitigate event, depending on passive equipment failure analysis 2 – Crane feature to prevent rapid rundown needs to be subjected to FTA	R-806, R-807
8.5	Temperature	(More) Motor temperature too high	1 – Human failure 2 – Mechanical malfunction	Potential radioactive release		Potential fire scenario	R-I303 thru R-I310
8.6	Motor Motive Force	(Less/No) Loss of motive force allows rapid rundown	1 – Human failure 2 – Mechanical malfunction	Potential radioactive release		1 – TC design may mitigate event, depending on passive equipment failure analysis 2 – Crane feature to prevent rapid rundown needs to be subjected to FTA	R-806, R-807
8.7	Maintenance	(No) Improper maintenance of crane	Human failure	Potential radioactive release	Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	N/A
8.8	Controls (PLC)	(Other Than) Control system failures	1 – Human failure 2 – Mechanical malfunction	Potential radioactive release	Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	N/A
8.9	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment	Potential radioactive release resulting from slap-down	1 – Crane operator training program 2 – Human factor evaluation 3 – Industrial hygiene standards	Considered in HRA	R-804, R-806, R-810
8.10	Alignment	(Other Than)	See 8.3 above				N/A
8.11	Pivot Point	(Other Than) Pivot point constraint fails	Cover brackets fail or are removed out of sequence	Potential radioactive release resulting from slap-down	1 – Transportation skid pedestal design 2 – Procedures and training		R-804, R-809
8.12	L-Frame	(Other Than) Cask not secured to L-frame prior to bringing upright	1 – Human failure 2 – Mechanical failure	Potential radioactive release from drop or impact	1 – Procedures and training 2 – L-frame design		R-804, R-807
8.13	L-Frame	(Other Than) Failure to release cask from L-frame after bringing upright	Human failure	Potential radioactive release from drop or impact	Procedures and training		R-804, R-807

NOTE: Guidewords not used in this node: As Well As and Part Of.
FTA = fault-tree analysis; HRA = human-reliability analysis; PLC = programmable logic controller; RF = Receipt Facility; TC = transportation cask.
Events that have no direct safety consequences but may be precursors to events that occur in other nodes are noted as “No safety consequences.”

Source: Original

Table E-10. HAZOP Worksheet

Facility/Operation: RF						Process: TC Preparation	
Node 9: Prepare Cask for Unloading						Process/Equipment: Preparation Station, Common Tools, Cask Shield Ring, Standard Rigging, Cask Handling Crane	
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of						Consequence Categories: Radioactive Release, Lack of Shielding, Criticality	
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
9.1	Load	(More) Too much load for crane	1 – Human failure 2 – Equipment failure	Potential release of materials in cask canister annulus to environment	1 – Procedures and training 2 – TC design	TC design may mitigate event, depending on passive equipment failure analysis	R-902, R-903
9.2	Load	(Less) Too light		No safety consequences			N/A
9.3	Loosen/Remove Lid Bolts	(Other Than) Failure to remove	Human failure	No safety consequences		1 – Sequence of bolt removal and installation of lift fixture may impact human failure probability associated with failure to remove bolts 2 – Precursor to cask drop if remaining bolts overloaded	N/A
9.4	Loosen/Remove Lid Bolts	(Reverse) Tighten bolts instead of loosen	1 – Human failure 2 – Equipment failure	No safety consequences		Potential precursor to cask drop if remaining bolts overloaded	N/A
9.5	Attach TC Lid Lift Fixture	(Other Than) Improper attachment	1 – Human failure 2 – Equipment failure	No safety consequences	1 – Procedures and training 2 – Potentially precluded by design	Potential precursor to cask lid drop	N/A
9.6	Remove TC Lid	(More) Attempting to lift more than lid alone (see 9.3 and 9.4 above)	Human failure	Potential drop of cask when attempting to remove lid leading to radioactive release	1 – Procedures and training 2 – Crane design features	Model crane overload protection features and failure modes	R-903, R-1003
9.7	Remove TC Lid	(More) Attempting to lift lid too high (i.e., two-blocking)	Human failure	Potential drop of lid onto canister leading to radioactive release	1 – Procedures and training 2 – Crane design features		R-902, R-1001
9.8	Remove TC Lid	(Less) Not lifting lid high enough to clear cask	Human failure	Catch of lid on cask causing cask to tip over and leading to radioactive release	Procedures and training		R-1004
9.9	Remove TC Lid	(Other Than) Lift with fixture improperly attached (see 9.5 above)	Human failure	Potential drop of lid onto canister leading to radioactive release	Procedures and training		R-1001
9.10	Install Shield Ring	(More) Lift too high	1 – Human failure 2 – Equipment failure	Drop of ring onto canister leading to radioactive release	Procedures and training	Shield ring installation includes attaching ring to auxiliary hook of cask crane and moving it to shield stand	R-1001
9.11	Install Shield Ring	(Less) Lift does not lift high enough to clear cask	Human failure	Impact to side of cask leading to cask and canister drop and radioactive release	Procedures and training		R-1005
9.12	Install Shield Ring	(No) No installation	Human failure	Direct exposure	Procedures and training		R-1008
9.13	Install Shield Ring	(Other Than) Improperly installed	Human failure	Direct exposure	Procedures and training	Improper installation includes lopsided installation or misalignment	R-1008
9.14	Install Canister Lift Fixture	(More) Lift too high	1 – Human failure 2 – Equipment failure	Drop of fixture onto canister leading to radioactive release	Procedures and training	Lifted by auxiliary hook of cask crane	R-902
9.15	Install Canister Lift Fixture	(Less) Lift not high enough to clear cask	Human failure	Impact to side of cask leading to potential cask and canister drop and radioactive release	Procedures and training		R-902

Table E-10. HAZOP Worksheet (Continued)

Facility/Operation: RF							Process: TC Preparation
Node 9: Prepare Cask for Unloading							Process/Equipment: Preparation Station, Common Tools, Cask Shield Ring, Standard Rigging, Cask Handling Crane
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
9.16	Install Canister Lift Fixture	(Other Than) Improperly installed for movement to installation position	Human failure	Drop of fixture onto canister leading to radioactive release	Procedures and training		R-902
9.17	Install Canister Lift Fixture	(Other Than) Improperly installed	Human failure	No safety consequences	Procedures and training	Precursor to canister drop during lift	N/A
9.18	Remove and Store Shield Ring	(More) Lift too high	1–Human failure 2–Equipment failure	Drop of ring onto canister leading to radioactive release	Procedures and training		R-1001
9.19	Remove and Store Shield Ring	(Less) Lift not high enough to clear cask	Human failure	Impact on side of cask leading to potential cask and canister drop and radioactive release	Procedures and training		R-1002
9.20	Remove and Store Shield Ring	(No) No removal	Human failure	No safety consequences	Procedures and training	Precursor to drop of or impact to canister during CTM lift	N/A

NOTE: Guidewords not used in this node: As Well As and Part Of.
CTM = canister transfer machine; RF = Receipt Facility; TC = transportation cask.
Events that have no direct safety consequences but may be precursors to events that occur in other nodes are noted as “No safety consequences.”

Source: Original

Table E-11. HAZOP Worksheet

Facility/Operation: RF							Process: TC/DPC Preparation
Node 10: Move CTT into Cask Unloading Room							Process/Equipment: CTT
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
10.1	CTT Lift	(More) Too much lift	No cause identified			Unable to lift more than 5/16-inch over longest dimension	N/A
10.2	CTT Lift	(Less) Not enough lift	1 – Lack of air pressure 2 – Cone malfunction	No safety consequences			N/A
10.3	CTT Lift	(Other Than) Uneven lift	Cone malfunction	No safety consequences		Unable to lift more than 5/16-inch over longest dimension	N/A
10.4	CTT Lift	(Other Than) Drop	Loss of air	No safety consequences			N/A
10.5	CTT Movement	(More) Moves too far	1 – Human failure 2 – Mechanical malfunction	Potential collision leading to radioactive release	1 – Procedures and training 2 – CTT design 3 – TC design	Shield door open, collision with facility structure	R-1102
10.6	CTT Movement	(More) Moves too far	1 – Human failure 2 – Mechanical malfunction	Potential collision leading to radioactive release	1 – Procedures and training 2 – CTT design 3 – TC design	Shield door closed, collision with shield door	R-1102
10.7	CTT Movement	(Less) Does not move enough	1 – Human failure 2 – Mechanical malfunction	No safety consequences			N/A
10.8	CTT Movement	(Reverse) Moves in opposite direction	1 – Human failure 2 – Mechanical malfunction	Potential collision leading to radioactive release	1 – Procedures and training 2 – CTT design 3 – TC design		R-1102, R-1103
10.9	CTT Movement	(Other Than) Sideways movement	1 – Human failure 2 – Mechanical malfunction	Potential collision leading to radioactive release	1 – Procedures and training 2 – CTT design 3 – TC design		R-1102, R-1103
10.10	Shield Door Movement	(Other Than) Spurious closure of shield door	1 – Human failure 2 – Mechanical malfunction	Potential collision leading to radioactive release	1 – Procedures and training 2 – Design of shield-door controls 3 – TC design		R-1101
10.11	Preparation Platform Position	(Other Than) Out of position leading to platform collision with CTT frame	1 – Human failure 2 – Mechanical malfunction	Potential collision leading to radioactive release	1 – Procedures and training 2 – CTT design 3 – TC design		R-1102

NOTE: Guidewords not used in this node: No, As Well As, and Part Of.
CTT = cask transfer trolley; DPC = dual-purpose canister; RF = Receipt Facility; TC = transportation cask.
Events that have no direct safety consequences but may be precursors to events that occur in other nodes are noted as “No safety consequences.”

Source: Original

Table E-12. HAZOP Worksheet

Facility/Operation: RF — Process: CTM Operation

Node 11: Remove Canister from Cask using CTM (Vertical CTM Movement) — Process/Equipment: CTM, CTM Bay/Cell

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

Node Item Number	Parameter	Deviation Considered	Postulated Cause	Consequence(s)	Potential Prevention/Mitigation Design of Operational Feature	Notes	MLD Index Number
11.1	Shield Door Movement	(Other Than) Failure to close shield door	1 – Human failure 2 – Mechanical malfunction	Direct exposure	1 – Procedures and training 2 – Design of shield-door controls	Must be concurrent with removal of canister	R-1201
11.2	Shield Door Movement	(Other Than) Spurious opening of shield door	1 – Human failure 2 – Mechanical malfunction	Direct exposure	1 – Procedures and training 2 – Design of shield-door controls	Must be concurrent with removal of canister	R-1201
11.3	Shield Door Movement	(Other Than) Failure to evacuate personnel prior to door closure	1 – Human failure 2 – Mechanical malfunction	Direct exposure	1 – Procedures and training 2 – Design of shield-door controls	Must be concurrent with removal of canister	R-1201
11.4	Port Slide Gate	(Other Than) Failure to open slide gate	1 – Human failure 2 – Mechanical malfunction	No safety consequences	1 – Procedures and training 2 – Design of slide-gate controls		
11.5	Port Slide Gate	(Other Than) Failure to close slide gate	1 – Human failure 2 – Mechanical malfunction	Potential direct exposure to personnel on second floor when CTM moves	1 – Procedures and training 2 – Design of slide-gate controls		R-1201
11.6	Port Slide Gate	(Other Than) Opening of port slide gate	1 – Human failure 2 – Mechanical malfunction	Potential direct exposure to personnel on second floor when CTM moves	1 – Procedures and training 2 – Design of slide-gate controls		R-1201
11.7	Port Slide Gate	(Other Than) Closure while lifting canister	1 – Human failure 2 – Mechanical malfunction	Potential release	1 – Procedures and training 2 – Design of slide-gate controls	Examine closures on rope as well as canister	R-1207, R-1208
11.8	CTM Slide Gate	(Other Than) Failure to open slide gate	1 – Human failure 2 – Mechanical malfunction	No safety consequences	1 – Procedures and training 2 – Design of slide-gate controls		
11.9	CTM Slide Gate	(Other Than) Failure to close slide gate	1 – Human failure 2 – Mechanical malfunction	Potential direct exposure to personnel on second floor when skirt lifts	1 – Procedures and training 2 – Design of slide-gate controls		R-1201
11.10	CTM Slide Gate	(Other Than) Opening of CTM slide gate	1 – Human failure 2 – Mechanical malfunction	Potential direct exposure to personnel on second floor when skirt lifts	1 – Procedures and training 2 – Design of slide-gate controls		R-1201
11.11	CTM Slide Gate	(Other Than) Closure while lifting canister	1 – Human failure 2 – Mechanical malfunction	Potential release	1 – Procedures and training 2 – Design of slide-gate controls	N/A Examine closures on rope as well as canister	R-1208, R-1209
11.12	Lid Grapple Engagement	(Other Than) Improper attachment	1 – Human failure 2 – Equipment failure	No safety consequences	1 – Procedures and training 2 – Potentially precluded by design	Potential precursor to cask lid drop	N/A
11.13	Remove TC Lid	(More) Attempting to lift more than lid alone	Human failure	Potential radioactive release from drop of cask when attempting to remove lid	1 – Procedures and training 2 – Crane design features	Model crane overload protection features and failure modes	R-1105
11.14	Remove TC Lid	(More) Attempting to lift lid too high (i.e., two-blocking)	Human failure	Potential radioactive release from drop of lid onto canister	1 – Procedures and training 2 – Crane design features	Does not apply to DPC canisters	R-1104
11.15	Remove TC Lid	(Less) Not lifting lid high enough to clear cask	Human failure	Potential radioactive release from drop of lid onto canister	Procedures and training	Does not apply to DPC canisters N/A	R-1105
11.16	Remove TC Lid	(Other Than) Lift with grapple improperly attached (see 11.12 above)	Human failure	Potential radioactive release from drop of cask lid onto canister	Procedures and training	Does not apply to DPC canisters	R-1104
11.17	Canister Grapple Engagement	(Other Than) Improper attachment	1 – Human failure 2 – Equipment failure	No safety consequences	1 – Procedures and training 2 – Potentially precluded by design	Potential precursor to canister drop	N/A

Table E-12. HAZOP Worksheet (Continued)

Facility/Operation: RF							Process: CTM Operation
Node 11: Remove Canister from Cask using CTM (Vertical CTM Movement)							Process/Equipment: CTM, CTM Bay/Cell
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
11.18	Lift Canister	(More) Attempting to lift more than canister	Human failure	Potential drop of canister leading to radioactive release	1 – Procedures and training 2 – CTM design features	Model CTM overload protection features and failure modes	N/A
11.19	Lift Canister	(More) Attempting to lift canister too high (i.e., two-blocking)	Human failure	1 – Potential drop of canister leading to radioactive release 2 – Direct exposure if lifted above top of shield bell	1 – Procedures and training 2 – CTM design features		R-1202
11.20	Lift Canister	(Less) Not lifting canister high enough to clear floor	Human failure	Potential shear of canister or cable when CTM moved leading to radioactive release	Procedures and training		R-1203, R-1207
11.21	Lift Canister	(Other Than) Movement of carrier (CTT) during lift of canister	Human failure	Potential shear of canister or cable if carrier moves during lift leading to radioactive release	1 – Procedures and training 2 – CTT and ST design features		R-1205
11.22	Lift Canister	(Other Than) Miscellaneous mechanical failures	Mechanical malfunction	Potential drop leading to radioactive release	CTM design features	Maintenance program	R-1210, R-1211
11.23	Lift Canister	(Other Than) Lift with grapple improperly attached (see 11.17 above)	1 – Human failure 2 – Mechanical malfunction	Potential drop of canister leading to radioactive release	Procedures and training		R-1212

NOTE: Guidewords not used in this node: No, Reverse, As Well As, and Part Of.
CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; RF = Receipt Facility; ST = site transporter; TC = transportation cask.
Events that have no direct safety consequences but may be precursors to events that occur in other nodes are noted as “No safety consequences.”

Source: Original

Table E-13. HAZOP Worksheet

Facility/Operation: RF						Process: CTM Operation	
Node 12: Move CTM Laterally						Process/Equipment: CTM	
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of						Consequence Categories: Radioactive Release, Lack of Shielding, Criticality	
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
12.1	Speed (CTM)	(More) CTM moves faster than allowed by procedures	1 – Human failure 2 – Mechanical failure	Potential radioactive release resulting from collision with structures or equipment	1 – CTM design 2 – Procedures and training		R-1203
12.2	Speed (CTM)	(No) CTM stuck in middle of room during move	1 – Human failure 2 – Mechanical failure	Potential radioactive release due to heat-up, etc.		Verify cooling requirements	R-101
12.3	Speed (CTM)	(Less) CTM moves too slow	1 – Human failure 2 – Mechanical failure	No safety consequences			N/A
12.4	Speed (CTM)	(Other Than) Abrupt stop	1 – Human failure 2 – Mechanical failure	Potential radioactive release resulting from collision between canister and CTM	1 – CTM design 2 – Procedures and training		R-1203
12.5	Direction (CTM)	(More) CTM moves too far	1 – Human failure 2 – Mechanical failure	Potential radioactive release resulting from collision with structures or equipment	1 – CTM design 2 – Procedures and training		R-1203
12.6	Direction (CTM)	(Less) CTM does not move enough	1 – Human failure 2 – Mechanical failure	No safety consequences			
12.7	Direction (CTM)	(Other Than) Moves in wrong direction	1 – Human failure 2 – Mechanical failure	Potential radioactive release resulting from collision with facility structures	1 – CTM design 2 – Procedures and training		R-1203
12.8	Miscellaneous (CTM)	(Other Than) Moves over lid not properly stored	Human failure	Potential radioactive release resulting from collision	1 – Facility design 2 – Procedures and training		R-1203

NOTE: Guidewords not used in this node: Reverse, As Well As, and Part Of.
CTM = canister transfer machine; RF = Receipt Facility.
Events that have no direct safety consequences but may be precursors to events that occur in other nodes are noted as "No safety consequences."

Source: Original

Table E-14. HAZOP Worksheet

Facility/Operation: RF							Process: CTM Operation
Node 13: Lower Canister from CTM into AO							Process/Equipment: CTM, AO
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
13.1	Shield Door Movement	(Other Than) Failure to close shield door	1 – Human failure 2 – Mechanical malfunction	Direct exposure	1 – Procedures and training 2 – Design of shield-door controls	Must be concurrent with lowering of canister	R-1201
13.2	Shield Door Movement	(Other Than) Spurious opening of shield door	1 – Human failure 2 – Mechanical malfunction	Direct exposure	1 – Procedures and training 2 – Design of shield-door controls	Must be concurrent with lowering of canister	R-1201
13.3	Shield Door Movement	(Other Than) Failure to evacuate personnel prior to door closure	1 – Human failure 2 – Mechanical malfunction	Direct exposure	1 – Procedures and training 2 – Design of shield-door controls	Must be concurrent with lowering of canister	R-1201
13.4	Port Slide Gate	(Other Than) Failure to open slide gate	1 – Human failure 2 – Mechanical malfunction	No safety consequences	1 – Procedures and training 2 – Design of slide-gate controls	Verify with passive equipment failure analysis	N/A
13.5	Port Slide Gate	(Other Than) Failure to close slide gate	1 – Human failure 2 – Mechanical malfunction	Potential direct exposure to personnel on second floor when CTM moves	1 – Procedures and training 2 – Design of slide-gate controls	After canister is lowered into receptacle	R-1201
13.6	Port Slide Gate	(Other Than) Inadvertent opening of port slide gate	1 – Human failure 2 – Mechanical malfunction	Potential direct exposure to personnel on second floor when CTM moves	1 – Procedures and training 2 – Design of slide-gate controls	After canister is lowered into receptacle	R-1201
13.7	Port Slide Gate	(Other Than) Closure while lowering canister	1 – Human failure 2 – Mechanical malfunction	Potential release	1 – Procedures and training 2 – Design of slide-gate controls	Examine closures on rope as well as canister	R-1207, R-1208, R-1209
13.8	CTM Slide Gate	(Other Than) Failure to open slide gate	1 – Human failure 2 – Mechanical malfunction	No safety consequences	1 – Procedures and training 2 – Design of slide-gate controls		N/A
13.9	CTM Slide Gate	(Other Than) Failure to close slide gate	1 – Human failure 2 – Mechanical malfunction	No safety consequences			N/A
13.10	CTM Slide Gate	(Other Than) Opening of CTM slide gate	1 – Human failure 2 – Mechanical malfunction	Potential direct exposure to personnel on second floor when skirt lifts	1 – Procedures and training 2 – Design of slide-gate controls		R-1201
13.11	CTM Slide Gate	(Other Than) Closure while lowering canister	1 – Human failure 2 – Mechanical malfunction	Potential release	1 – Procedures and training 2 – Design of slide-gate controls	Examine closures on rope as well as canister	R-1208, R-1209
13.12	Lowering of Canister	(Less) Not lowering canister enough to clear bottom of second floor	Human failure	Potential shear of canister or cable when CTM or receiver moved leading to radioactive release	Procedures and training		R-1207
13.13	Lowering of Canister	(Other Than) Movement of carrier (CTT, ST) during lowering of canister	Human failure	Potential shear of canister or cable if carrier moves during lift leading to radioactive release	1 – Procedures and training 2 – CTT design features		R-1204
13.14	Lowering of Canister	(Other Than) Miscellaneous mechanical failures	Mechanical malfunction	Potential drop leading to radioactive release	CTM design features	Maintenance program	R-1210, R-1211
13.15	Lowering of Canister	(Other Than) Lower canister without receptacle below	1 – Human failure 2 – Mechanical malfunction	Potential direct exposure	Procedures and training		R-1201
13.16	Lowering of Canister	(Other Than) Misalignment of CTM and port	1 – Human failure 2 – Mechanical malfunction	Potential canister impact or drop leading to radioactive release	Procedures and training	Potential of catching ledge and dropping into hole	R-1207

Table E-14. HAZOP Worksheet (Continued)

Facility/Operation: RF							Process: CTM Operation
Node 13: Lower Canister from CTM into AO							Process/Equipment: CTM, AO
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
13.17	Lid Grapple Engagement	(Other Than) Improper attachment	1 – Human failure 2 – Equipment failure	No safety consequences	1 – Procedures and training 2 – Potentially precluded by design	Potential precursor to cask lid drop	N/A
13.18	Install AO Lid	(More) Lowering too rapidly impacts cask/canister	Human failure	Potential drop of cask when attempting to remove lid leading to radioactive release	1 – Procedures and training 2 – CTM design features		R-1301
13.19	Install AO Lid	(More) Attempting to lift lid too high (i.e., two-blocking)	Human failure	Potential drop of lid onto canister leading to radioactive release	1 – Procedures and training 2 – CTM design features		R-1301
13.20	Install AO Lid	(Less) Not lowering lid enough to engage cask	Human failure	Potential drop of lid onto canister if slide gate closes while lid suspended leading to radioactive release	1 – Procedures and training 2 – Grapple and CTM design features		R-1301
13.21	Install AO Lid	(Other Than) Lift with grapple improperly attached (see 13.17 above)	Human failure	Potential drop of cask lid onto canister leading to radioactive release	1 – Procedures and training 2 – Grapple and CTM design features		R-1301

NOTE: Guidewords not used in this node: No, Reverse, As Well As, and Part Of.
AO = aging overpack; CTM = canister transfer machine; CTT = cask transfer trolley; RF = Receipt Facility; ST = site transporter.
Events that have no direct safety consequences but may be precursors to events that occur in other nodes are noted as “No safety consequences.”

Source: Original

Table E-15. HAZOP Worksheet

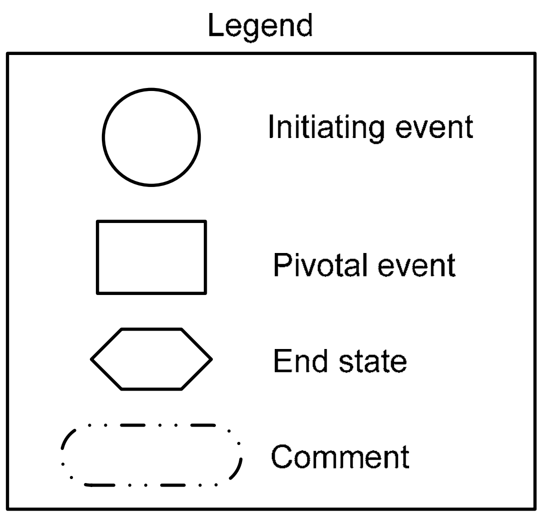
Facility/Operation: RF						Process: ST Operations	
Node 14: Move Loaded AO on ST out of RF						Process Equipment: ST, AO	
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of						Consequence Categories: Radioactive Release, Lack of Shielding, Criticality	
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
14.1	ST Movement	(More) Moves too far	1 – Human failure 2 – Mechanical malfunction	Potential collision leading to radioactive release	1 – Procedures and training 2 – ST design 3 – Receptacle/carrier design	Receptacle/carrier may mitigate event, depending on passive equipment failure analysis	R-1306, R-1305
14.2	ST Movement	(Less) Doesn't move enough	1 – Human failure 2 – Mechanical malfunction	No safety consequences			N/A
14.3	ST Movement	(Less) ST loses track or has other breakdown	1 – Human failure 2 – Mechanical malfunction	Potential collision leading to radioactive release	1 – Procedures and training 2 – ST design 3 – Receptacle/carrier design		R-1306, R-1305
14.4	ST Movement	(Reverse) Moves in opposite direction	1 – Human failure 2 – Mechanical malfunction	Potential collision leading to radioactive release	1 – Procedures and training 2 – ST design 3 – Receptacle/carrier design		R-1306, R-1305, R-1403
14.5	ST Movement	(Other Than) Steers off designated path	1 – Human failure 2 – Mechanical malfunction	Potential collision leading to radioactive release	1 – Procedures and training 2 – ST design 3 – Receptacle/carrier design		R-1306, R-1305
14.6	ST	(Other Than) Fire	1 – Human failure 2 – Mechanical malfunction	Potential release of radioactivity	1 – Procedures and training 2 – ST design	For PCSA fire analysis	R-I303 thru R-I310
14.7	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	R-1306, R-1305
14.8	Lift	(Less) ST not lifted to required transport height	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – ST design 2 – Procedures and training		R-1306, R-1305
14.9	Lift	(No) ST does not lift load	1 – Human failure 2 – Mechanical failure	No safety consequences		1 – No loss of shielding or radioactive release 2 – Expected damage to bottom plate only	N/A

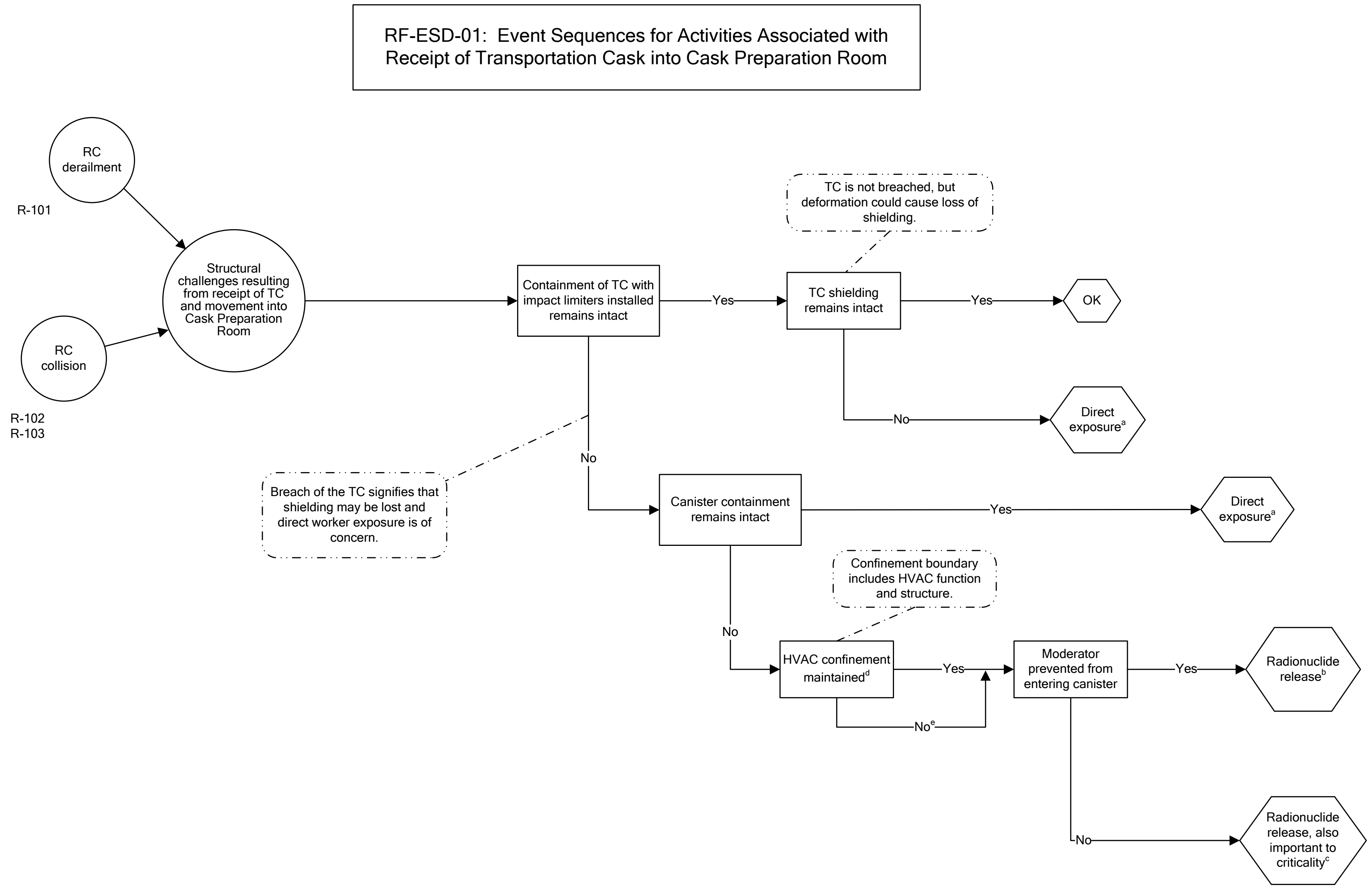
NOTE: Guidewords not used in this node: As Well As and Part Of.
AO = aging overpack; ft = foot; PCSA = preclosure safety analysis; RF = Receipt Facility; ST = site transporter.
Events that have no direct safety consequences but may be precursors to events that occur in other nodes are noted as “No safety consequences.”

Source: Original

ATTACHMENT F
RECEIPT FACILITY EVENT SEQUENCE DIAGRAMS

Event sequence diagrams for the Receipt Facility are presented in Figures F-1 to F-12. The corresponding event trees are presented in Attachment G.





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.

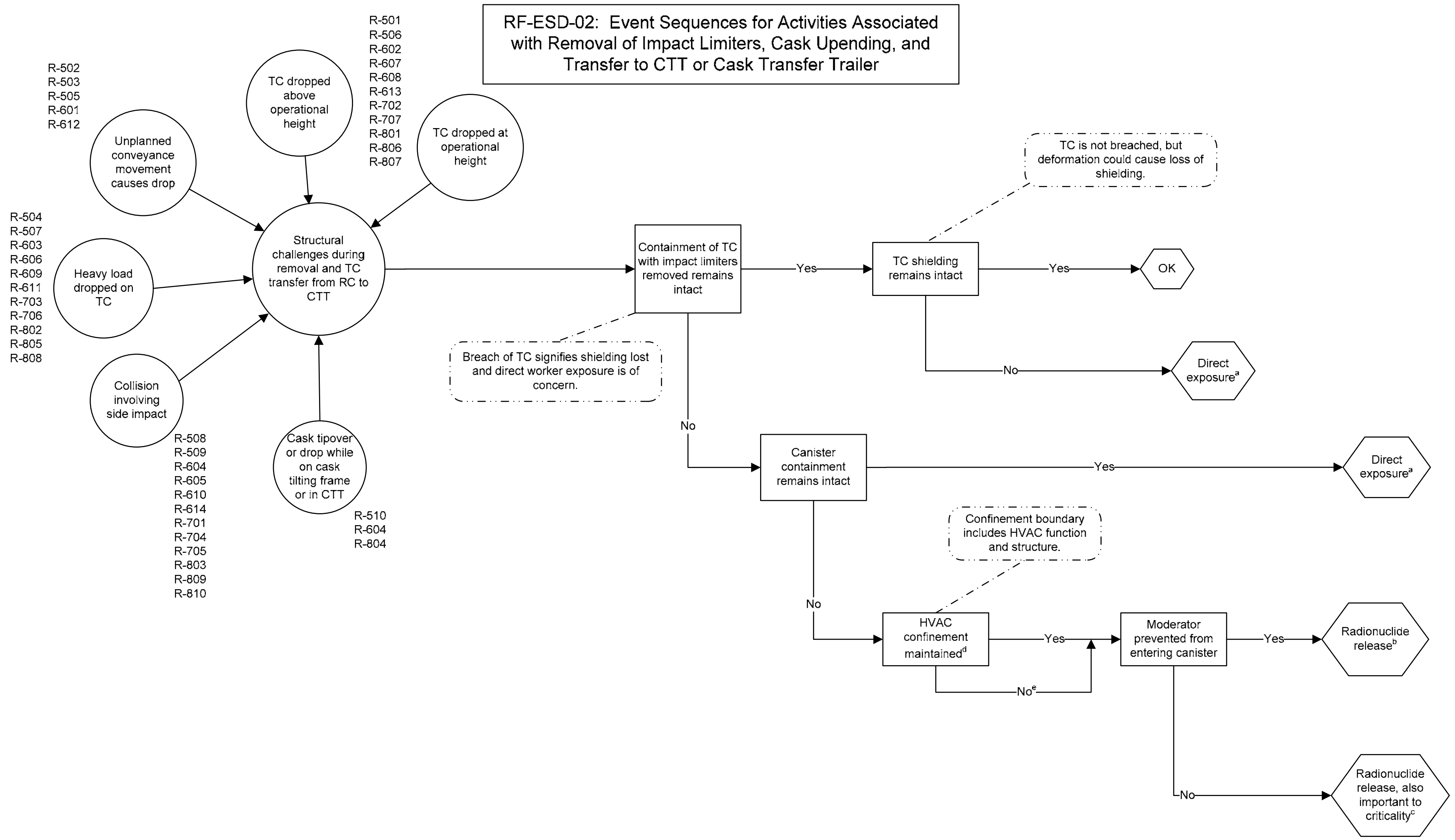
[d] Successful operation of the HVAC system would mitigate a radionuclide release.

[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

ESD = event sequence diagram; HVAC = heating, ventilation and air conditioning; RC = railcar; RF = Receipt Facility; TC = transportation cask.

Source: Original

Figure F-1. RF-ESD-01 Event Sequences for Activities Associated with Receipt of Transportation Cask into Cask Preparation Room



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.

[b] 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.

[c] Successful operation of the HVAC system would mitigate a radionuclide release.

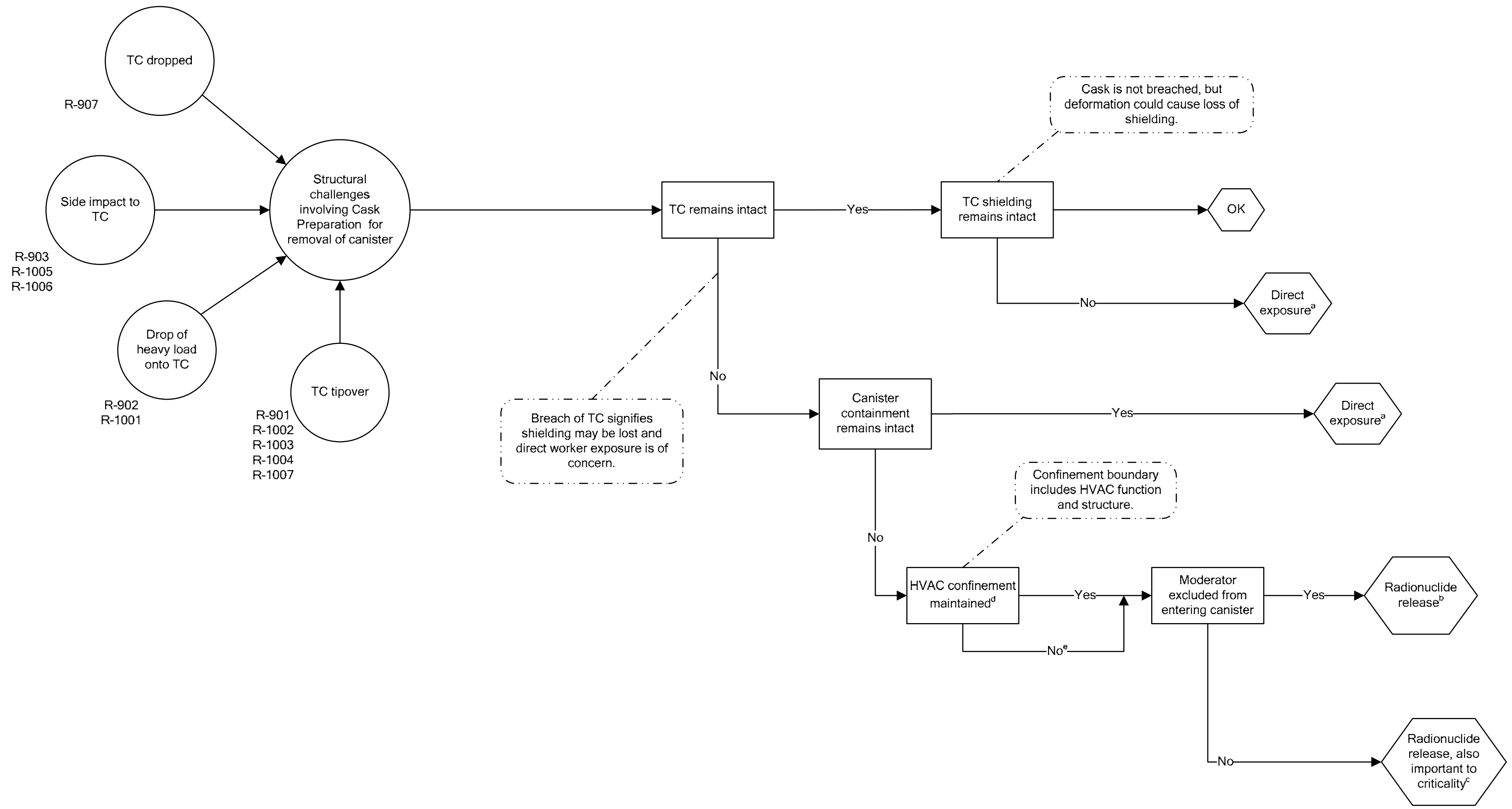
[d] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

[e] CTT = cask transfer trolley; ESD = event sequence diagram; HVAC = heating, ventilation and air conditioning; RC = railcar; RF = Receipt Facility; TC = transportation cask.

Source: Original

Figure F-2. RF-ESD-02 Event Sequences for Activities Associated with Removal of Impact Limiters, Cask Upending, and Transfer to CTT or Cask Transfer Trailer

RF-ESD-03: Event Sequences Associated with Unbolting and Lid Adapter Installation

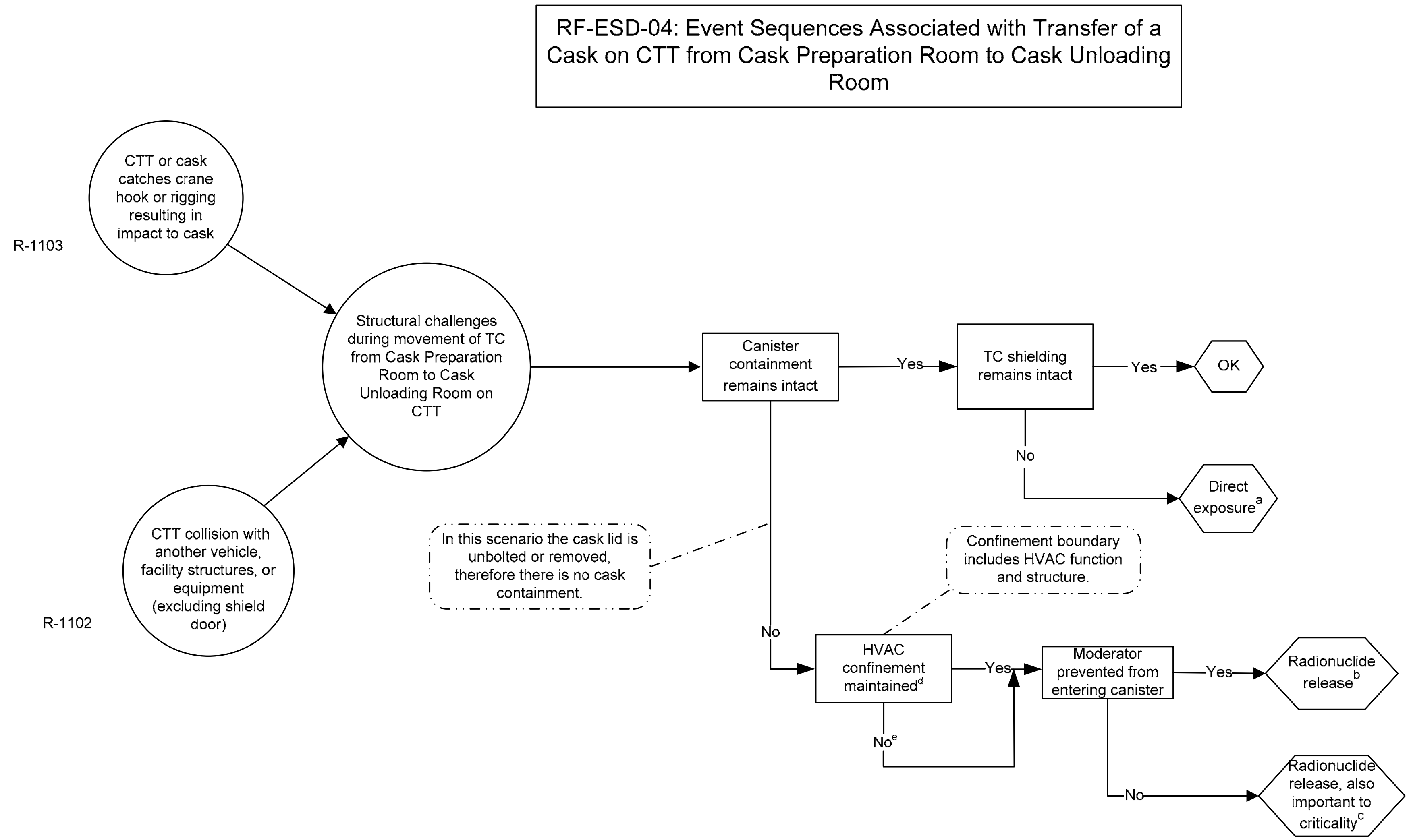


NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a breach of a waste form container.
[b] Radionuclide release describes a condition where radioactive material has been released from the container creating a potential inhalation or ingestion 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.
[d] Successful operation of the HVAC system would mitigate a radionuclide release.
[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

ESD = event sequence diagram; HVAC = heating, ventilation and air conditioning; RF = Receipt Facility; TC = transportation cask.

Source: Original

Figure F-3. RF-ESD-03 Event Sequences Associated with Unbolting and Lid Adapter Installation



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.

[d] Successful operation of the HVAC system would mitigate a radionuclide release.

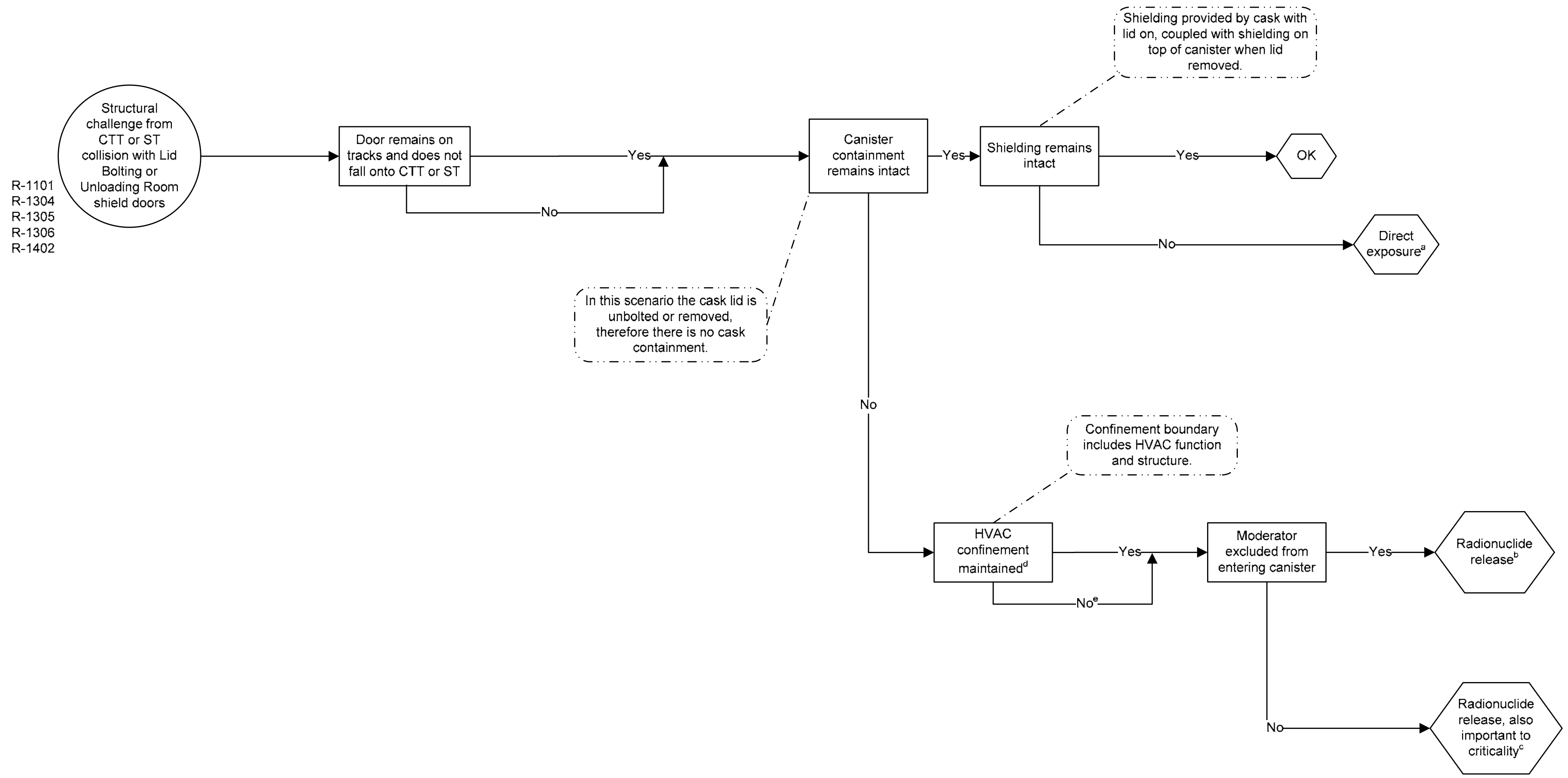
[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

CTT = cask transfer trolley; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; RF = Receipt Facility; TC = transportation cask.

Source: Original

Figure F-4. RF-ESD-04 Event Sequences Associated with Transfer of a Cask on CTT from Cask Preparation Area to Cask Unloading Room

RF-ESD-05: Event Sequences Associated with a Transportation Cask on a CTT or Site Transporter Colliding with Lid Bolting Room or Cask Unloading Room Shield Doors

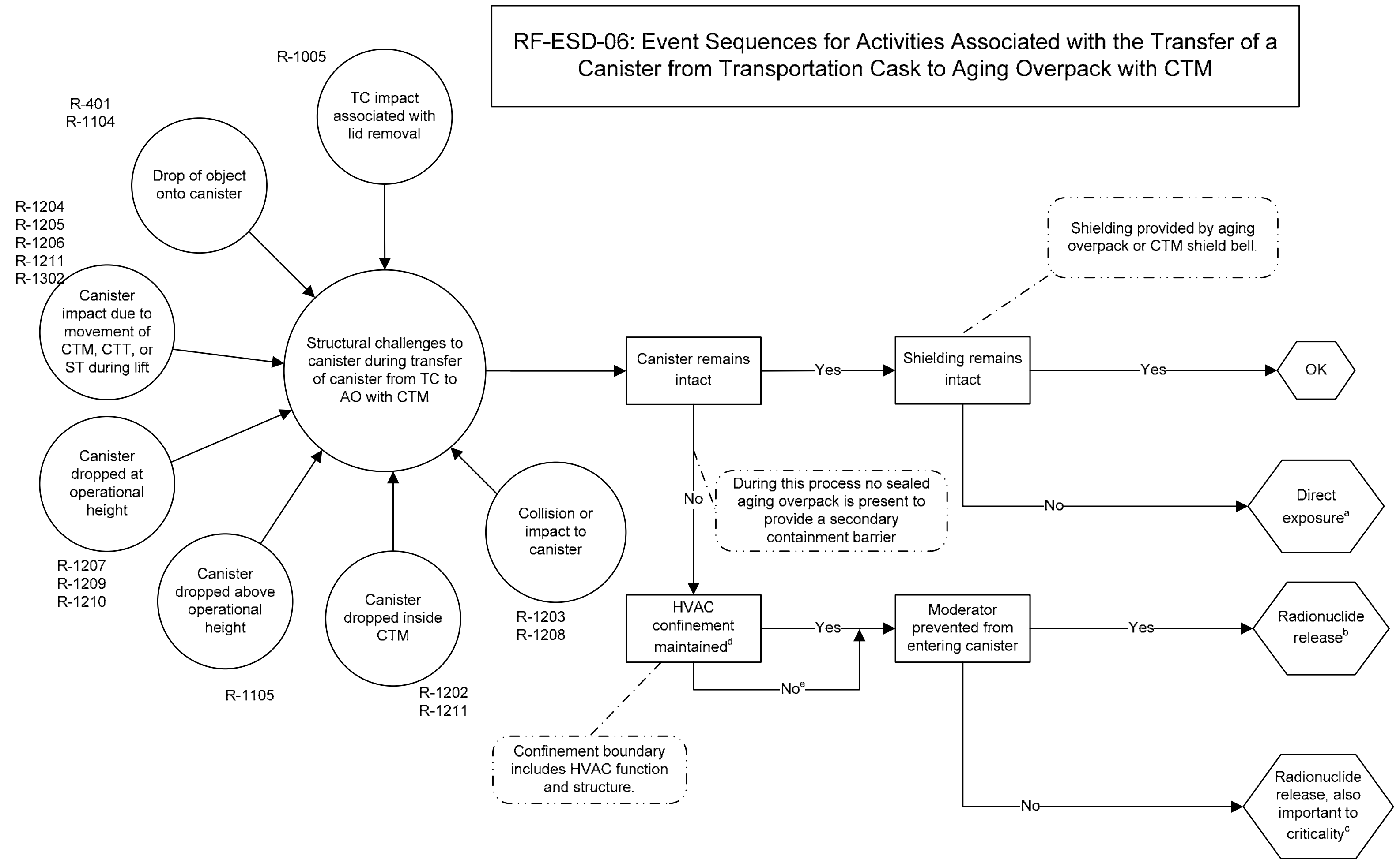


NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a breach of a waste form container.
[b] Radionuclide release describes a condition where radioactive material has been released from the container creating a potential inhalation or ingestion 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.
[d] Successful operation of the HVAC system would mitigate a radionuclide release.
[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

CTT = cask transfer trolley; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; RF = Receipt Facility; ST = site transporter.

Source: Original

Figure F-5. RF-ESD-05: Event Sequences Associated with a Transportation Cask on a CTT or Site Transporter Colliding with Lid Bolting Room or Cask Unloading Room Shield Doors



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.

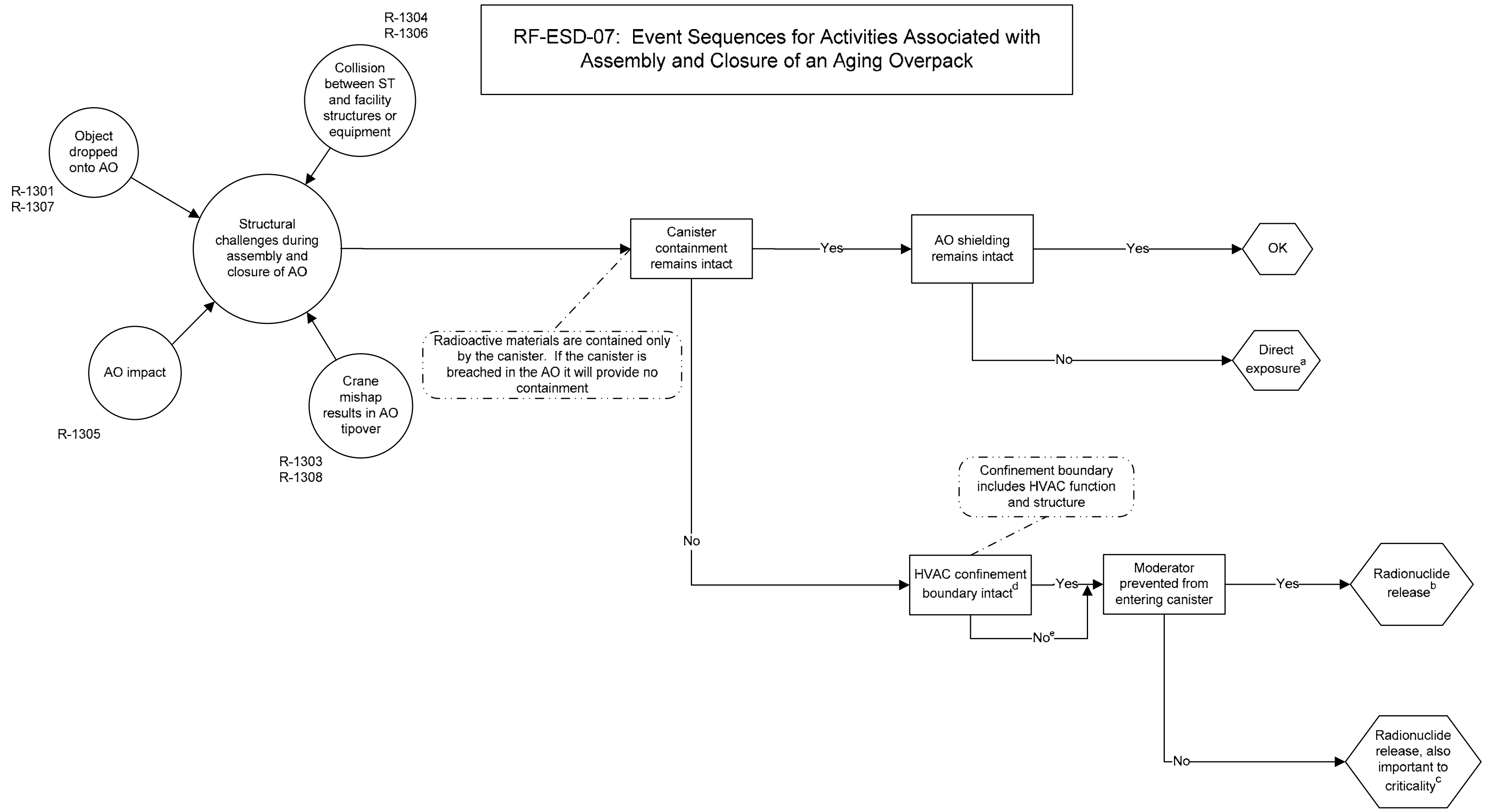
[d] Successful operation of the HVAC system would mitigate a radionuclide release.

[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

AO = aging overpack; CTM = canister transfer machine; CTT = canister transfer trolley; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; RF = Receipt Facility; ST = site transporter; TC = transportation cask.

Source: Original

Figure F-6. RF-ESD-06 Event Sequences for Activities Associated with the Transfer of a Canister from Transportation Cask to Aging Overpack with CTM



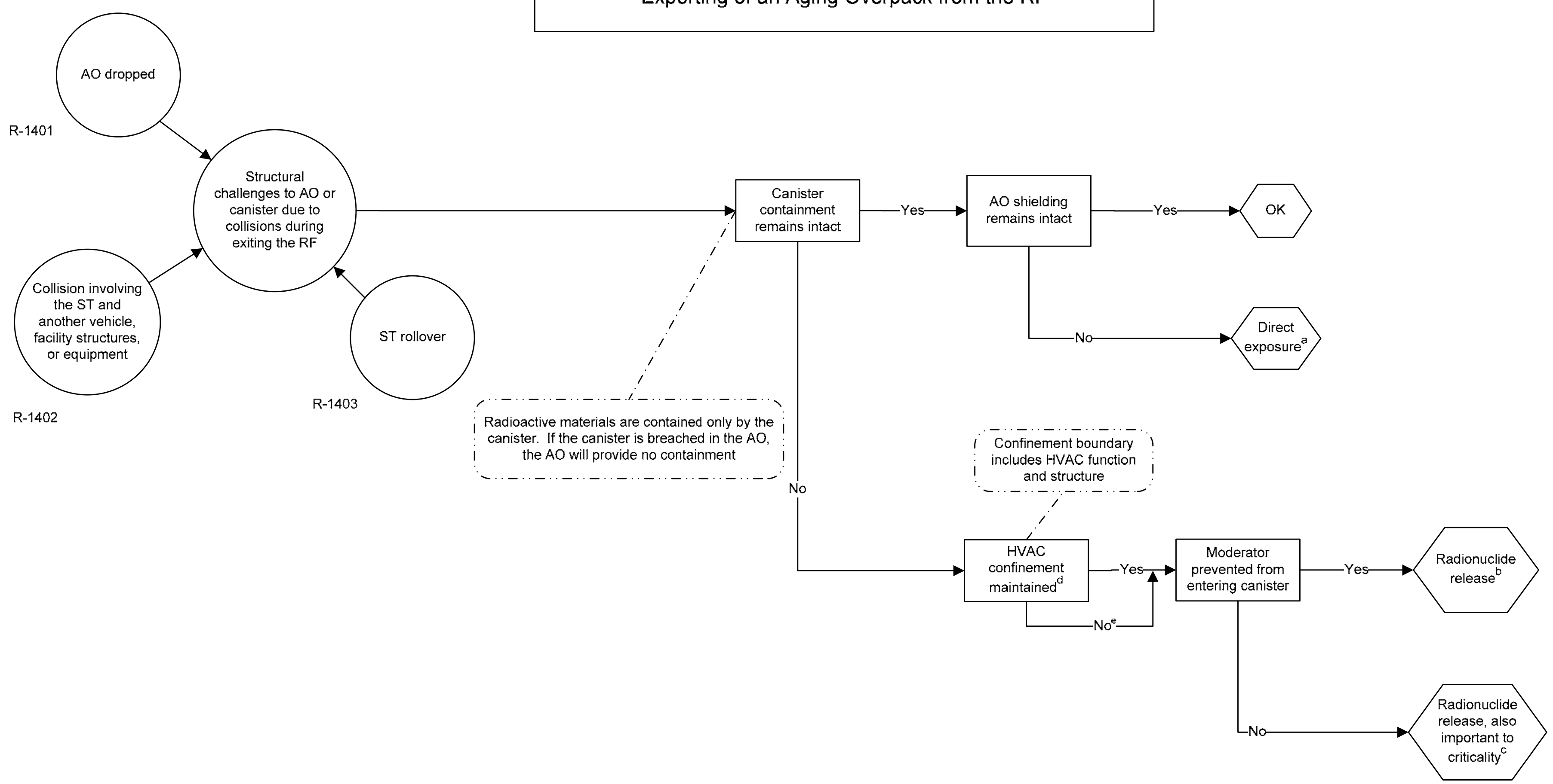
NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a breach of a waste form container.
[b] Radionuclide release describes a condition where radioactive material has been released from the container creating a potential inhalation or ingestion 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.
[d] Successful operation of the HVAC system would mitigate a radionuclide release.
[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

AO = aging overpack; ESD = event sequence diagram; HVAC = heating, ventilation and air conditioning; RF = Receipt Facility; ST = site transporter.

Source: Original

Figure F-7. RF-ESD-07 Event Sequences for Activities Associated with Assembly and Closure of an Aging Overpack

RF-ESD-08: Event Sequences for Activities Associated with the Exporting of an Aging Overpack from the RF



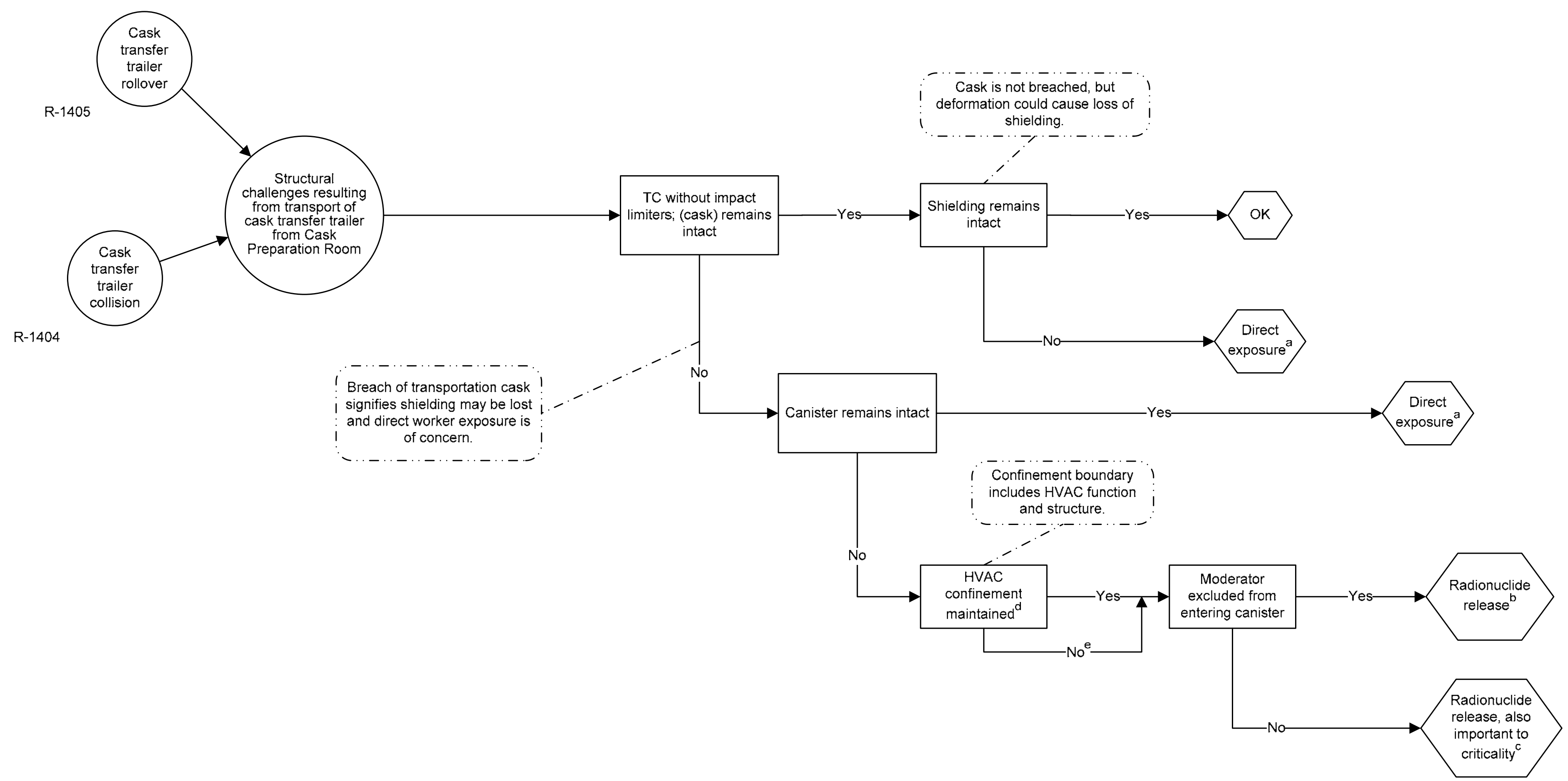
NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a breach of a waste form container.
[b] Radionuclide release describes a condition where radioactive material has been released from the container creating a potential inhalation or ingestion 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.
[d] Successful operation of the HVAC system would mitigate a radionuclide release.
[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

AO = aging overpack; ESD = event sequence diagram; HVAC = heating, ventilation and air conditioning; RF = Receipt Facility; ST = site transporter.

Source: Original

Figure F-8. RF-ESD-08 Event Sequences for Activities Associated with the Exporting of an Aging Overpack from the RF

RF-ESD-09: Event Sequences for Activities Associated with Export of Horizontal Cask on Cask Transfer Trailer



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.

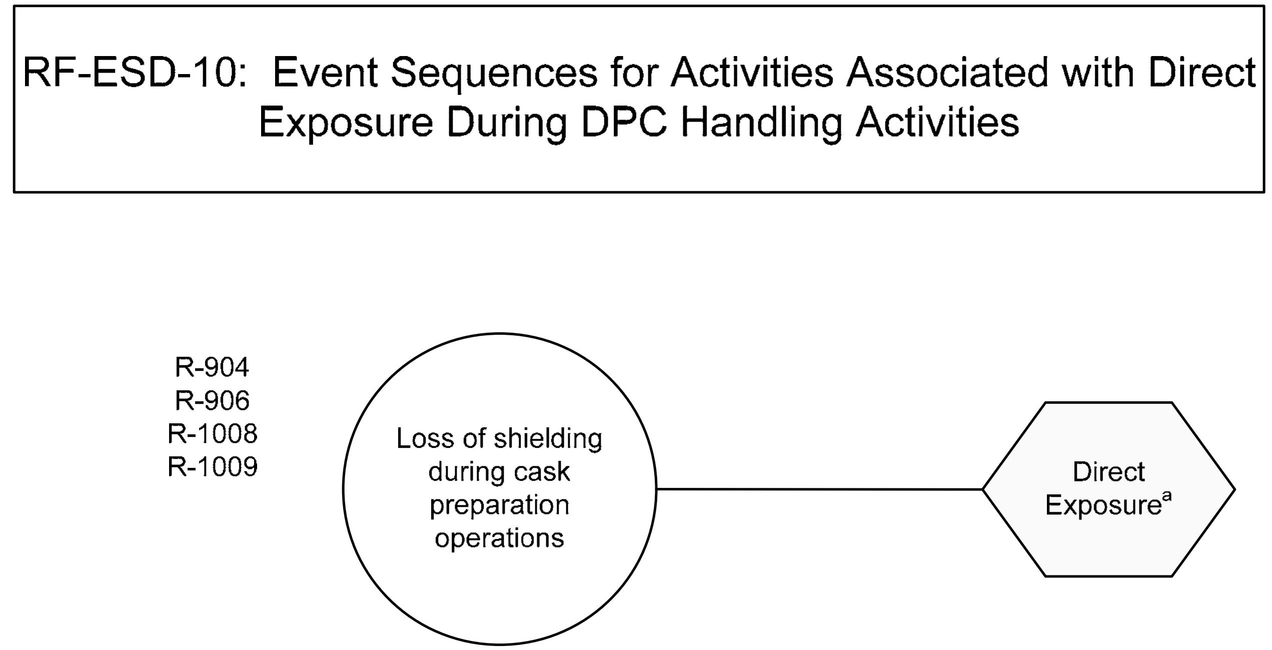
[d] Successful operation of the HVAC system would mitigate a radionuclide release.

[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

ESD = event sequence diagram; HVAC = heating, ventilation and air conditioning; RF = Receipt Facility; TC = transportation cask.

Source: Original

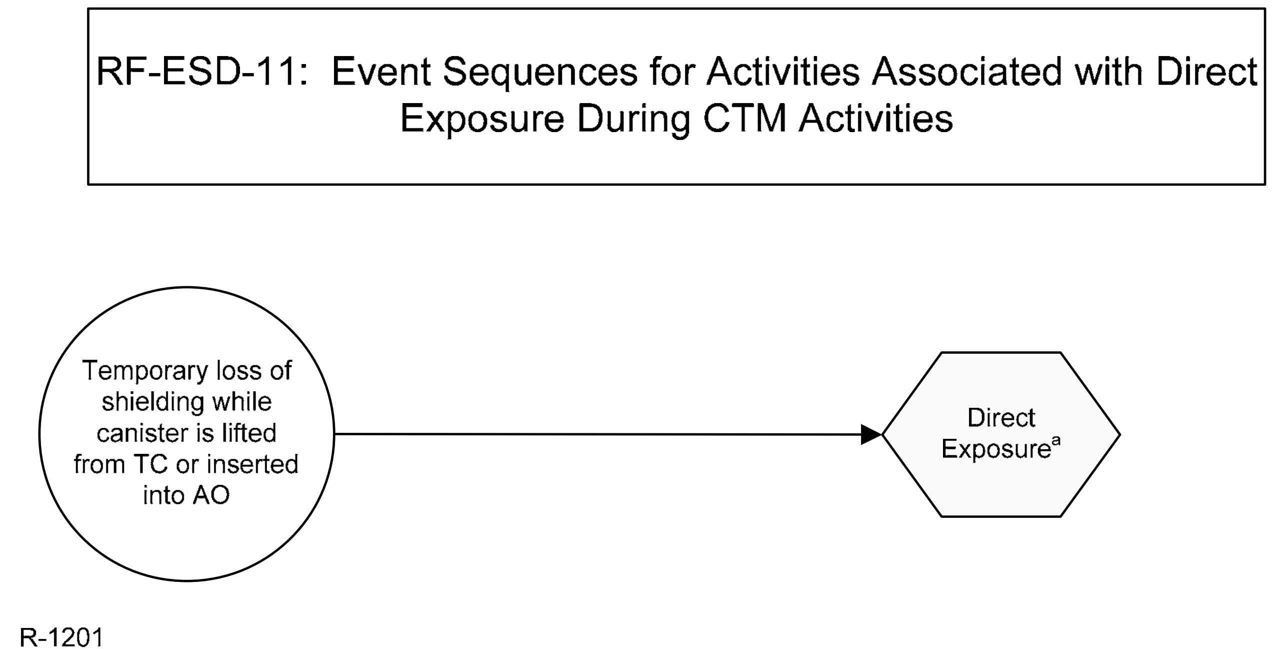
Figure F-9. RF-ESD-09 Event Sequences for Activities Associated with Export of Horizontal Cask on Cask Transfer Trailer



NOTE: [a] Direct exposure is that condition where individuals are directly exposed to the radiation beam streaming through areas where shielding has been compromised.
DPC = dual-purpose canister; ESD = event sequence diagram; RF = Receipt Facility.

Source: Original

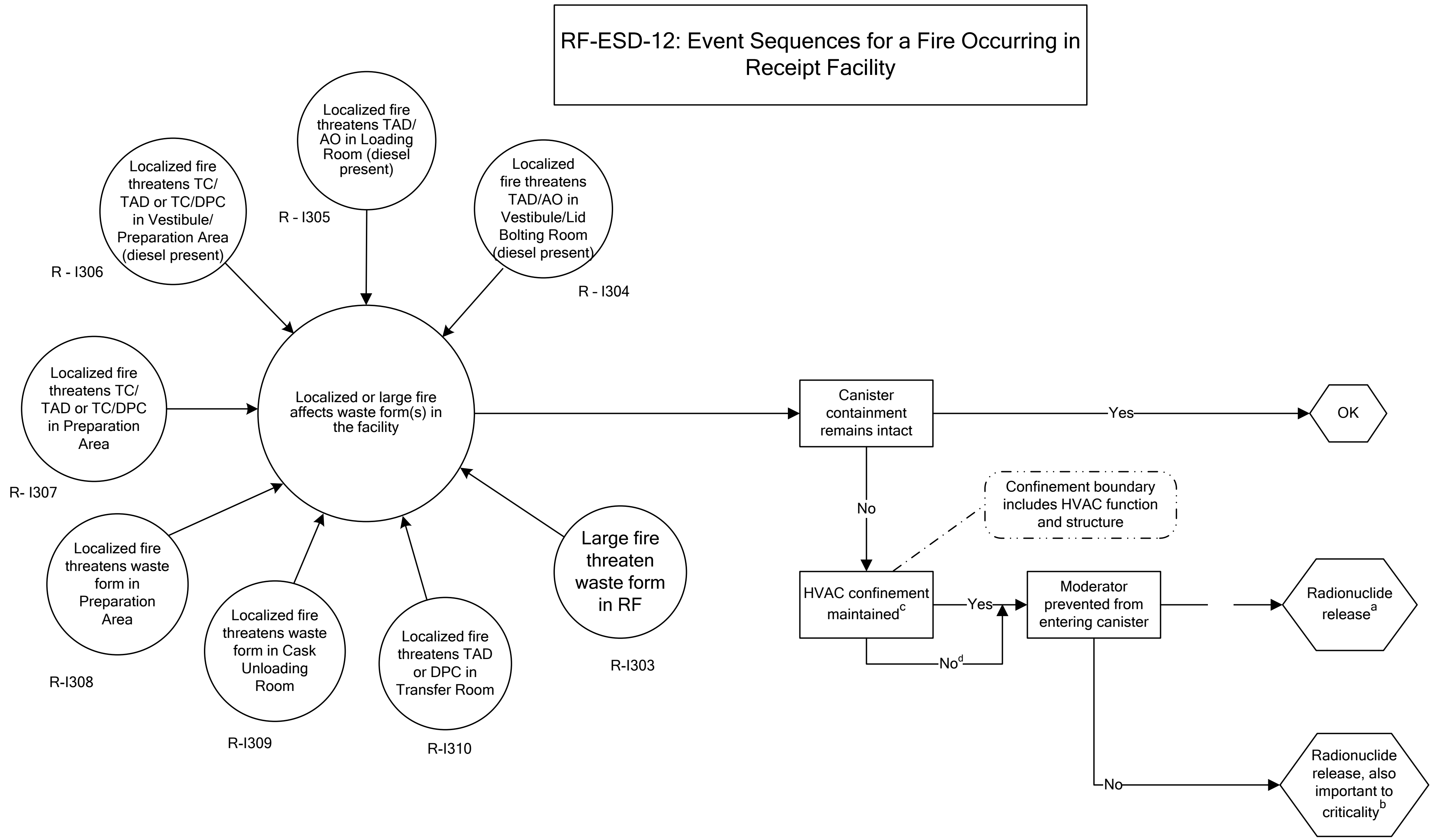
Figure F-10. RF-ESD-10 Event Sequences for Activities Associated with Direct Exposure During DPC Handling Activities



NOTE: [a] Direct exposure is that condition where individuals are directly exposed to the radiation beam streaming through areas where shielding has been compromised.
AO = aging overpack; CTM = canister transfer machine; ESD = event sequence diagram; RF = Receipt Facility; TC = transportation cask.

Source: Original

Figure F-11. RF-ESD-11 Event Sequences for Activities Associated with Direct Exposure During CTM Activities



NOTE: When the canister is inside a cask or AO, the pivotal event "canister remains intact " includes the protection afforded by the overpack.

[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 and direct exposure, as described above.

[b] 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.

[c] Successful operation of the HVAC system would mitigate a radionuclide release.

[d] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

AO = aging overpack; ESD = event sequence diagram; HVAC = heating, ventilation and air conditioning; RF = Receipt Facility; ST = site transporter; TAD = transportation, aging, and disposal canister; TTC = a transportation cask that is upended using a tilt frame.

Source: Original

Figure F-12. RF-ESD-12 Event Sequences for a Fire Occurring in Receipt Facility

ATTACHMENT G
RECEIPT FACILITY 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-27 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.

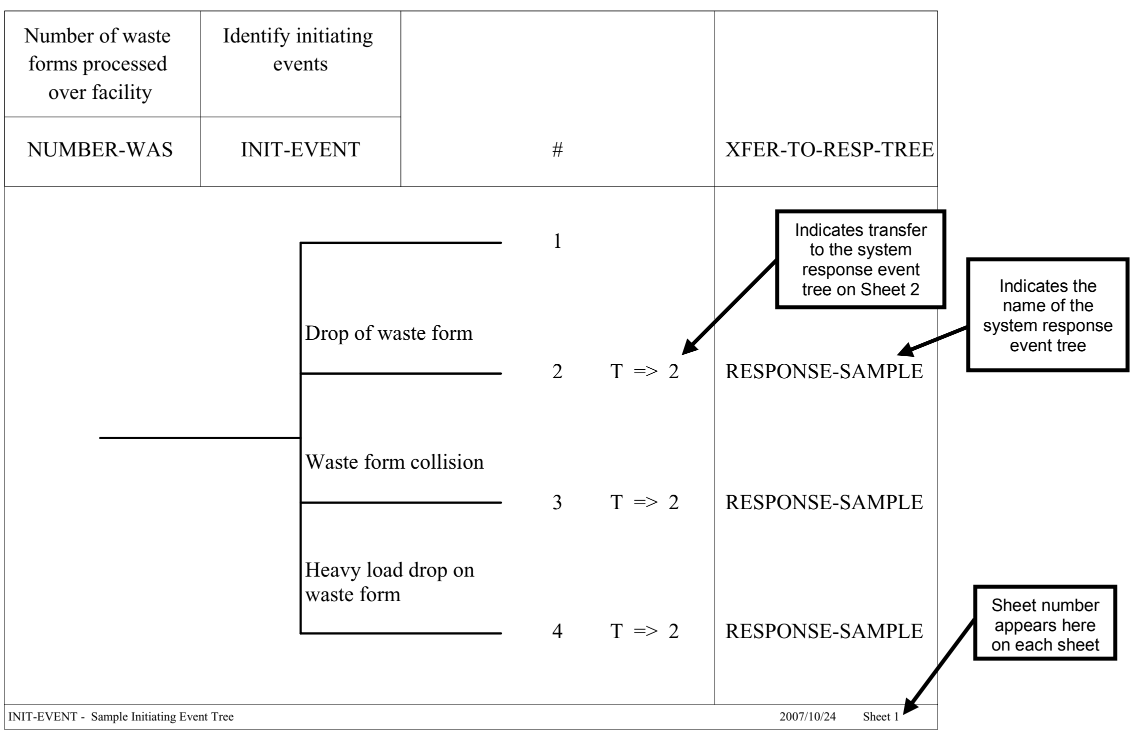


Figure G-1. Example Initiator Event Tree Showing Navigation Aids

Table G-1. Correspondence between ESDs and Event Trees

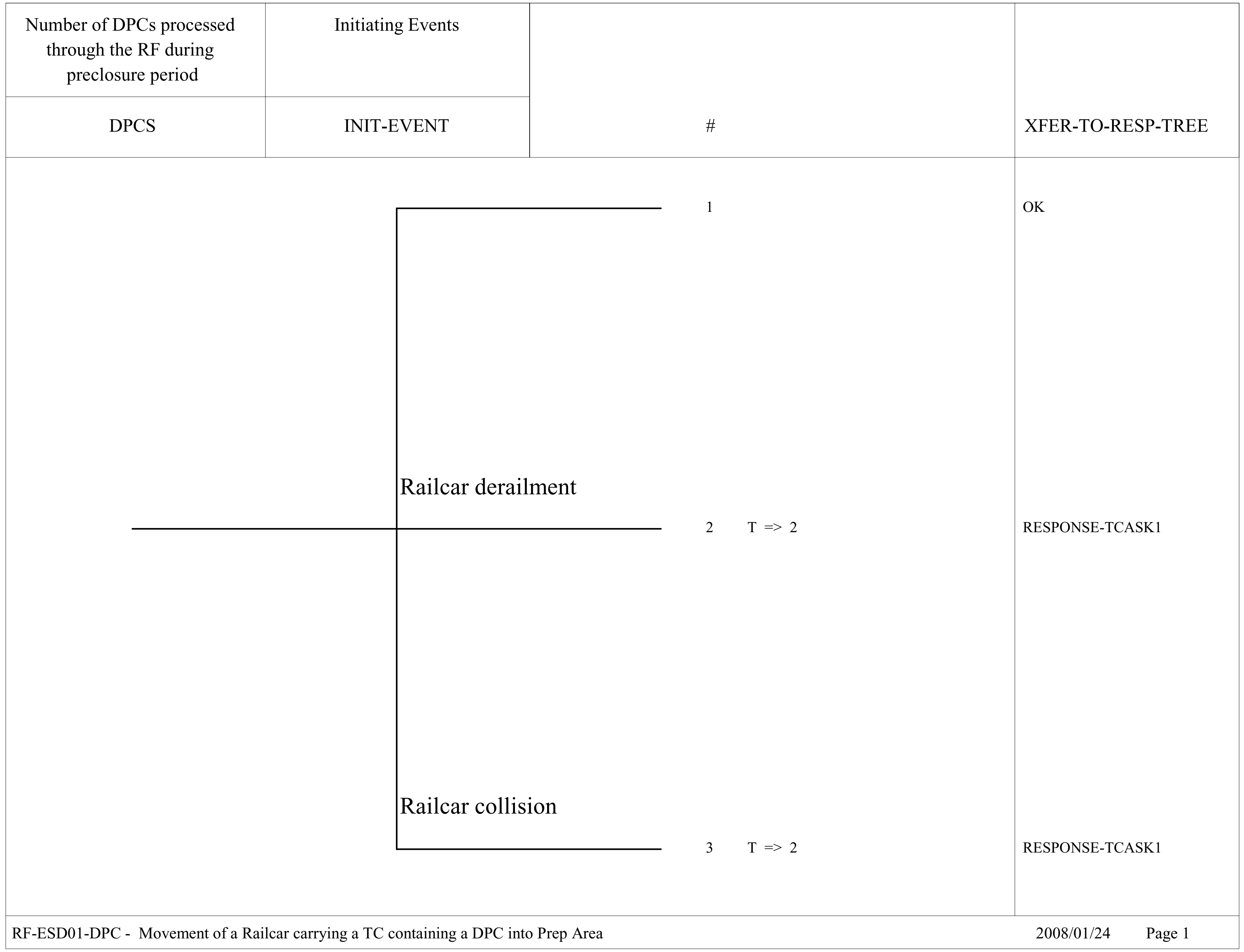
ESD#	ESD Title	IE Event Tree Name	IE Event Tree Location	Response Tree Name	Response Tree Location
RF-ESD-01	Event Sequences for Activities Associated with Receipt of Transportation Cask into Cask Preparation Room	RF-ESD01-DPC RF-ESD01-TAD	Figure G-2 Figure G-4	RESPONSE-TCASK1	Figure G-3
RF-ESD-02	Event Sequences for Activities Associated with Removal of Impact Limiters, Cask Upending, and Transfer to CTT or Cask Transfer Trailer	RF-ESD02-DPC RF-ESD02-TAD	Figure G-5 Figure G-6	RESPONSE-TCASK1	Figure G-3
RF-ESD-03	Event Sequences Associated with Unbolting and Lid Adapter Installation	RF-ESD03-DPC RF-ESD03-TAD	Figure G-7 Figure G-8	RESPONSE-TCASK1	Figure G-3
RF-ESD-04	Event Sequences Associated with Transfer of a Cask on CTT from Cask Preparation Area to Cask Unloading Room	RF-ESD04-DPC RF-ESD04-TAD	Figure G-9 Figure G-11	RESPONSE-TCASK2	Figure G-10
RF-ESD-05	Event Sequences Associated with a Transportation Cask on a CTT or Site Transporter Colliding with Lid Bolting Room or Cask Unloading Room Shield Doors	RF-ESD05-DPC RF-ESD05-TAD	Figure G-12 Figure G-13	N/A	N/A
RF-ESD-06	Event Sequences for Activities Associated with the Transfer of a Canister from Transportation Cask, to Aging Overpack with CTM	RF-ESD06-DPC RF-ESD06-TAD	Figure G-14 Figure G-16	RESPONSE-CANISTER1	Figure G-15
RF-ESD-07	Event Sequences for Activities Associated with Assembly and Closure of an Aging Overpack	RF-ESD07-DPC RF-ESD07-TAD	Figure G-17 Figure G-19	RESPONSE-AO1	Figure G-18

Table G-1. Correspondence Between ESDs and Event Trees (Continued)

ESD#	ESD Title	IE Event Tree Name	IE Event Tree Location	Response Tree Name	Response Tree Location
RF-ESD-08	Event Sequences for Activities Associated with the Exporting of an Aging Overpack from the RF	RF-ESD08-DPC RF-ESD08-TAD	Figure G-20 Figure G-21	RESPONSE-AO1	Figure G-18
RF-ESD-09	Event Sequences for Activities Associated with Export of Horizontal Cask on Cask Transfer Trailer	RF-ESD09	Figure G-22	RESPONSE-TCASK1	Figure G-3
RF-ESD-10	Event Sequences for Activities Associated with Direct Exposure During DPC Handling Activities	RF-ESD10	Figure G-23	N/A	N/A
RF-ESD-11	Event Sequences for Activities Associated with Direct Exposure During CTM Activities	RF-ESD11	Figure G-24	N/A	N/A
RF-ESD-12	Event Sequences for a Fire Occurring in Receipt Facility	RF-ESD12-DPC RF-ESD12-TAD	Figure G-25 Figure G-27	RESPONSE-FIRE	Figure G-26

NOTE: DPC = dual-purpose canister; ESD = event sequence diagram; IE = initiating event; RF = Receipt Facility; TAD = transportation, aging, and disposal canister.

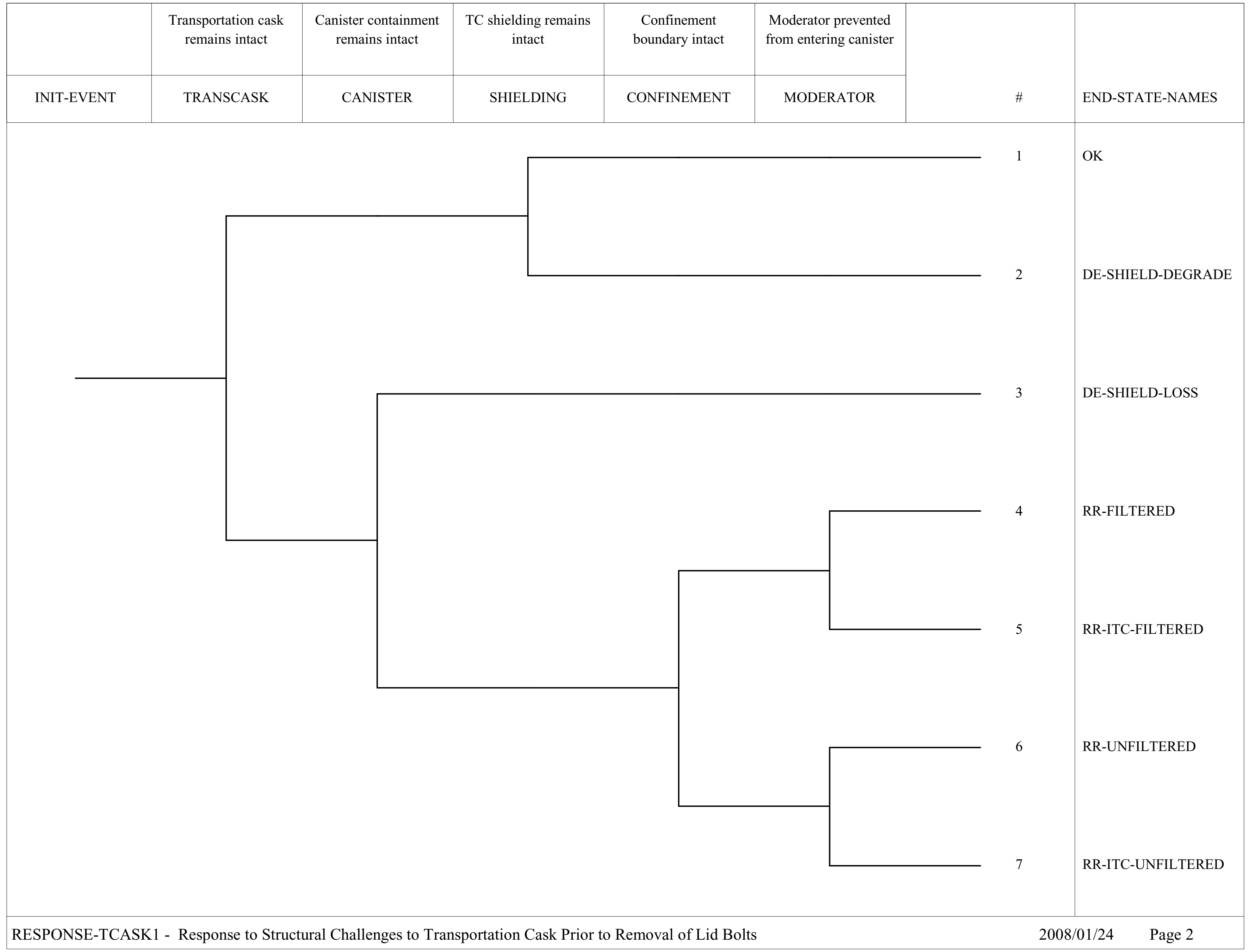
Source: Original



NOTE: DPC = dual-purpose canister; INIT = initiating; RESP = response; RF = Receipt Facility; T = transfer; TC = transportation cask; TCASK = transportation cask; XFER = transfer.

Source: Original

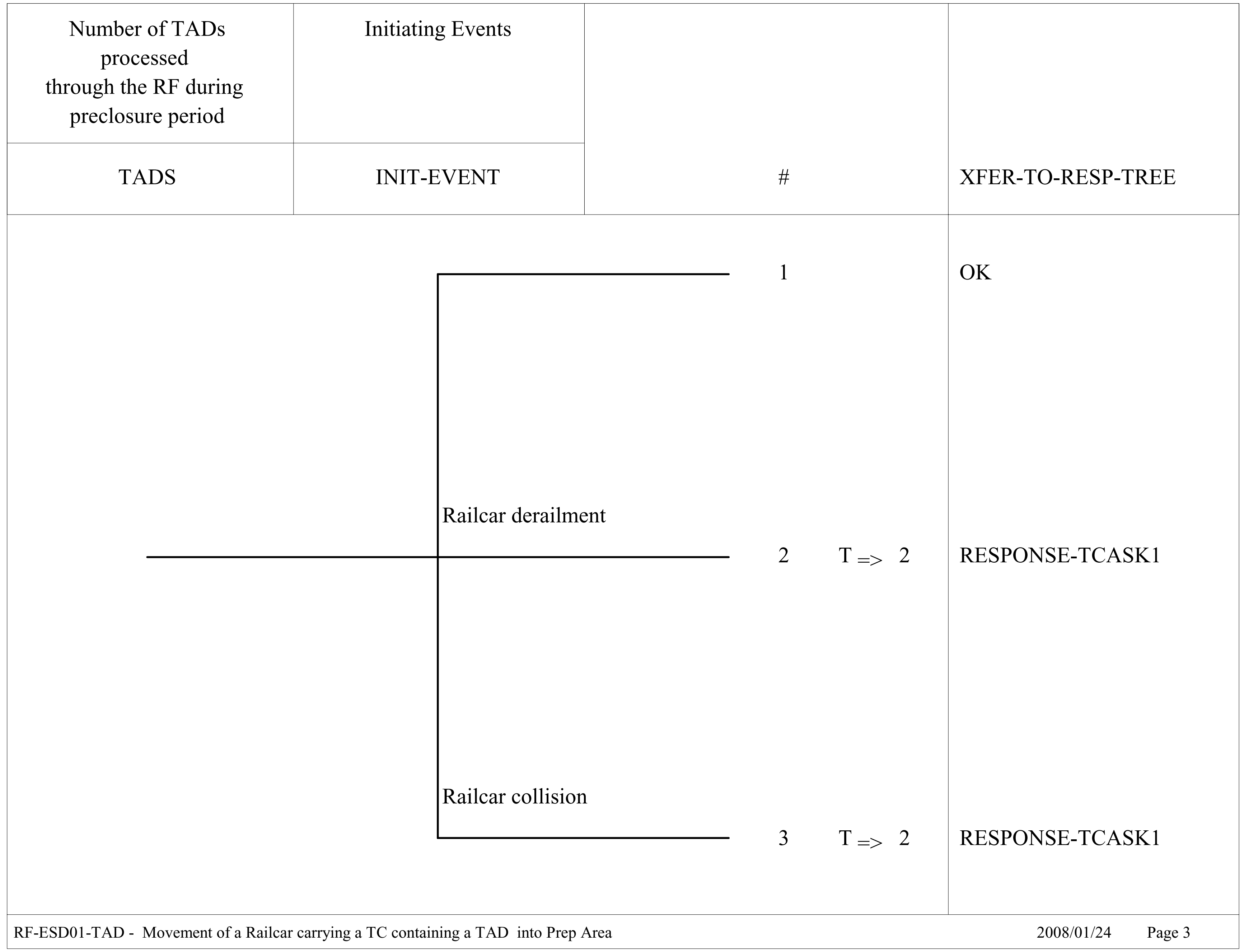
Figure G-2. Event Tree RF-ESD01-DPC – Movement of a Railcar Carrying a Transportation Cask Containing a DPC into Preparation Area



NOTE: DE = direct exposure; INIT = initiating; ITC = important to criticality; RR = radionuclide release; TC = transportation cask; TRANSCASK = transportation cask.

Source: Original

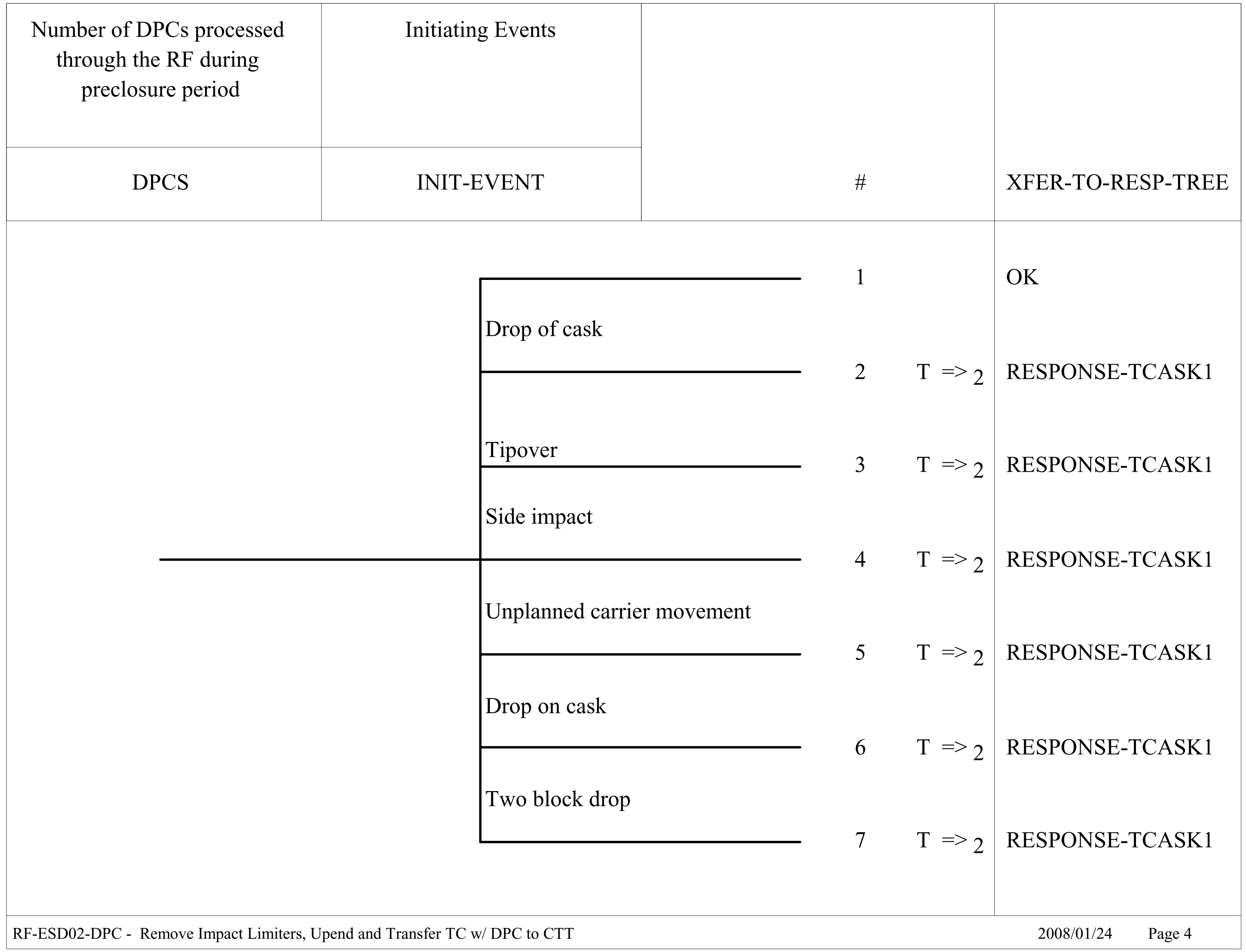
Figure G-3. Event Tree RESPONSE-TCASK1 – Response to Structural Challenges to Transportation Cask Prior to Removal of Lid Bolts



NOTE: INIT = initiating; RESP = response; RF = Receipt Facility; T = transfer; TAD = transportation, aging, and disposal canister; TC = transportation cask; TCASK = transportation cask; XFER = transfer.

Source: Original

Figure G-4. Event Tree RF-ESD01-TAD – Movement of a Railcar Carrying a Transportation Cask Containing a TAD Canister into Preparation Area



NOTE: CTT = cask transfer trolley; DPC = dual-purpose canister; INIT = initiating; RESP = response; RF = Receipt Facility; T = transfer; TC = transportation cask; TCASK = transportation cask; XFER = transfer.

Source: Original

Figure G-5. Event Tree RF-ESD02-DPC – Remove Impact Limiters, Upend and Transfer Transportation Cask with DPC to CTT

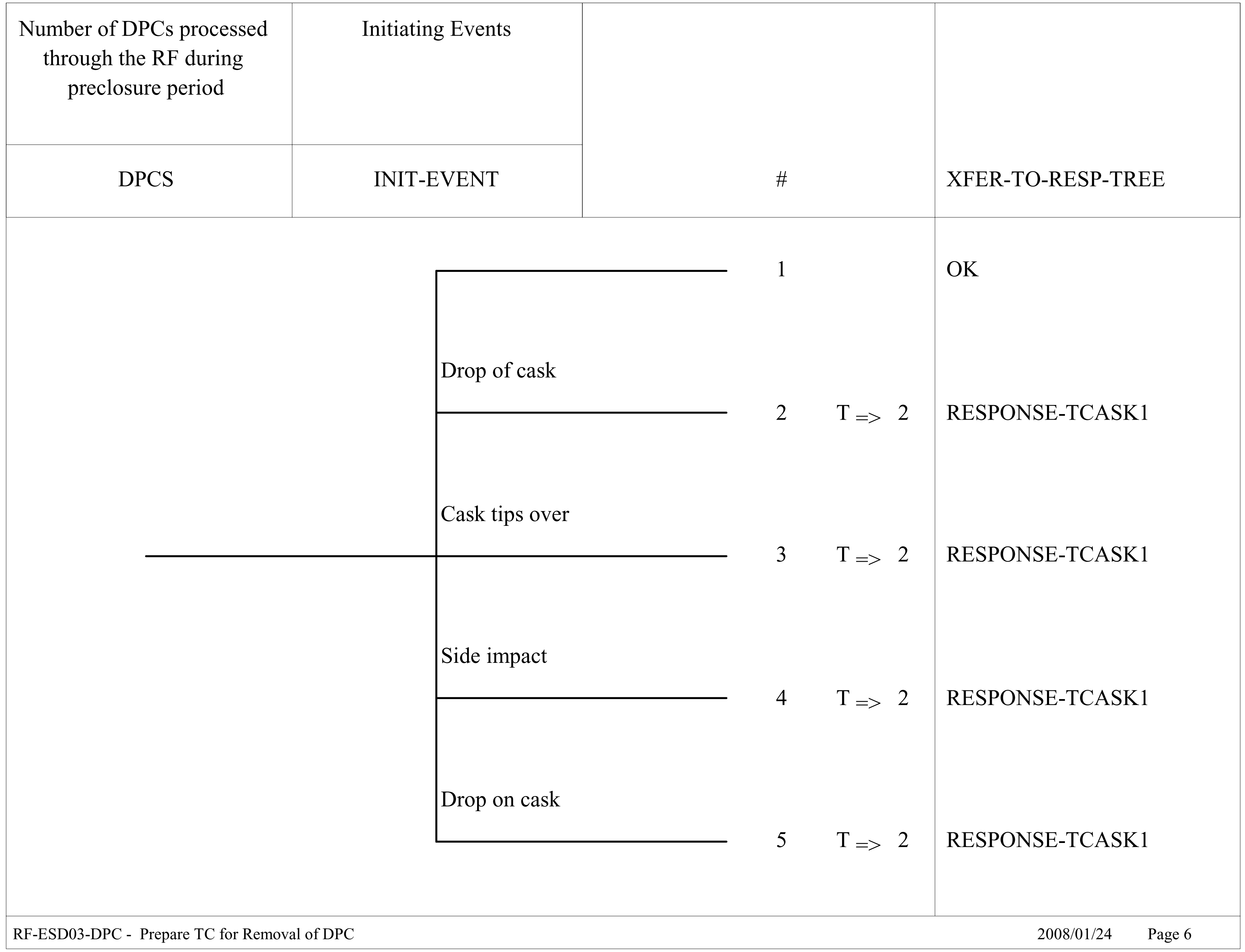
Number of TADs processed through the RF during preclosure period	Initiating Events			
TADS	INIT-EVENT	#		XFER-TO-RESP-TREE
		1		OK
	Drop of cask	2	T => 2	RESPONSE-TCASK1
	Tipover	3	T => 2	RESPONSE-TCASK1
	Side impact	4	T => 2	RESPONSE-TCASK1
	Unplanned carrier movement	5	T => 2	RESPONSE-TCASK1
	Drop on cask	6	T => 2	RESPONSE-TCASK1
	Two block drop	7	T => 2	RESPONSE-TCASK1

RF-ESD02-TAD - Remove Impact Limiters, Upend and Transfer TC w/ TAD to CTT 2008/01/24 Page 5

NOTE: CTT = cask transfer trolley; INIT = initiating; RESP = response; RF = Receipt Facility; T = transfer; TAD = transportation, aging, and disposal canister; TC = transportation cask; TCASK = transportation cask; XFER = transfer.

Source: Original

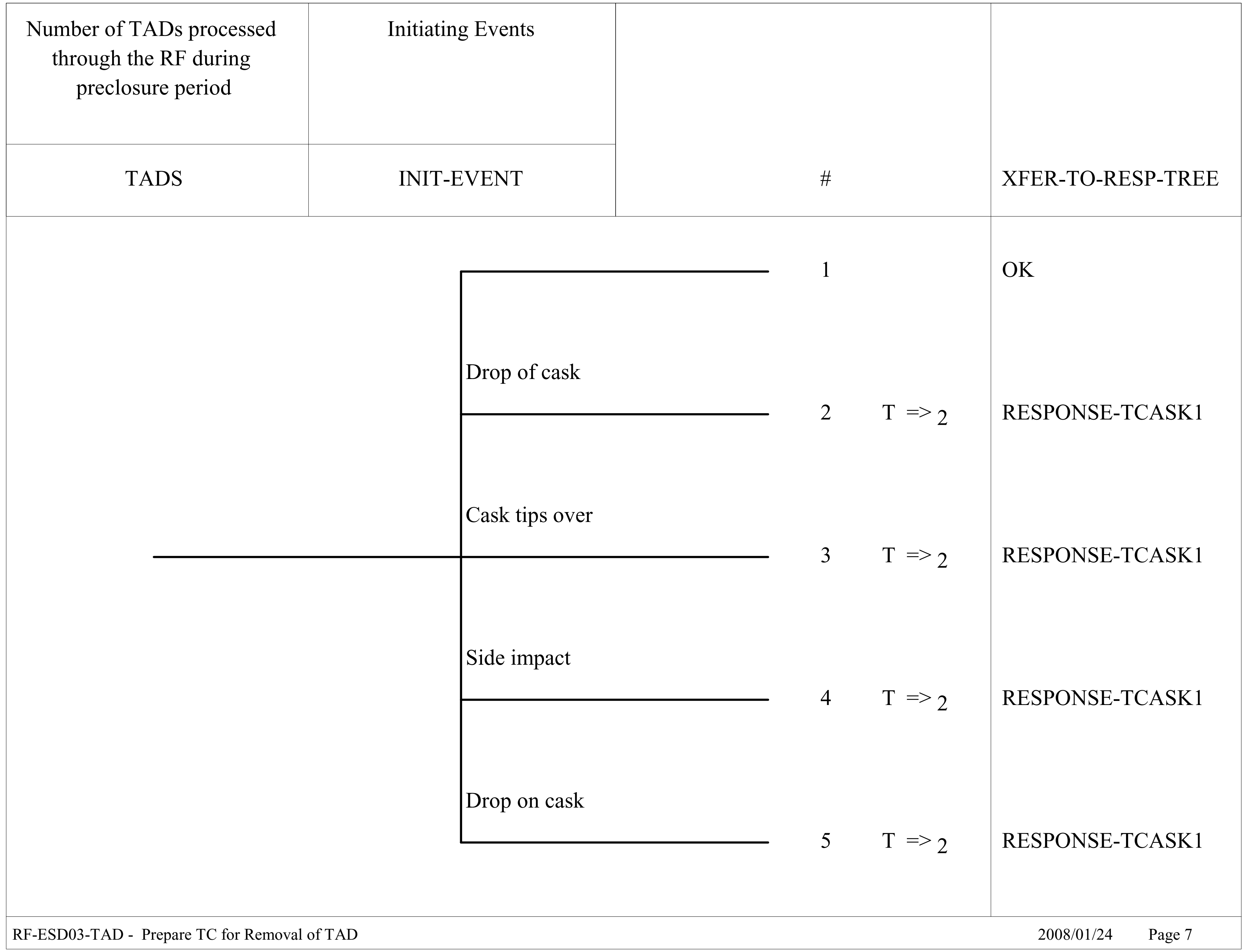
Figure G-6. Event Tree RF-ESD02-TAD – Remove Impact Limiters, Upend and Transfer Transportation Cask with TAD Canister to CTT



NOTE: DPC = dual-purpose canister; INIT = initiating; RESP = response; RF = Receipt Facility; T = transfer; TC = transportation cask; TCASK = transportation cask; XFER = transfer.

Source: Original

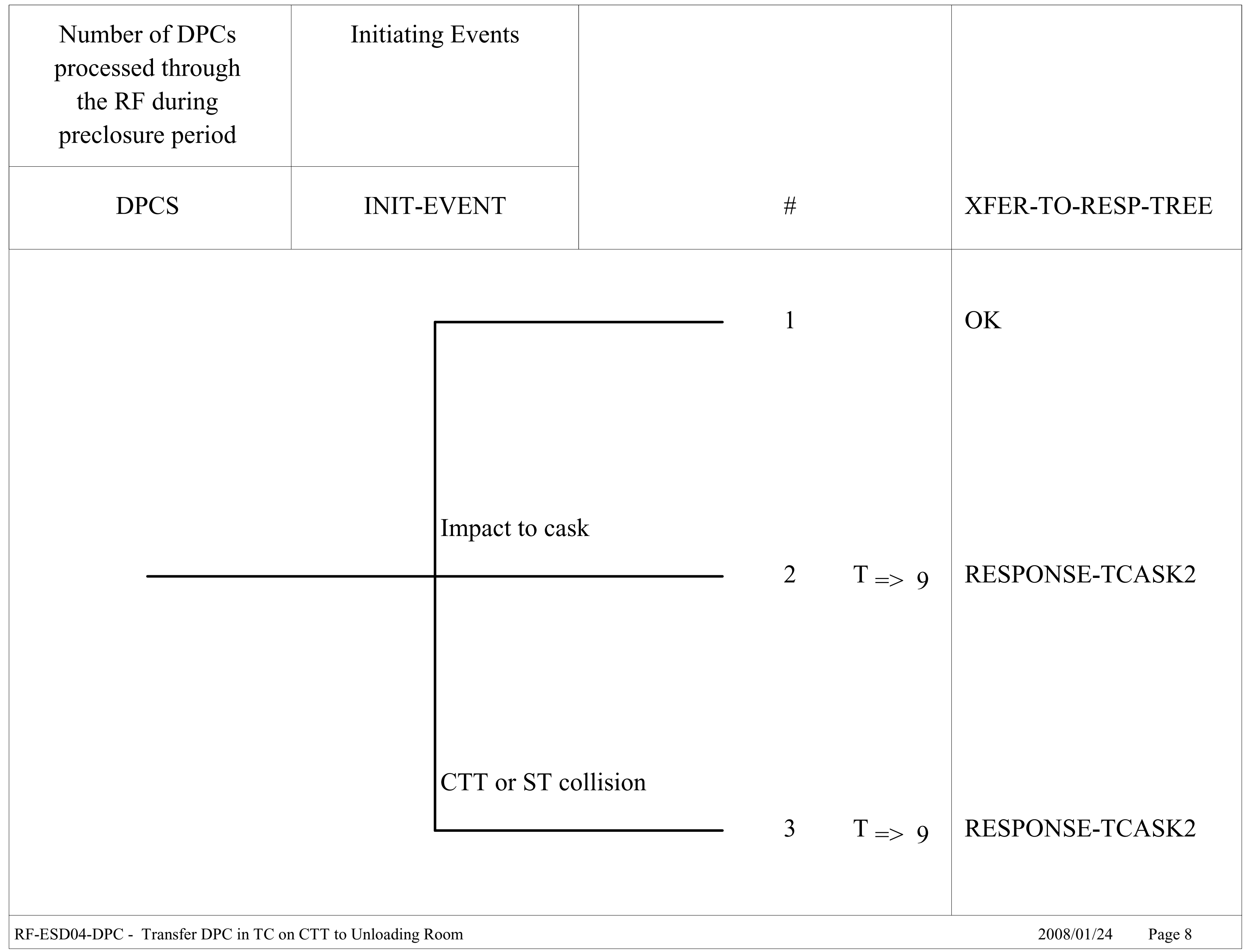
Figure G-7. Event Tree RF-ESD03-DPC – Prepare Transportation Cask for Removal of DPC



NOTE: INIT = initiating; RESP = response; RF = Receipt Facility; T = transfer; TAD = transportation, aging, and disposal canister; TC = transportation cask; TCASK = transportation cask; XFER = transfer.

Source: Original

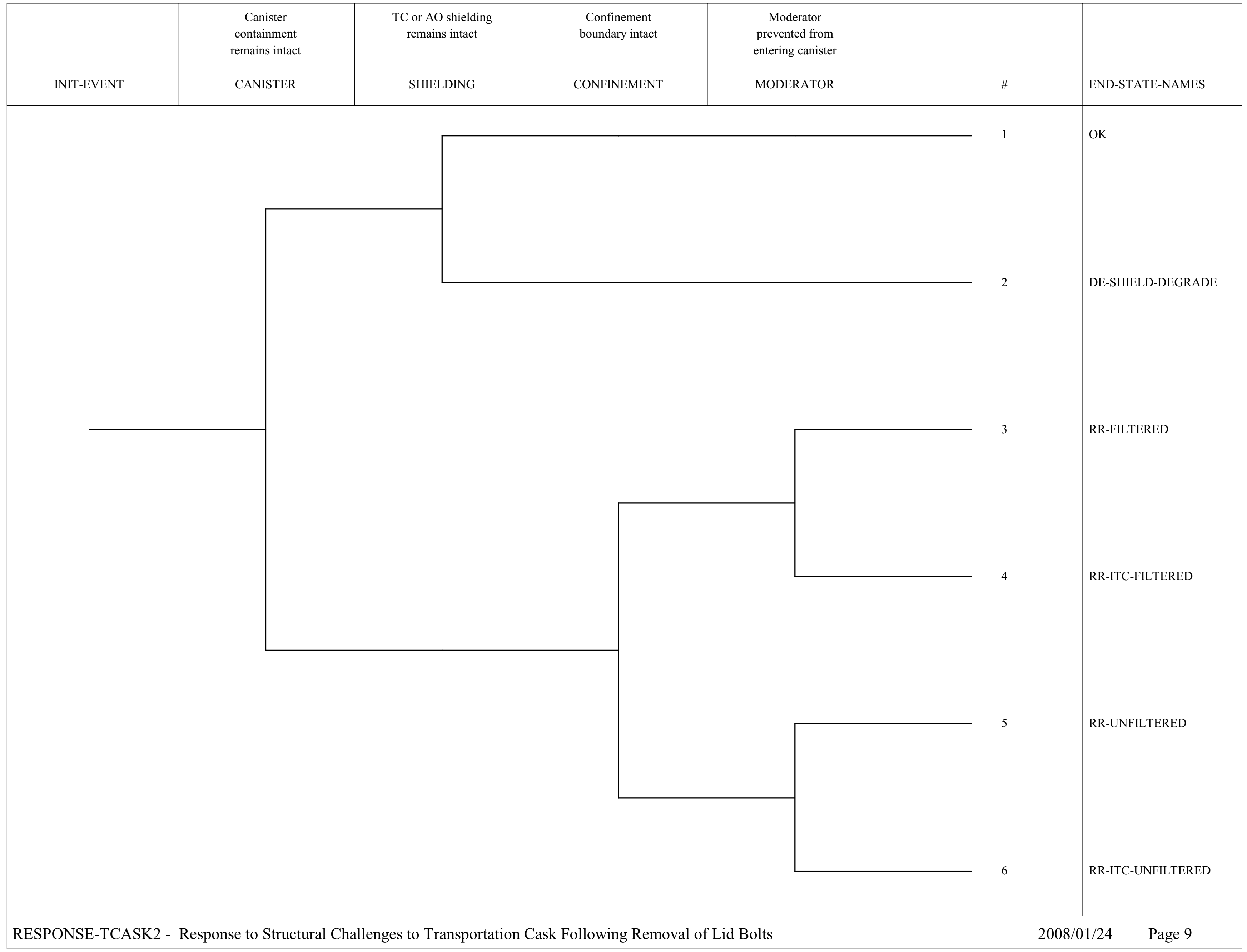
Figure G-8. Event Tree RF-ESD03-TAD – Prepare Transportation Cask for Removal of TAD Canister



NOTE: CTT = cask transfer trolley; DPC = dual-purpose canister; INIT = initiating; RESP = response; RF = Receipt Facility; ST = site transporter; T = transfer; TC = transportation cask; TCASK = transportation cask; XFER = transfer.

Source: Original

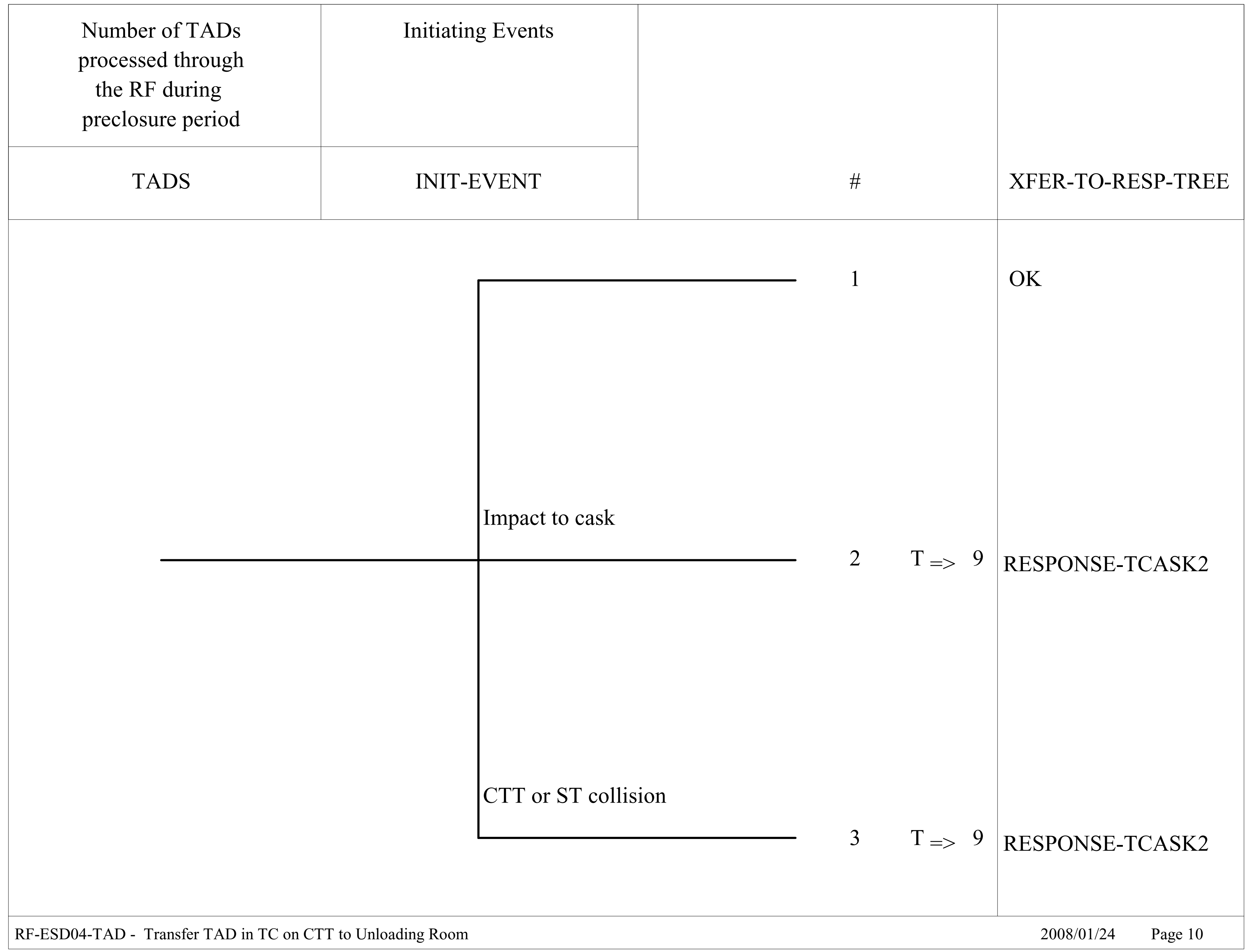
Figure G-9. Event Tree RF-ESD04-DPC – Transfer DPC in Transportation Cask on CTT to Unloading Room



NOTE: AO = aging overpack; DE = direct exposure; HVAC = heating, ventilation, and air conditioning; INIT = initiating; ITC = important to criticality; RR = radionuclide release; TC = transportation cask.

Source: Original

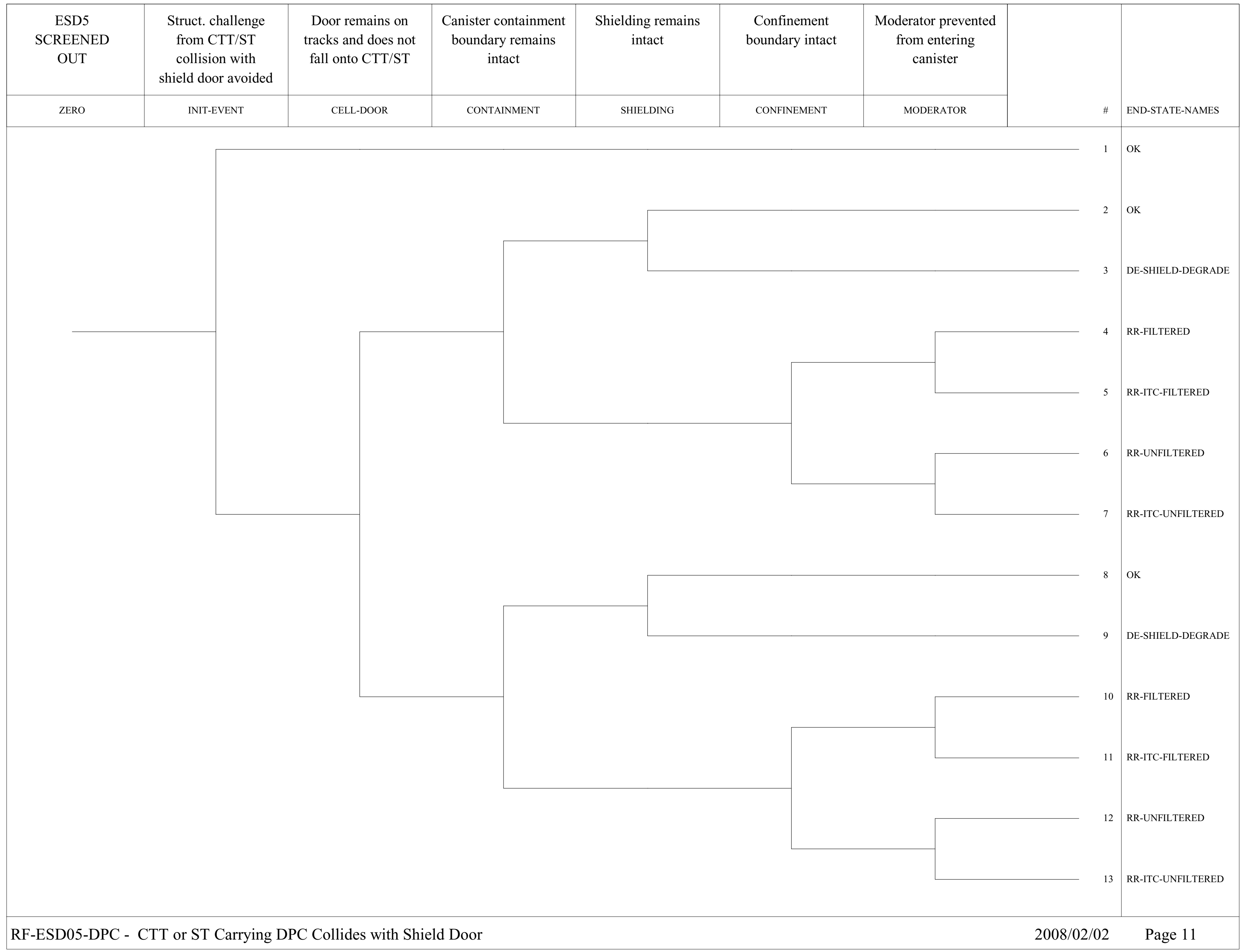
Figure G-10. Event Tree RESPONSE-TCASK2 – Response to Structural Challenges to Transportation Cask Following Removal of Lid Bolts



NOTE: CTT = cask transfer trolley; INIT = initiating; RESP = response; RF = Receipt Facility; ST = site transporter; T = transfer; TAD = transportation, aging, and disposal canister; TC = transportation cask; XFER = transfer.

Source: Original

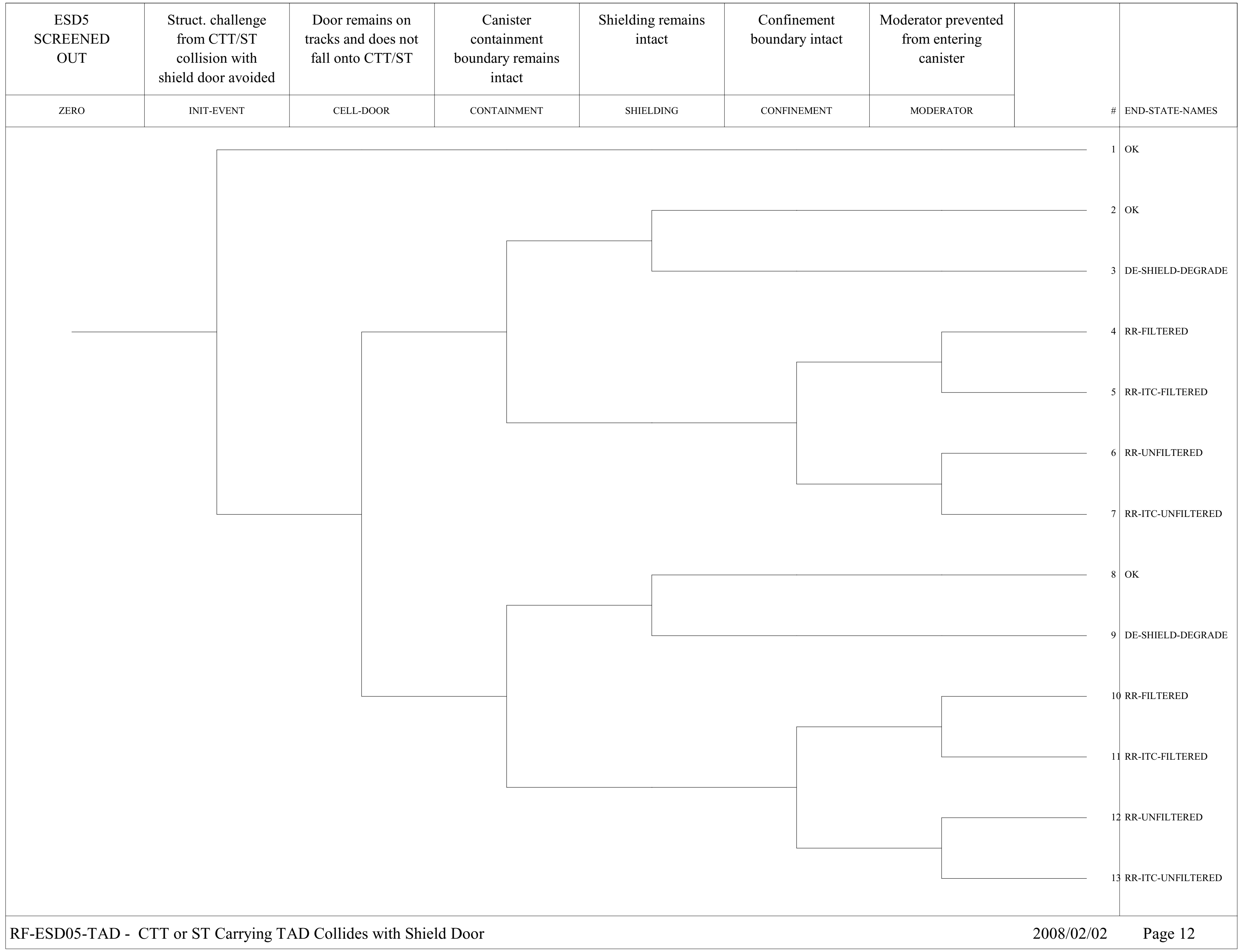
Figure G-11. Event Tree RF-ESD04-TAD – Transfer TAD Canister in Transportation Cask on CTT to Unloading Room



NOTE: CTT = cask transfer trolley; DE = direct exposure; DPC = dual-purpose canister; HVAC = heating, ventilation, and air conditioning; INIT = initiating; ITC = important to criticality; RESP = response; RF = Receipt Facility; RR = radionuclide release; ST = site transporter; TC = transportation cask.

Source: Original

Figure G-12. Event Tree RF-ESD05-DPC – CTT or Site Transporter Carrying DPC Collides with Shield Door



NOTE: CTT = cask transfer trolley; DE = direct exposure; HVAC = heating, ventilation, and air conditioning; ITC = important to criticality; INIT = initiating; RESP = response; RF = Receipt Facility; RR = radionuclide release; ST = site transporter; T = transfer; TAD = transportation, aging, and disposal canister; TC = transportation cask.

Source: Original

Figure G-13. Event Tree RF-ESD05-TAD – CTT or Site Transporter Carrying TAD Canister Collides with Shield Door

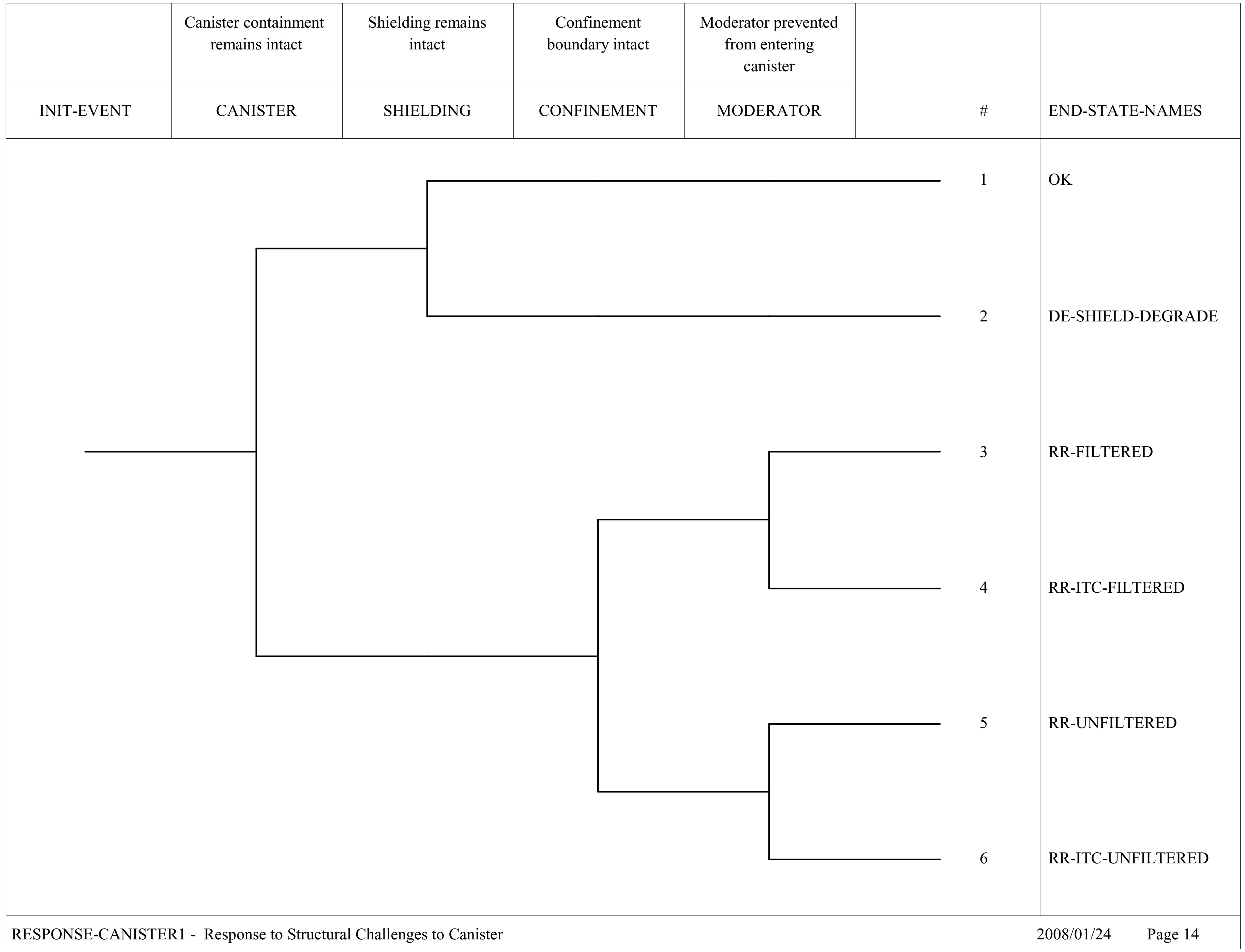
Number of DPCs processed through the RF during preclosure period	Initiating Events			
DPCS	INIT-EVENT	#		XFER-TO-RESP-TREE
		1		OK
	Impact with lid removed	2	T => 14	RESPONSE-CANISTER1
	Canister drop at operational height	3	T => 14	RESPONSE-CANISTER1
	Spurious movement	4	T => 14	RESPONSE-CANISTER1
	Side impact	5	T => 14	RESPONSE-CANISTER1
	Object dropped on canister	6	T => 14	RESPONSE-CANISTER1
	Canister dropped inside bell	7	T => 14	RESPONSE-CANISTER1
	Canister drop > operational height	8	T => 14	RESPONSE-CANISTER1

RF-ESD06-DPC - Transfering DPC from TC to AO with CTM 2008/01/24 Page 13

NOTE: CTM = canister transfer machine; DPC = dual-purpose canister; INIT = initiating; RESP = response; RF = Receipt Facility; T = transfer; XFER = transfer.

Source: Original

Figure G-14. Event Tree RF-ESD06-DPC – Transferring DPC from Transportation Cask to Aging Overpack with CTM



NOTE: DE = direct exposure; INIT = initiating; ITC = important to criticality; RR = radionuclide release.

Source: Original

Figure G-15. Event Tree RESPONSE-CANISTER1 – Response to Structural Challenges to Canister

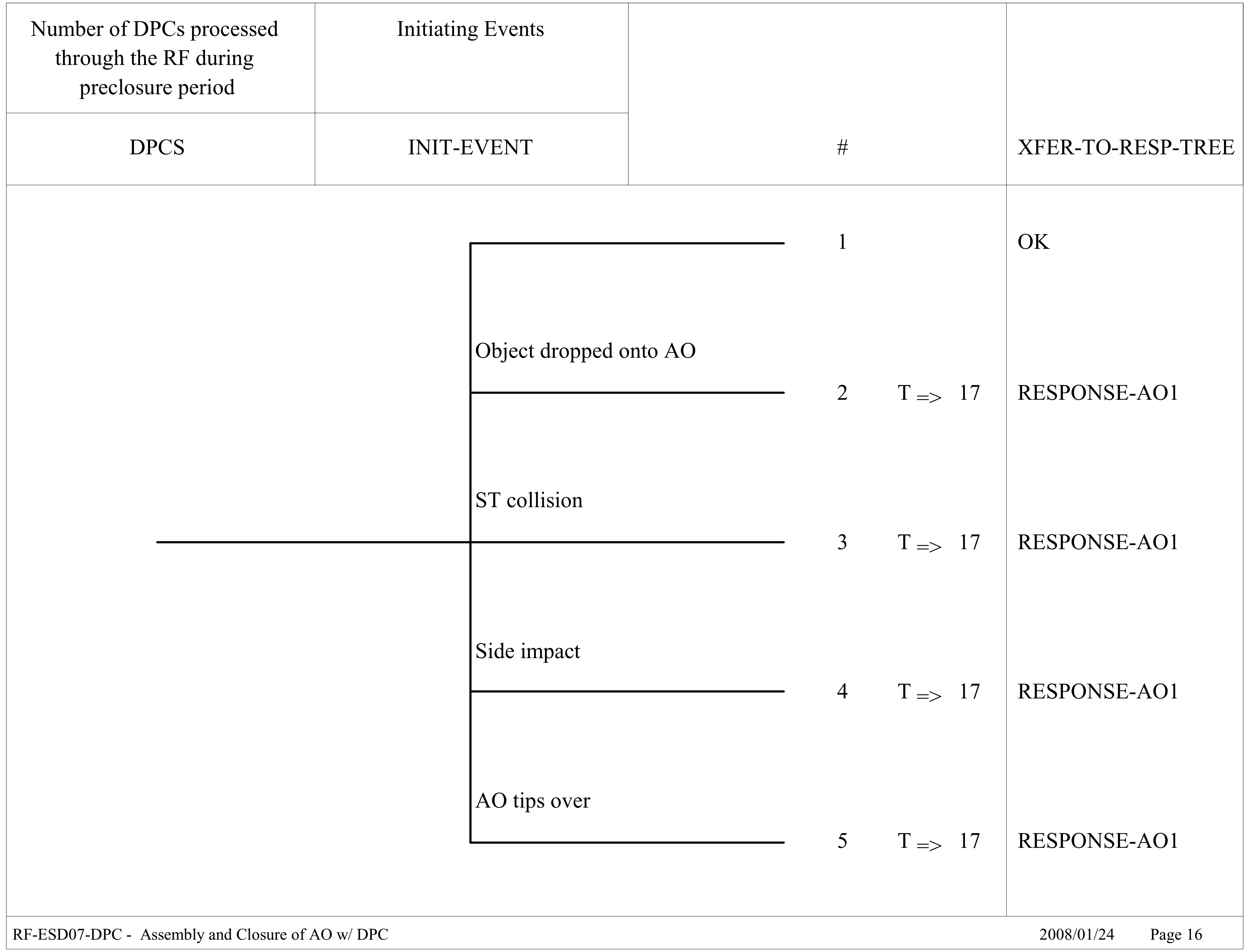
Number of TADs processed through the RF during preclosure period	Initiating Events	#		XFER-TO-RESP-TREE
TADS	INIT-EVENT			
		1		OK
	Impact with lid removed	2	T => 14	RESPONSE-CANISTER1
	Canister drop at operational height	3	T => 14	RESPONSE-CANISTER1
	Spurious movement	4	T => 14	RESPONSE-CANISTER1
	Side impact	5	T => 14	RESPONSE-CANISTER1
	Object dropped on canister	6	T => 14	RESPONSE-CANISTER1
	Canister dropped inside bell	7	T => 14	RESPONSE-CANISTER1
	Canister drop > operational height	8	T => 14	RESPONSE-CANISTER1

RF-ESD06-TAD - Transfering TAD from TC to AO with CTM 2008/01/24 Page 15

NOTE: CTM = canister transfer machine; INIT = initiating; RESP = response; RF = Receipt Facility; T = transfer; TAD = transportation, aging, and disposal canister; XFER = transfer.

Source: Original

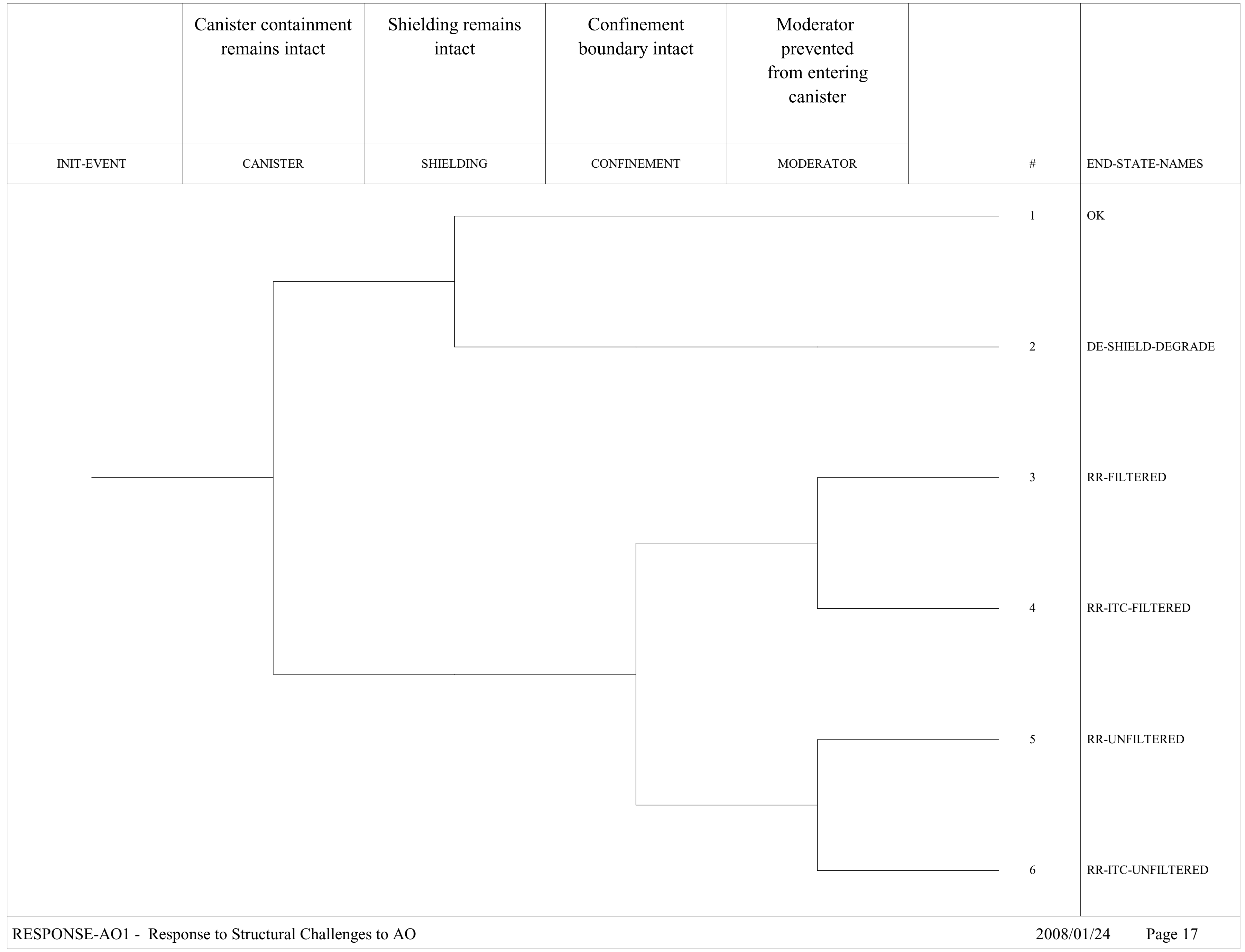
Figure G-16. Event Tree RF-ESD06-TAD – Transferring TAD Canister from Transportation Cask to Aging Overpack with CTM



NOTE: AO = aging overpack; DPC = dual-purpose canister; INIT = initiating; RESP = response; RF = Receipt Facility; ST = site transporter; T = transfer; TCASK = transportation cask; XFER = transfer.

Source: Original

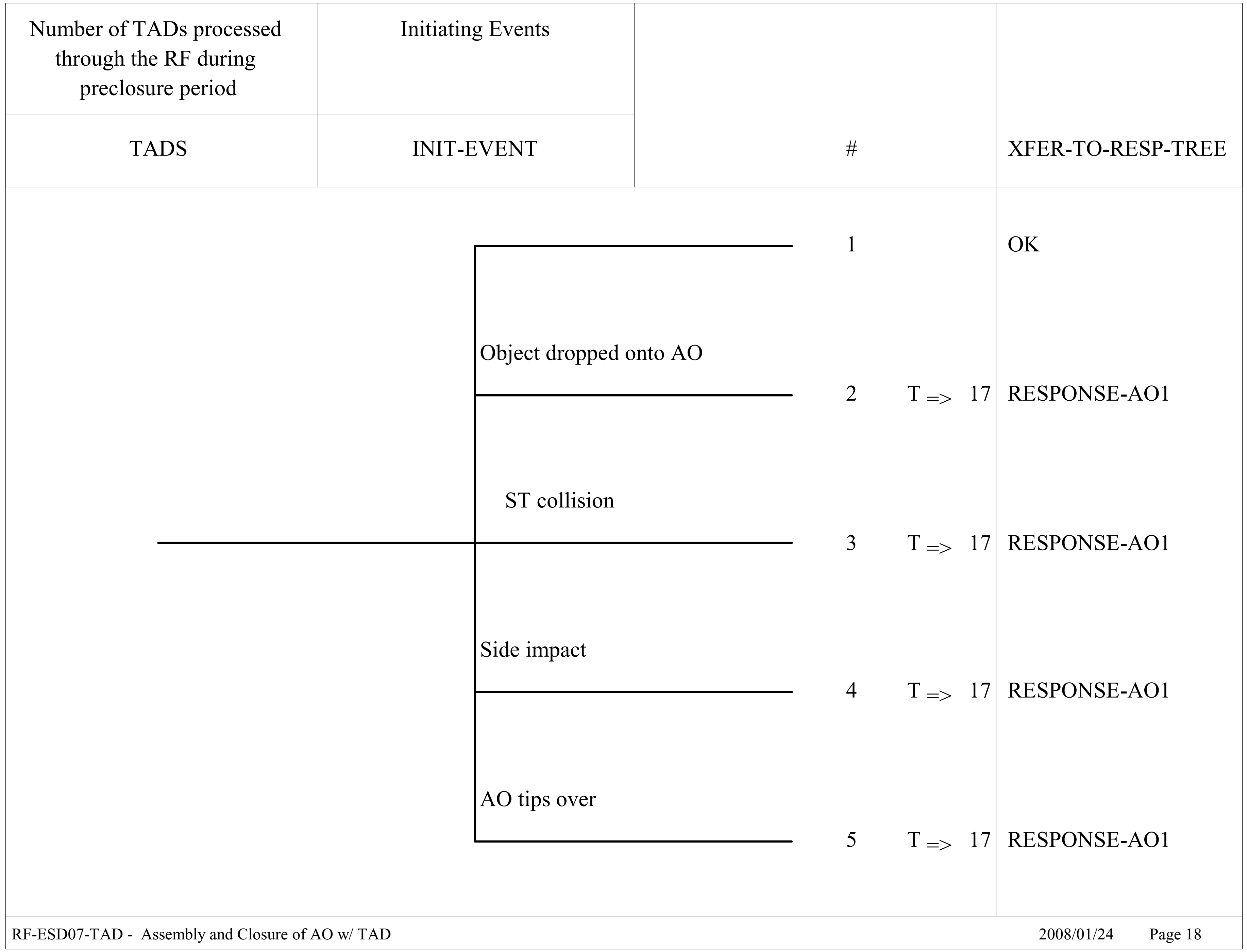
Figure G-17. Event Tree RF-ESD07-DPC – Assembly and Closure of Aging Overpack with DPC



NOTE: AO = aging overpack; DE = direct exposure; INIT = initiating; ITC = important to criticality; RR = radionuclide release.

Source: Original

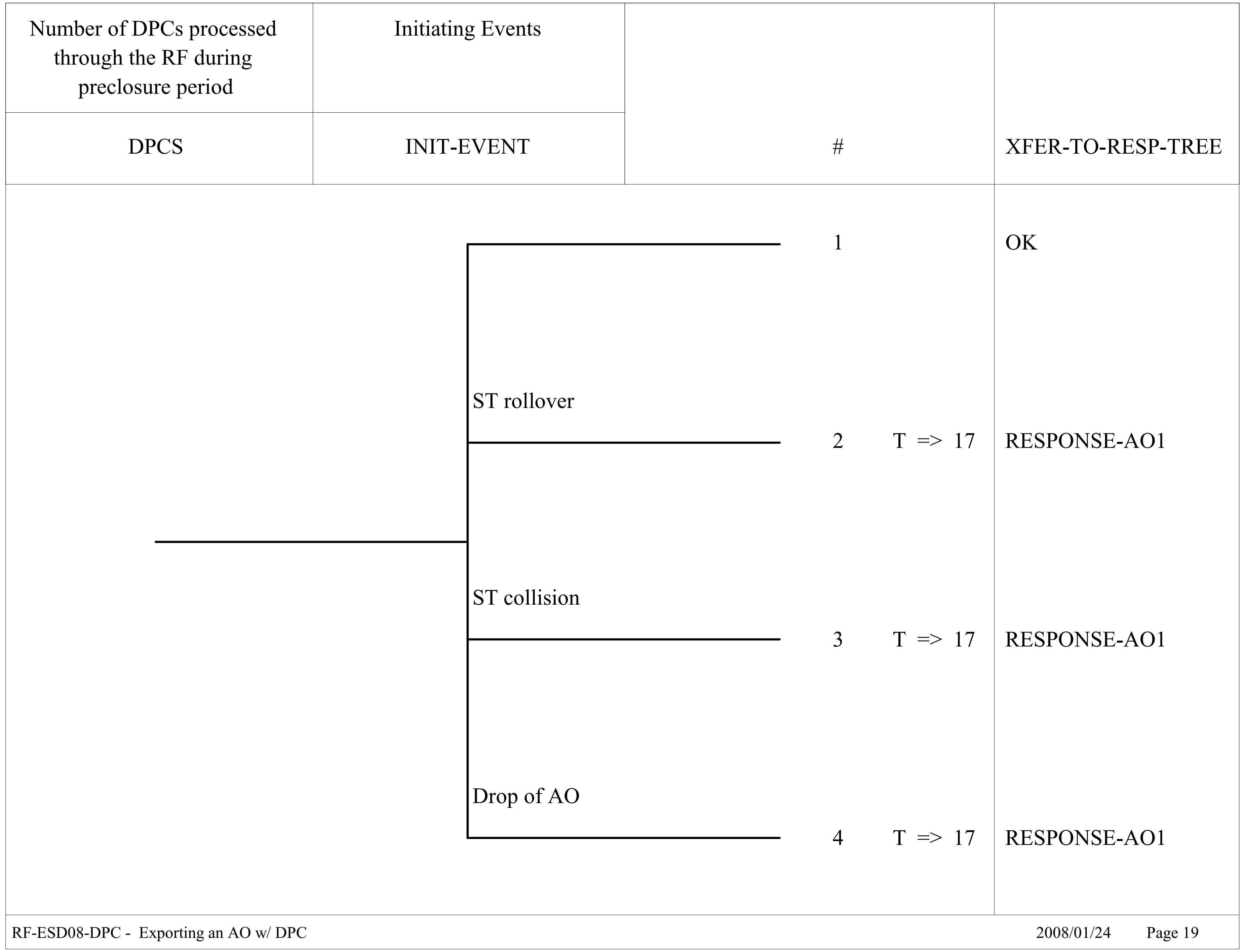
Figure G-18. Event Tree RESPONSE-AO1 – Response to Structural Challenges to Aging Overpack



NOTE: AO = aging overpack; INIT = initiating; RESP = response; RF = Receipt Facility; ST = site transporter; T = transfer; TAD = transportation, aging, and disposal canister; XFER = transfer.

Source: Original

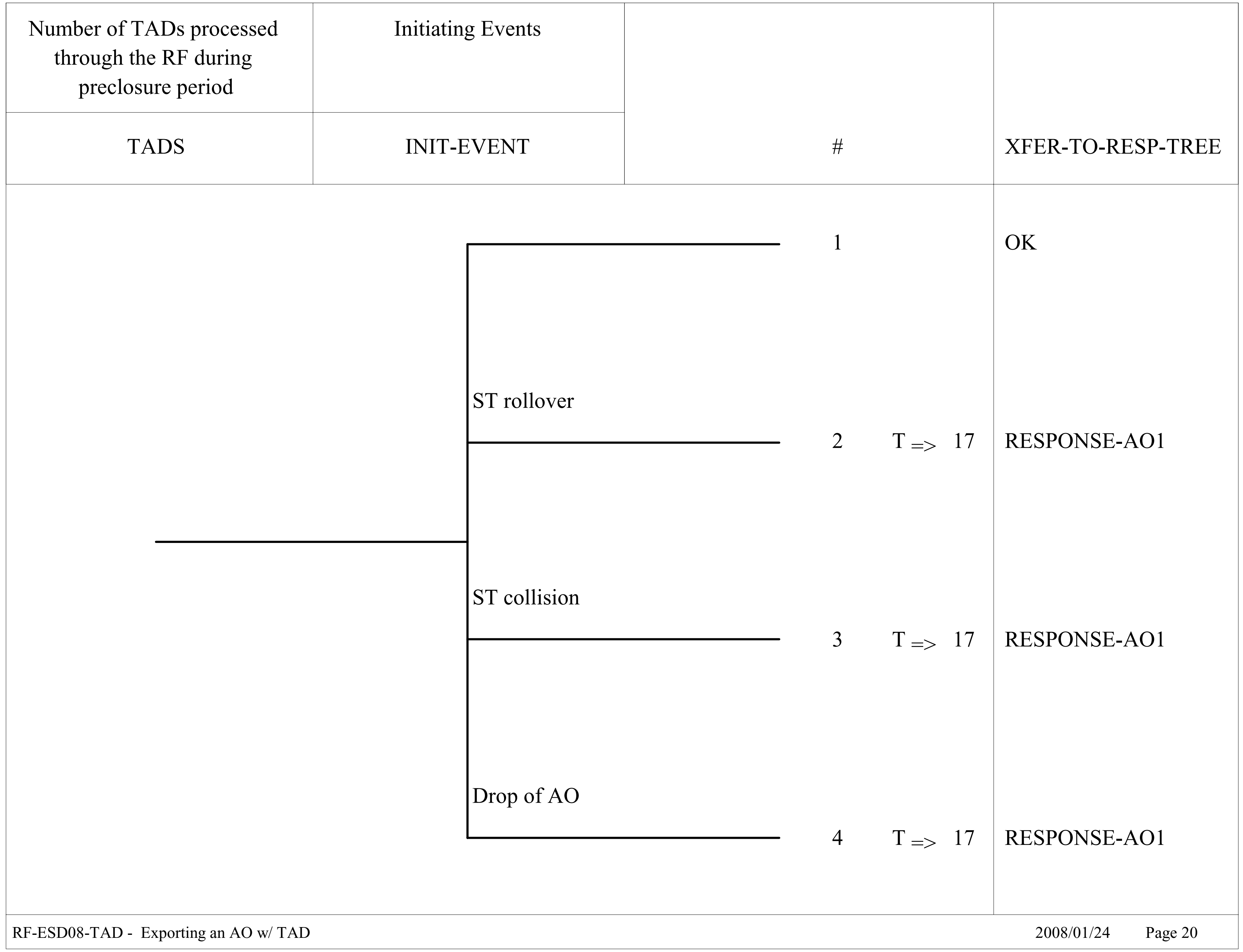
Figure G-19. Event Tree RF-ESD07-TAD – Assembly and Closure of Aging Overpack with TAD Canister



NOTE: AO = aging overpack; DPC = dual-purpose canister; INIT = initiating; RESP = response; RF = Receipt Facility; ST = site transporter; T = transfer; XFER = transfer.

Source: Original

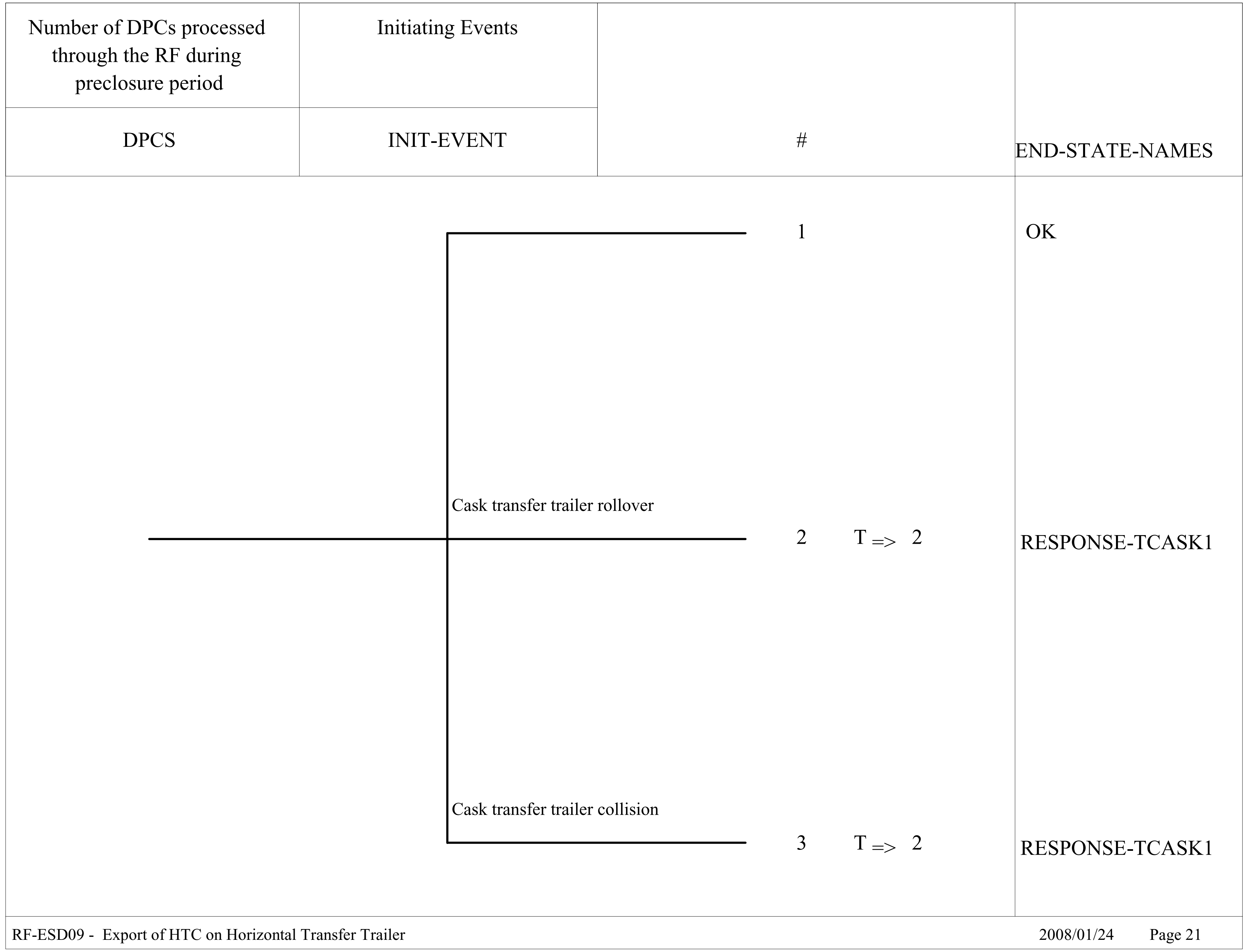
Figure G-20. Event Tree RF-ESD08-DPC – Export of an Aging Overpack with DPC



NOTE: AO = aging overpack; INIT = initiating; RESP = response; RF = Receipt Facility; ST = site transporter; T = transfer; TAD = transportation, aging, and disposal canister; XFER = transfer.

Source: Original

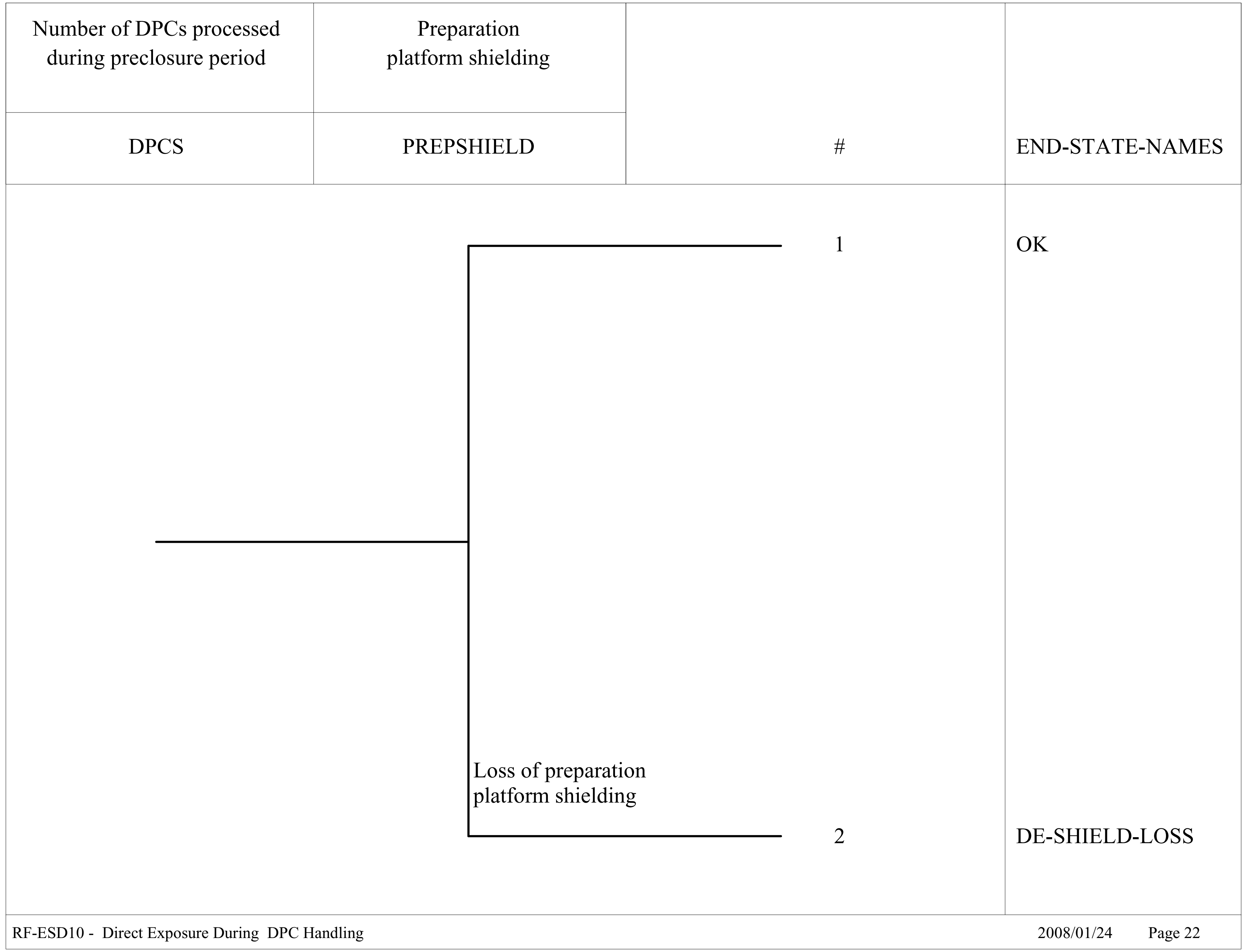
Figure G-21. Event Tree RF-ESD08-TAD – Export of an Aging Overpack with TAD Canister



NOTE: DPC = dual purpose canister; HTC = a transportation cask that is never upended; INIT = initiating; RF = Receipt Facility; T = transfer.

Source: Original

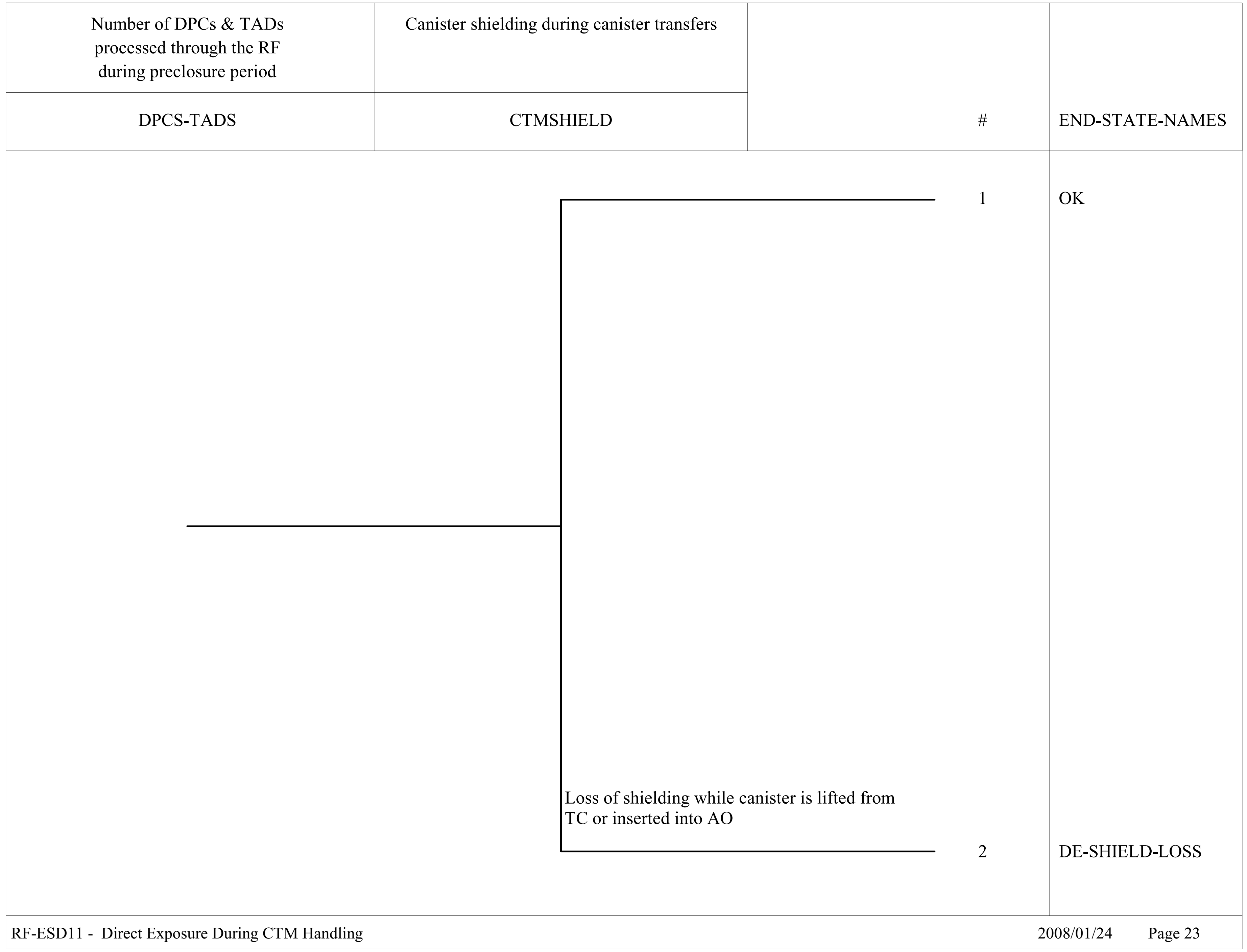
Figure G-22. Event Tree RF-ESD09 – Export of HTC on Horizontal Transfer Trailer



NOTE: DE = direct exposure; DPC = dual-purpose canister; PREP = preparation.

Source: Original

Figure G-23. Event Tree RF-ESD10 – Direct Exposure during DPC Handling



NOTE: AO = aging overpack; CTM = canister transfer machine; DE = direct exposure; DPC = dual-purpose canister; INIT = initiating; RF = Receipt Facility; TAD = transportation, aging, and disposal canister; TC = transportation cask.

Source: Original

Figure G-24. Event Tree RF-ESD11 – Direct Exposure during CTM Handling

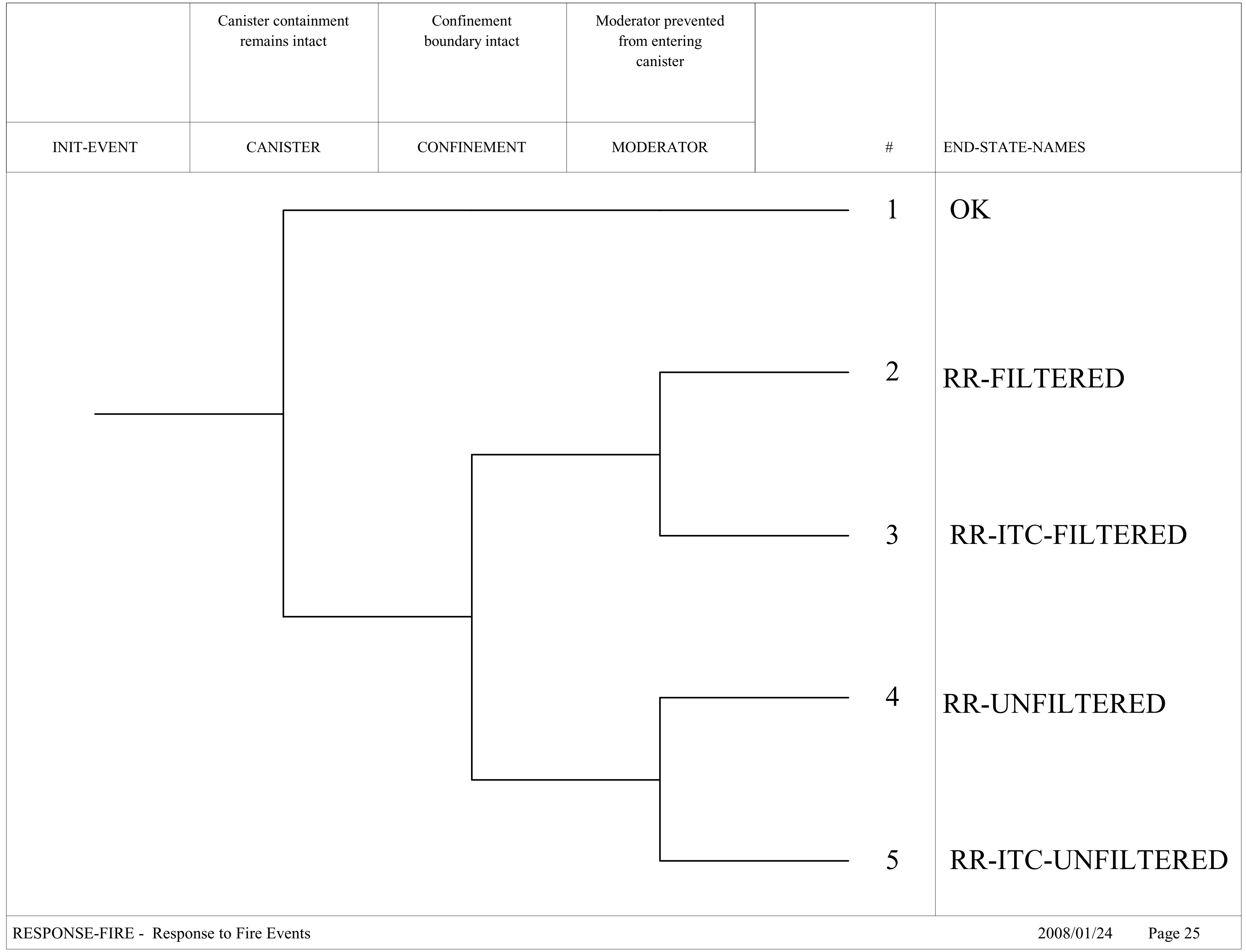
Number of DPCs processed through the RF during preclosure period	Initiating Events		
DPCS	INIT-EVENT	#	XFER-TO-RESP-TREE
		1	OK
	Local fire in vestibule or lid bolting room (diesel present)	2 T => 25	RESPONSE-FIRE
	Local fire in loading room (diesel present)	3 T => 25	RESPONSE-FIRE
	Local fire in vestibule or preparation area (diesel present)	4 T => 25	RESPONSE-FIRE
	Local fire threatens TC/TAD or TC/DPC in preparation area	5 T => 25	RESPONSE-FIRE
	Local fire threatens waste form in preparation area	6 T => 25	RESPONSE-FIRE
	Local fire in cask unloading room	7 T => 25	RESPONSE-FIRE
	Local fire in transfer room	8 T => 25	RESPONSE-FIRE
	Large fire in RF	9 T => 25	RESPONSE-FIRE

RF-ESD12-DPC - Fire with DPC 2008/01/24 Page 24

NOTE: DPC = dual-purpose canister; INIT = initiating; RESP = response; RF = Receipt Facility; T = transfer; TAD = transportation, aging, and disposal canister; TC = transportation cask; XFER = transfer.

Source: Original

Figure G-25. Event Tree RF-ESD12-DPC – Fire with DPC



NOTE: INIT = initiating; ITC = important to criticality; RR = radionuclide release.

Source: Original

Figure G-26. Event Tree RESPONSE-FIRE – Response to Fire Events

Number of TADs processed through the RF during preclosure period	Initiating Events		
TADS	INIT-EVENT	#	XFER-TO-RESP-TREE
		1	OK
	Local fire in vestibule or lid bolting room (diesel present)	2 T => 25	RESPONSE-FIRE
	Local fire in loading room (diesel present)	3 T => 25	RESPONSE-FIRE
	Local fire in vestibule or preparation area (diesel present)	4 T => 25	RESPONSE-FIRE
	Local fire threatens TC/TAD or TC/DPC in preparation area	5 T => 25	RESPONSE-FIRE
	Local fire threatens waste form in preparation area	6 T => 25	RESPONSE-FIRE
	Local fire in cask unloading room	7 T => 25	RESPONSE-FIRE
	Local fire in transfer room	8 T => 25	RESPONSE-FIRE
	Large fire in RF	9 T => 25	RESPONSE-FIRE

RF-ESD12-TAD - Fire with TAD 2008/01/24 Page 26

NOTE: DPC = dual-purpose canister; INIT = initiating; RESP = response; RF = Receipt Facility; T = transfer; TAD = transportation, aging, and disposal canister; TC = transportation cask; XFER = transfer.

Source: Original

Figure G-27. Event Tree RF-ESD12-TAD – Fire with TAD Canister