**BSC**

# Design Calculation or Analysis Cover Sheet

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# ACRONYMS AND ABBREVIATIONS

## Acronyms

| | |
|---|---|
| BSC | Bechtel SAIC Company, LLC |
| CFR | Code of Federal Regulations |
| CTM | canister transfer machine |
| CTT | cask transfer trolley |
| ESD | event sequence diagram |
| GROA | geologic repository operations area |
| HAZOP | hazard and operability |
| HEPA | high-efficiency particulate air |
| HLW | high-level radioactive waste |
| HVAC | heating, ventilation, and air conditioning |
| IHF | Initial Handling Facility |
| MAP | mobile access platform |
| MLD | master logic diagram |
| PCSA | preclosure safety analysis |
| PFD | process flow diagram |
| PRA | probabilistic risk assessment |
| RHS | remote handling system |
| SNF | spent nuclear fuel |
| SPM | site prime mover |
| SSC | structure, system, or component |
| SSCs | structures, systems, and components |
| TAD | transportation, aging, and disposal |
| TEV | transport and emplacement vehicle |
| TWF | typical waste-handling facility |
| WPTT | waste package transfer trolley |

## Abbreviations

| | |
|---|---|
| ft | foot, feet |
| in. | inch, inches |

# 1. PURPOSE

This document along with its companion document entitled *Initial Handling Facility 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. 2.3.1).

The PCSA uses probabilistic risk assessment (PRA) technology derived from both nuclear power plant and aerospace methods and applications in order to perform analyses to comply with the risk informed aspects of 10 CFR 63.111 and 10 CFR 63.112 (Ref. 2.3.1) and to be responsive to the acceptance criteria articulated in the *Yucca Mountain Review Plan* (Ref. 2.2.70). The PCSA, however, limits the use of PRA technology to identification and development of event sequences that might lead to direct exposure of workers or onsite members of the public, radiological releases that may affect the public or workers (onsite and offsite), and criticality.

The radiological consequence assessment relies on bounding inputs with deterministic methods to obtain bounding dose estimates. These were developed using broad categories of scenarios that might cause a radiological release or direct exposure to workers and the public, both onsite and offsite. These broad categories of scenarios 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 particulate air (HEPA) filters when applicable. After completion of the event sequence development in the present analysis and its companion document, each Category 1 and Category 2 event sequence was conservatively matched with one of the categories of dose estimates.

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

> Event sequence means a series of actions and/or occurrences within the natural and engineered components of a geologic repository operations area that could potentially lead to exposure of individuals to radiation. An event sequence includes one or more initiating events and associated combinations of repository system component failures, including those produced by the action or inaction of operating personnel.
>
> Those event sequences that are expected to occur one or more times before permanent closure of the geologic repository operations area are referred to as Category 1 event sequences. Other event sequences that have at least one chance in 10,000 of occurring before permanent closure are referred to as Category 2 event sequences.

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

10 CFR 63.112, Paragraph (e) and Subparagraph (e)(6) (Ref. 2.3.1) requires analyses to identify the controls that are relied upon to limit or prevent potential event sequences or mitigate their consequences. Subparagraph (e)(6) specifically notes that the analyses should include consideration of “means to prevent and control criticality.” The PCSA criticality analyses employ specialized deterministic methods 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 reactivity increase that should be analyzed to determine if reactivity can exceed the upper subcriticality limit.

In order to determine the criticality potential for each waste form and associated facility and handling operations, criticality sensitivity calculations are performed. These calculations evaluate the impact on system reactivity of variations in each of the parameters important to criticality during the preclosure period, which are waste form characteristics, reflection, interaction, neutron absorbers (fixed and soluble), geometry, and moderation. The criticality sensitivity calculations determine the sensitivity of the effective neutron multiplication factor ($k_{eff}$) to variations in any of these parameters as a function of the other parameters. The analysis determined the parameters that this event sequence analysis should include. Presence of moderation in association with a path to exposed fuel was 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 similar reasons are multiple U.S. Department of Energy (DOE) spent nuclear fuel (SNF) canisters in the 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, and components (SSCs) before they reach the site (e.g., drops of casks, canisters, or fuel assemblies during loading at a reactor site, improper drying, closing, or inerting at the reactor site, rail accidents during transport, 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. 2.3.2), 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 practice to not consider the occurrence of other initiating events (human-induced or naturally occurring) during the time span of an event sequence because: (a) the probability of two simultaneous initiating events within the time window is small and, (b) each initiating event will cease operations of the waste handling facility which further reduces the conditional probability of the occurrence of a second initiating event, given that the first has occurred.

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

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

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

The scope of the present analysis includes operations spanning the receipt of transportation casks on rail or truck conveyances into the Cask Preparation Area of the IHF through the loading of waste packages into the transport and emplacement vehicle (TEV) in the Waste Package Loadout Room of the Initial Handling Facility (IHF). Transport by the TEV from its loading position in the Waste Package Loadout Room to the subsurface is covered in the subsurface operations event sequence development analysis.

This analysis includes: a process flow diagram (PFD), a master logic diagram (MLD), a hazard and operability (HAZOP) evaluation, event sequence diagrams (ESDs), and event trees. Initiating events considered in this analysis include internal events (i.e., events that are initiated within the IHF) as well as external events (i.e., events that are initiated from outside the IHF). 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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2.2.69 NRC (U.S. Nuclear Regulatory Commission) 1983. *PRA Procedures Guide, A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants*. NUREG/CR-2300. Two volumes. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 205084. (DIRS 106591)

2.2.70 NRC 2003. *Yucca Mountain Review Plan, Final Report*. NUREG-1804, Rev. 2. Washington, D.C.: U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards. TIC: 254568. (DIRS 163274)

2.2.71 NRC 1980. *Control of Heavy Loads at Nuclear Power Plants.* NUREG-0612. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 209017. (DIRS 104939)

2.2.72 SAPHIRE V. 7.26. 2006. Windows 2000, XP. STN: 10325-7.26-00. (DIRS 177010)

2.2.73 SAPHIRE V. 7.26. 2007. VMware/WINDOWS XP. STN: 10325-7.26-01. (DIRS 183846)

2.2.74 Smartt, H.B. 2005. *Component Design Description: Welding and Inspection System*. TFR-283, Rev. 1. Idaho Falls, Idaho: Idaho National Engineering and Environmental Laboratory. ACC: ENG.20051025.0013.

2.2.75 Smith, C. 2007. *Master Logic Diagram.* Bethesda, Maryland: Futron Corporation. ACC: MOL.20071105.0153; MOL.20071105.0154. (DIRS 183769)

## 2.3 DESIGN CONSTRAINTS

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

2.3.2 10 CFR 50. Energy: Domestic Licensing of Production and Utilization Facilities.

2.3.3 10 CFR 71. Energy: Packaging and Transportation of Radioactive Material.

2.3.4 10 CFR 72. Energy: Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste.

## 2.4 DESIGN OUTPUTS

This analysis is used as input to the following analysis:

2.4.1 BSC 2008. *Initial Handling Facility Reliability and Event Sequence Categorization Analysis*. 51A-PSA-IH00-00200-000-00A. 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. 2.2.55)

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. 2.2.16)
- *CRCF, RF, WHF & IHF Personnel Barrier Lifting Device Mechanical Equipment Envelope* (Ref. 2.2.17)
- *Geologic Repository Operations Area North Portal Site Plan* (Ref. 2.2.56)
- *Initial Handling Facility Cask Preparation Platform Mechanical Equipment Envelope Sheet 1 of 2* (Ref. 2.2.24)
- *Initial Handling Facility Cask Preparation Platform Mechanical Equipment Envelope Sheet 2* (Ref. 2.2.25)
- *Initial Handling Facility Loadout Platform Mechanical Equipment Envelope* (Ref. 2.2.34)
- *Initial Handling Facility Mobile Access Platform Mechanical Equipment Envelope* (Ref. 2.2.46)
- *Nuclear Facilities Rail Cask Lid Adapter Mechanical Equipment Envelope* (Ref. 2.2.53)
- *Nuclear Facilities Truck Cask Lid Adapter Mechanical Equipment Envelope* (Ref. 2.2.54)

**Documentation of suitability for intended use of other inputs**. Some of the descriptive material in Attachment A that is related to the waste package closure system is taken from the supplier documents that are cited there: *Component Design Description: Remote Handling System* (Ref. 2.2.61) and *Component Design Description: Welding and Inspection System* (Ref. 2.2.74). This information is presented to give the reader a basic understanding of the processes involved. The supplier documents cited provide suitable descriptive information on waste package closure equipment that has been designed specifically for repository use.

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. 2.2.63)
- *Master Logic Diagram* (Ref. 2.2.75)
- *Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR): Data Manual, Part 4: Summary Aggregations* (Ref. 2.2.66)
- *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. 2.2.59)
- *Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants* (Ref. 2.2.60)
- *Canister Storage Building Design Basis Accident Analysis Documentation* (Ref. 2.2.62)
- *Safety Analysis Report, Idaho Spent Fuel Facility* (Ref. 2.2.67)
- *A Survey of Crane Operating Experience at U.S. Nuclear Power Plants from 1968 through 2002* (Ref. 2.2.68)
- *Control of Heavy Loads at Nuclear Power Plants* (Ref. 2.2.71).

## 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. 2.2.72 and Ref. 2.2.73), 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
- Windows XP
- Windows XP running inside a VMware virtual machine with VMware Player.

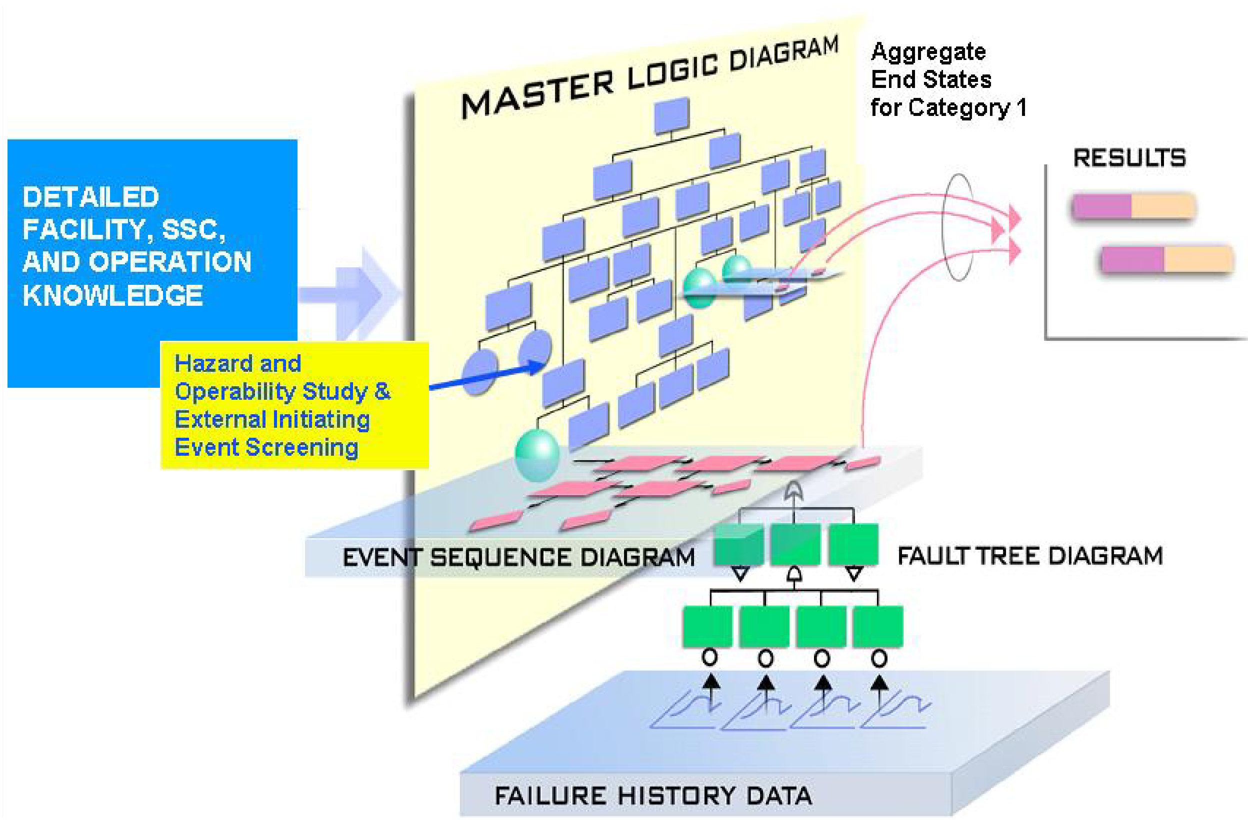
## 4.3 APPROACH AND ANALYSIS METHODS

This section presents the PCSA approach and analysis methods in the context of overall repository operations. As such, it includes a discussion of operations that may not apply to the IHF. Specific features of the IHF and its operations are not discussed until Section 6, where the methods described here are applied to IHF. The PCSA uses the technology of PRA as described in references such as American Society of Mechanical Engineers *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.

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 evaluation.




Source: Modified from Probabilistic Risk Assessment: Master Logic Diagram (Ref. 2.2.75) (Smith, C. 2007)

Figure 1. Event Sequence Analysis Process

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. 2.2.63) and *Nuclear Computerized Library for Assessing Reactor Reliability* (Ref. 2.2.66), 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. 2.3.1), each event sequence is categorized based on its frequency. Therefore, the focus of this analysis is to:

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

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

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

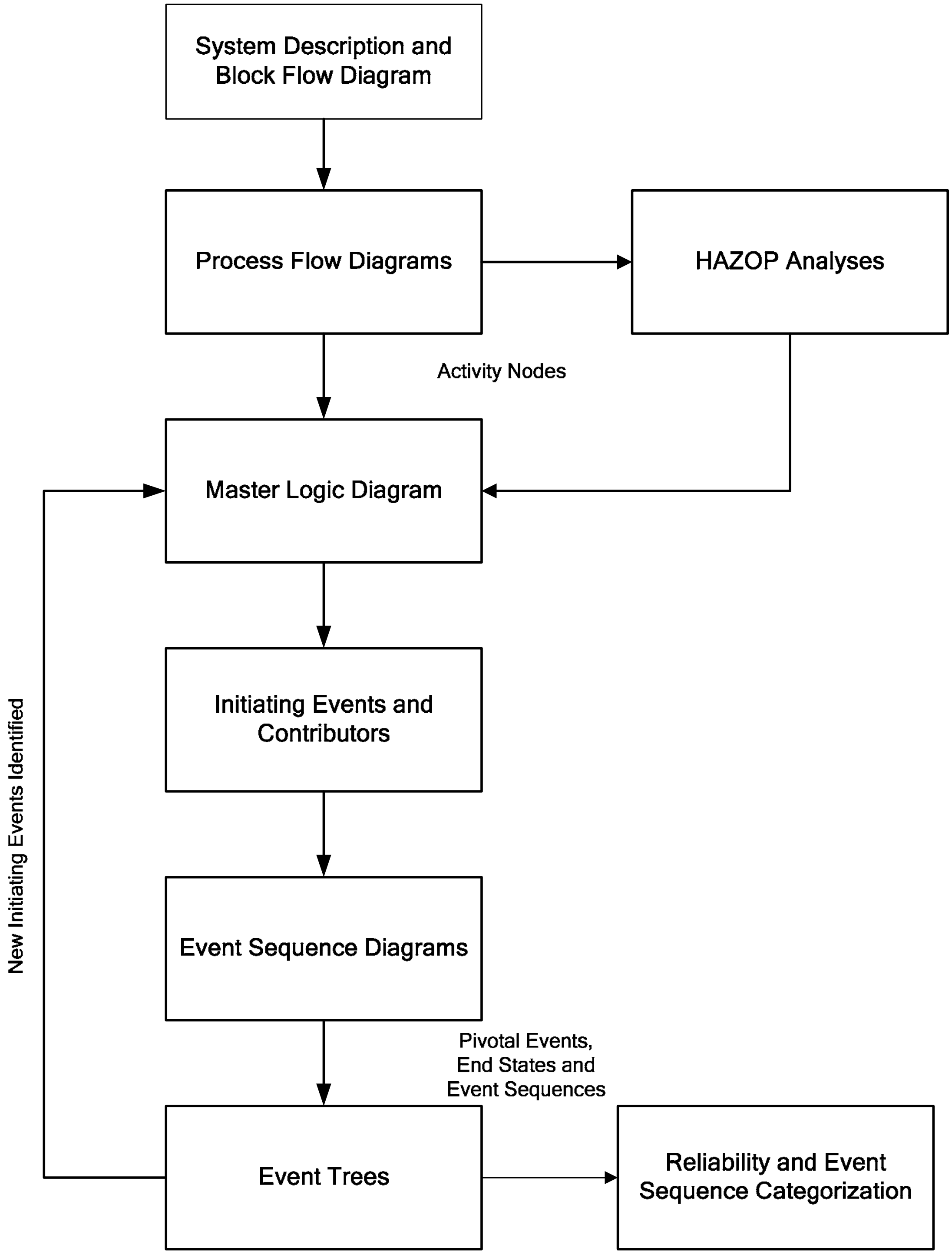
Event sequences are developed based upon a description of GROA operations as depicted in the process flow diagram of Section 6 and the equipment and operations descriptions of Attachments A and B. Accordingly, an event sequence, represented in an event sequence diagram, is particular to a given operational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

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 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.

[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.




Source: Original

Figure 2. Preclosure Safety Analysis Process

A HAZOP evaluation is used to supplement the MLD with respect to identification of initiating events. A HAZOP evaluation 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 evaluation was performed solely as a supplementary method to identify initiating events. If a HAZOP evaluation identified an initiating event that was not covered by the MLD, it was added to the MLD. Typically, the HAZOP evaluation 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 evaluation. It was found that deviations identified in the HAZOP evaluation 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 evaluation. Table 7 gives an example of the coordination of the MLD and HAZOP evaluation. The complete HAZOP evaluation 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. 2.2.69), 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. 2.2.59).
- *Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants*. (Ref. 2.2.60)
- *Canister Storage Building Design Basis Accident Analysis Documentation*. (Ref. 2.2.62)
- *Safety Analysis Report, Idaho Spent Fuel Facility*. (Ref. 2.2.67)
- *A Survey of Crane Operating Experience at U.S. Nuclear Power Plants from 1968 through 2002*. (Ref. 2.2.68)
- *Control of Heavy Loads at Nuclear Power Plants*. (Ref. 2.2.71).

The MLD is cross-checked to the HAZOP evaluation, 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 evaluation (and available on call when questions came up) has experience with such technologies and is well equipped to perform a HAZOP evaluation. As has already been noted, the MLD is modified to include any initiators and contributors that are identified in the HAZOP evaluation but 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 evaluation provide a diversity of viewpoints that add confidence that no important initiating events have been omitted. The HAZOP evaluation 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 evaluation 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 evaluation. 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 evaluation 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 evaluation table. This MLD index number correlates the initiator on the study 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 evaluation 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.

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. 2.2.69), 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.

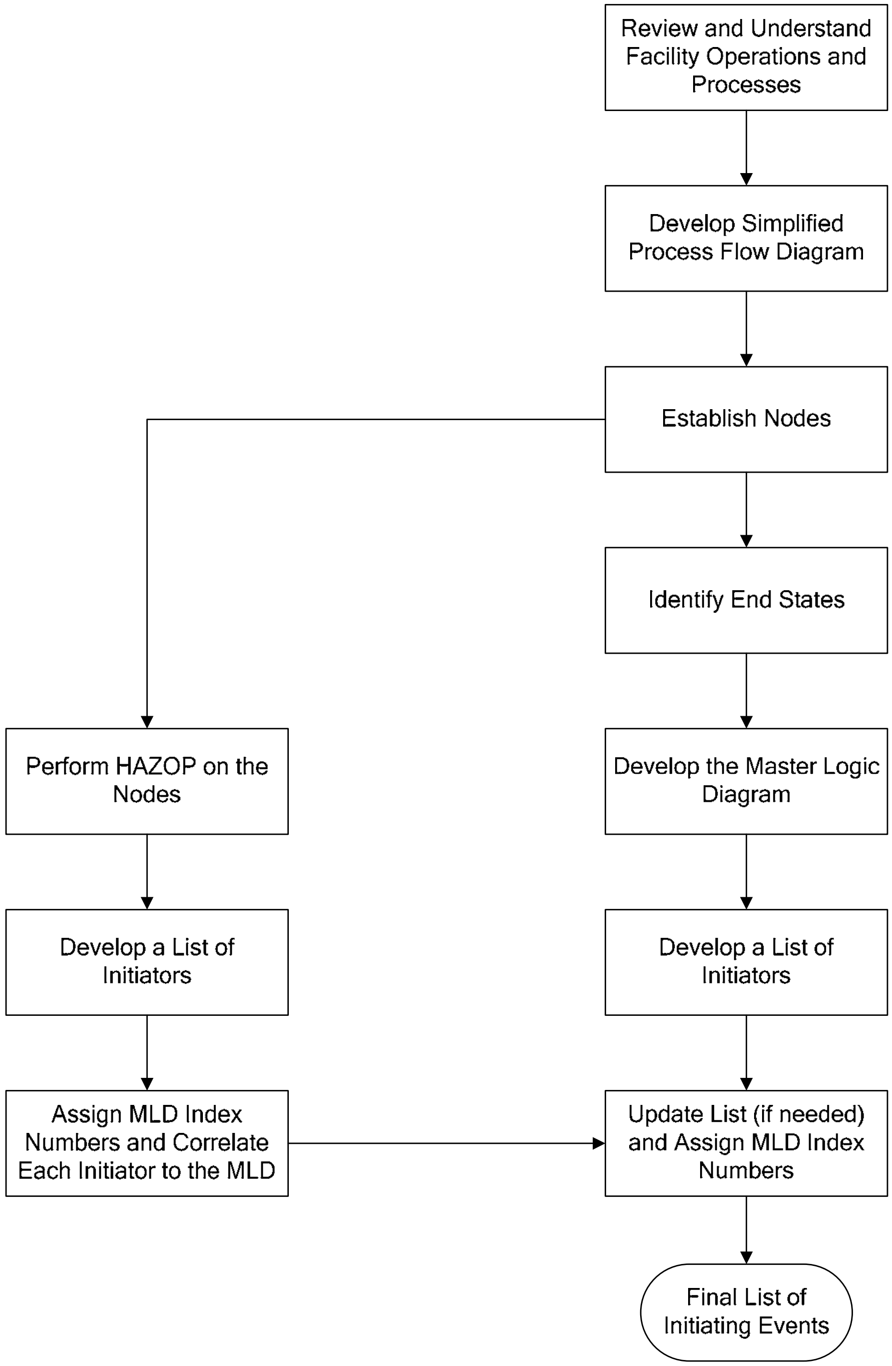



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Figure 3. Initiating Event Identification

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

A generalized logic structure for the PCSA MLD is presented below, and in Figure 4. In the development of a specific MLD (demonstrated per the example facility MLD shown in Section 4.3.4, 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.

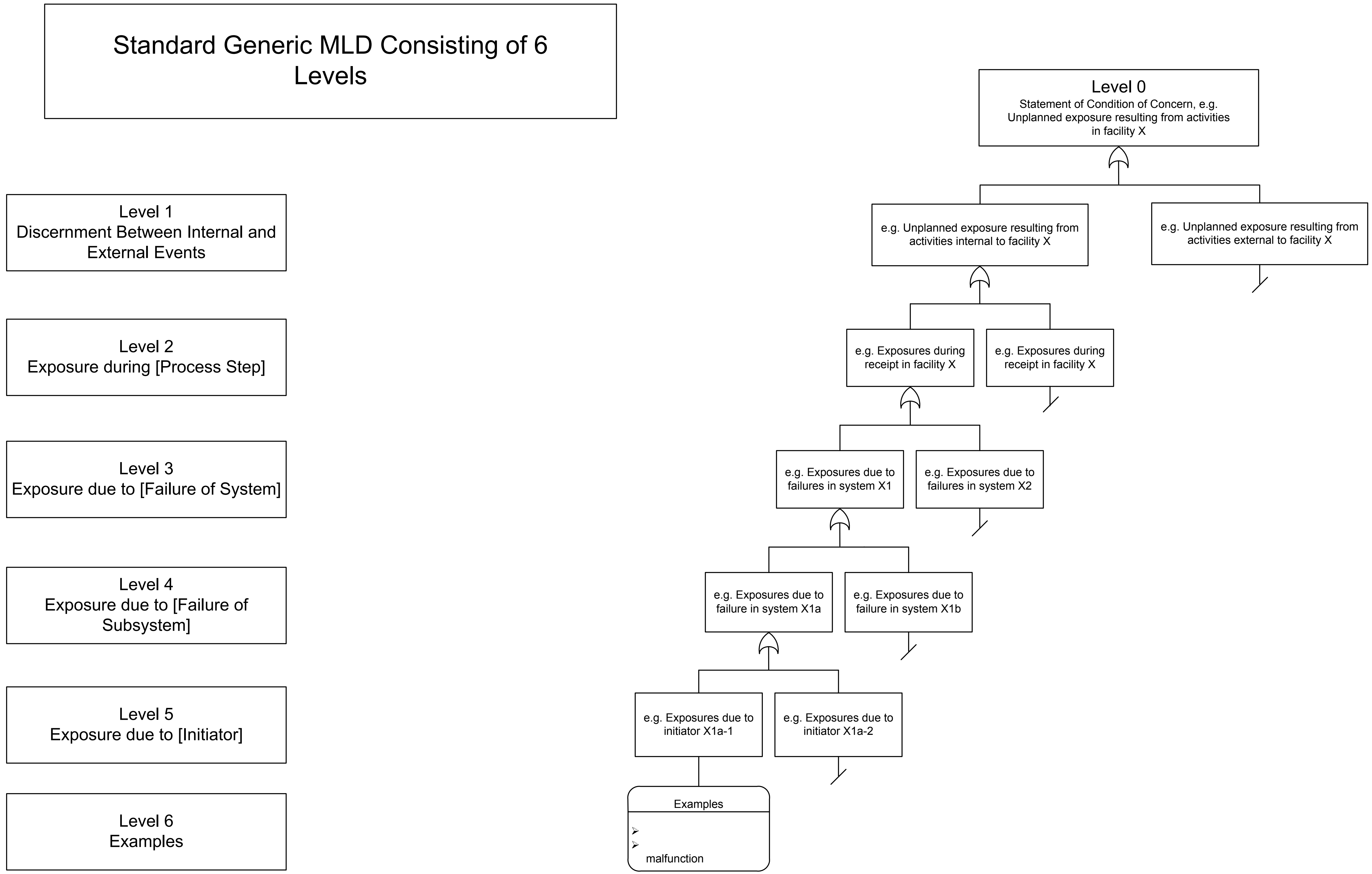
- Level 2: This level identifies the operational area where the initiating events can occur.

- 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.

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




Source: Original

Figure 4. Master Logic Diagram Framework

### 4.3.1.3 Hazard and Operability Evaluation

As previously discussed, the MLD and HAZOP evaluation 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 evaluation of the facility processes and operations. Any additional initiators identified by the HAZOP evaluation 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 evaluation 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 evaluation table. The MLD index number correlates the initiator associated with the HAZOP evaluation 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 evaluation is conducted to supplement the MLD results. The HAZOP evaluation 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. 2.3.1).

The HAZOP evaluation 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 evaluation 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 evaluation is conducted efficiently and productively.

The processes and definitions of terms for conducting a HAZOP evaluation have been widely applied in chemical and nuclear processing facilities for decades. The terminology commonly used in HAZOP evaluation is presented in Table 2. The application to the repository PCSA applies the HAZOP evaluation 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 American Institute of Chemical Engineers *Guidelines for Hazard Evaluation Procedures* (Ref. 2.2.2). The *Yucca Mountain Review Plan, Final Report* (Ref. 2.2.70, 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 evaluation 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<br>(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 evaluation 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). |

Table 2. Common Hazard and Operability Analysis Terminology (Continued)

| Term | Definition |
|---|---|
| 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 evaluation. 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). |

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

The HAZOP evaluation 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 evaluation team to ensure that the deviations and hazards so identified is a reasonably complete set. 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 evaluation 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 evaluation was completed, the results were compared with the MLD to verify the accuracy and completeness of the MLD. Deviations were 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, structures, and components, their safety functions, and the procedural safety controls that are relied on 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 *IHF 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 *IHF 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 *IHF 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 structures, systems, and components and personnel after an initiating event or group of initiating events (Ref. 2.2.69), Section 3.4.3.2. To construct an ESD, the analyst begins with the initiating events that were identified by the MLD and HAZOP evaluation 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 a radionuclide release occurs and (unless the associated event sequence is Beyond Category 2) a criticality investigation is indicated.

5. 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.

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.

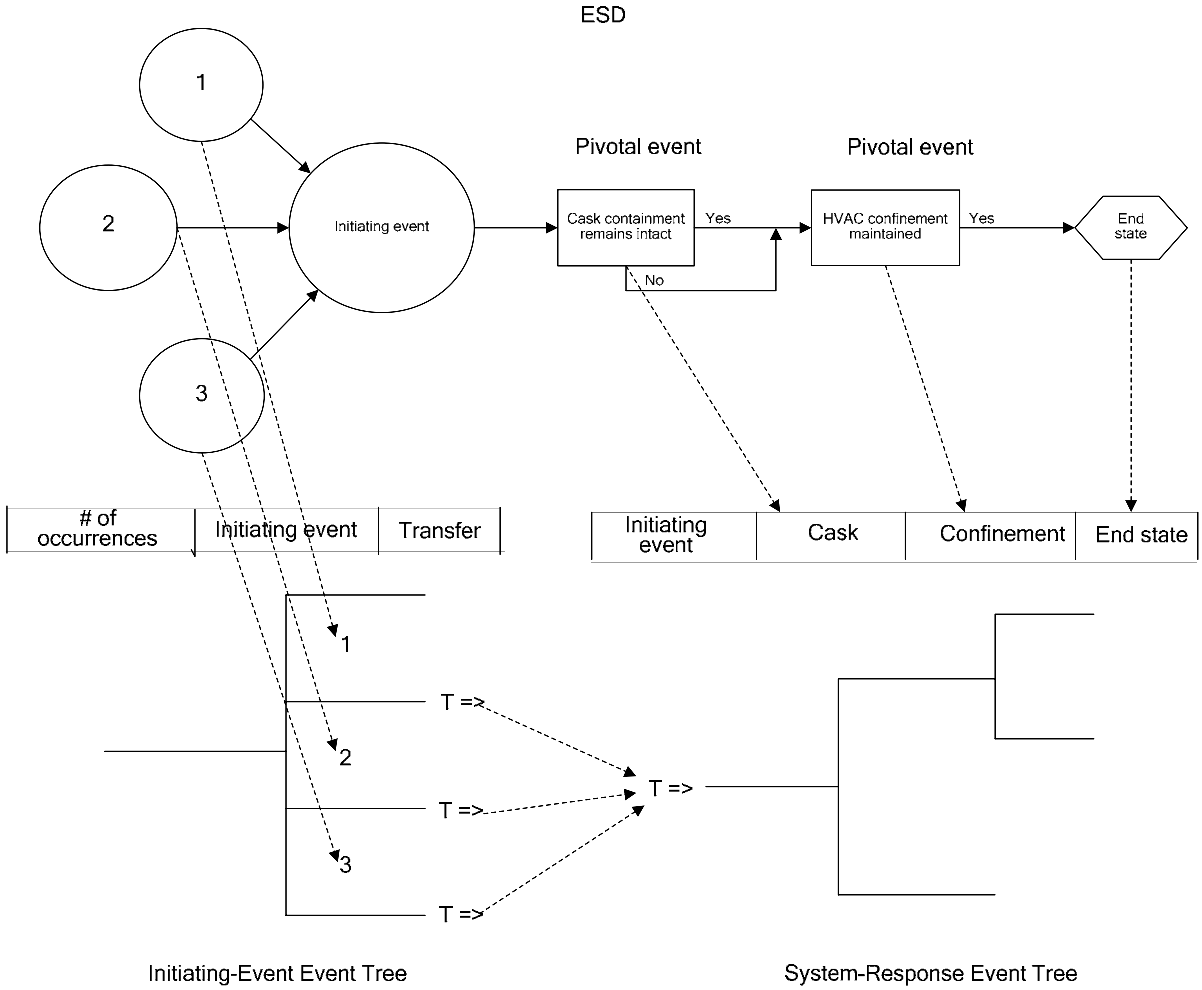
#### 4.3.2.2 Event Trees

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. 2.2.69), 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.

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.




Source: Original

Figure 5. Event Sequence Diagram–Event Tree Relationship

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 *IHF Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1).

### 4.3.3 Non-seismic External Events

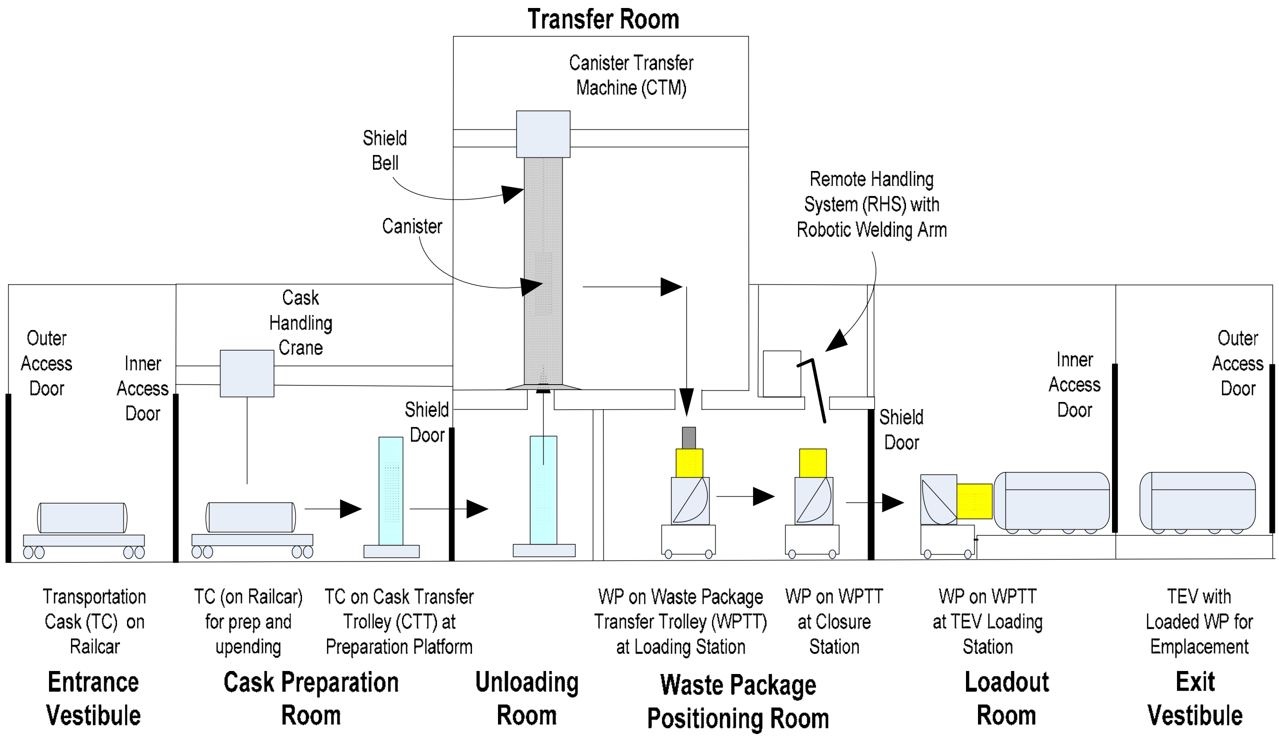
Non-seismic external initiating events are discussed further in the *Monitored Geologic Repository External Events Hazards Screening Analysis* (Ref. 2.2.5).

### 4.3.4 Example Facility Analysis

By the use of an exemplar, typical facility, this section illustrates the overall event sequence development approach. It is particularly useful for understanding the relationships among the PFD, MLD, HAZOP evaluation, ESDs and event trees. This example portrays a typical waste-handling facility (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 IHF. IHF 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 evaluation, 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 IHF and it has a fictitious mission, design features, and operations that differ from those of the IHF. The example facility receives radioactive waste in a 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. Offsite 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 TEV access for the removal of waste packages.

The mechanical handling systems, which are operated by 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 radionuclide 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 (if present), 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.

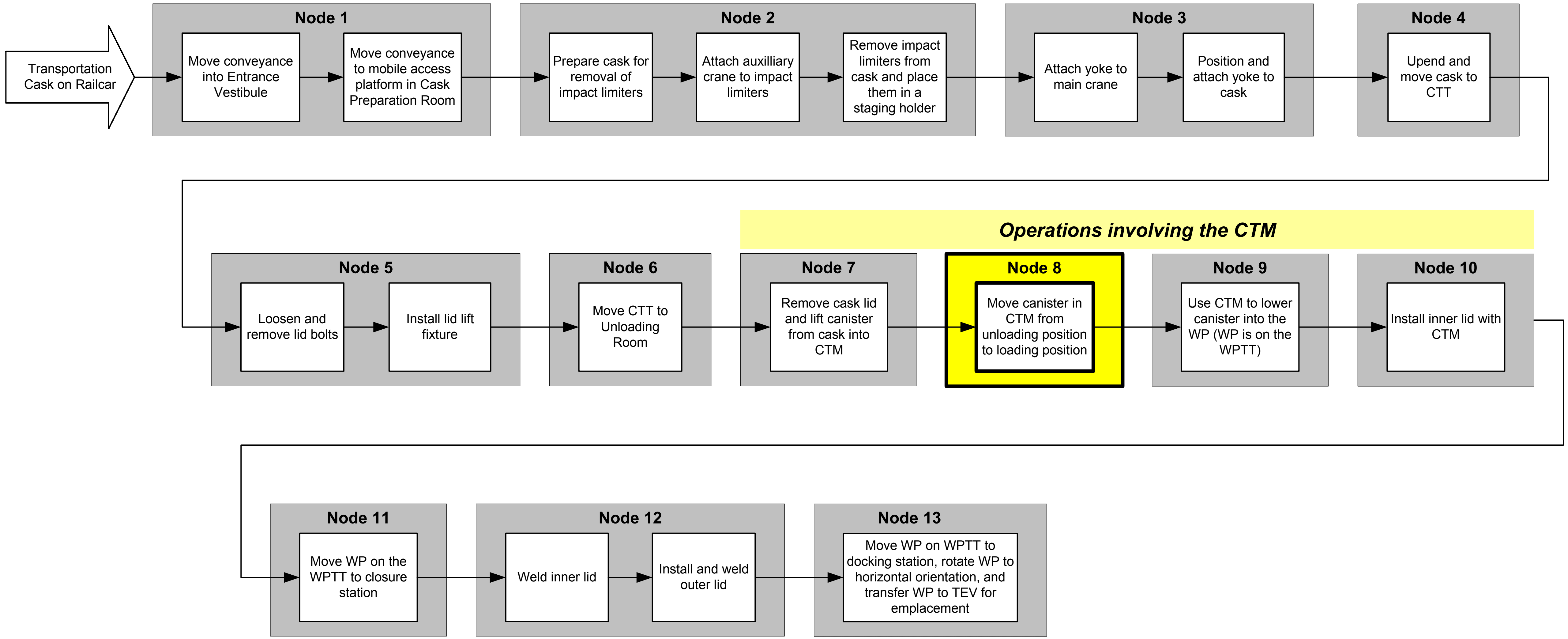
#### 4.3.4.1 Process Flow Diagram Development

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 facility, 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 evaluation, 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).




NOTE: CTM = canister transfer machine; CTT = cask transfer trolley; 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

<table>
<tr><th>Node No.</th><th>Description</th></tr>
<tr><td>1</td><td>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.<br><br>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.<br><br>Equipment involved in Node 1 operations:<br>• SPM<br>• Interlocked inner and outer access doors.<br><br>Additional equipment present during Node 1 operations:<br>• Mobile access platform<br>• Cask handling crane<br>• Common hand tools.</td></tr>
<tr><td>2</td><td>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.<br><br>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.<br><br>Equipment involved in Node 2 operations:<br>• Common hand tools<br>• Cask handling crane<br>• MAP.<br><br>Additional equipment present during Node 2 operations:<br>• Entrance Vestibule inner access door (closed)<br>• CTT<br><br>Unloading Room shield door (closed).</td></tr>
</table>

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.<br>Equipment involved in Node 3 operations:<br>• Lift yoke<br>• Common hand tools<br>• Cask handling crane<br>• MAP.<br>Additional equipment present during Node 3 operations:<br>• Railcar<br>• Entrance Vestibule inner access door (closed)<br>• CTT<br>• 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 restraining brackets and steel frame maintain the cask in its vertical orientation during preparation activities and cask movement.<br>Equipment involved in Node 4 operations:<br>• Cask pedestal<br>• CTT<br>• Cask handling crane<br>• Lift yoke.<br>Additional equipment present during Node 4 operations:<br>• Entrance Vestibule inner access door (closed)<br>• Common hand tools<br>• 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.<br>Equipment involved in Node 5 operations:<br>• Common hand tools<br>• Cask handling crane<br>• CTT (within the cask preparation platform).<br>Additional equipment present during Node 5 operations:<br>• Lift yoke<br>• MAP<br>• Entrance Vestibule inner access door (closed)<br>• 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.<br>Equipment involved in Node 6 operations:<br>• CTT<br>• Cask Unloading Room shield door.<br>Additional equipment present during Node 6 operations:<br>• Entrance Vestibule inner access door (closed)<br>• Unloading port shield gate (closed)<br>• 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.<br>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.<br>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 that 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.<br>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.<br>(Refer to Node 8 operation description regarding horizontal movement of the CTM through the Transfer Room.)<br>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<br>Cont'd | Equipment involved in Node 7,9 operations:<br>• Unloading Room shield door (open or closed, as appropriate)<br>• Waste Package Positioning Room shield door (open or closed, as appropriate)<br>• CTM (with grapple and shield bell)<br>• Unloading port shield gate<br>• Lid lifting fixture (and cask lid)<br>• Loading port shield gate.<br>Additional equipment present during Node 7,9 operations:<br>• CTT<br>• 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.<br>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.<br>Equipment involved in Node 8 operations:<br>• CTM (with grapple and shield bell)<br>• Unloading port shield gate<br>• Loading port shield gate.<br>Additional equipment present during Node 8 operations:<br>• 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.<br>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.<br>Equipment involved in Node 10 operations:<br>• CTM<br>• Loading port shield gate.<br>Additional equipment present during Node 10 operations:<br>• WPTT (assembly with waste package pedestals and transfer carriage)<br>• Waste Package Positioning Room shield door (closed). |

Table 4. Process Node Descriptions (Continued)

| Node No. | Description |
|---|---|
| 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.<br>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).<br>Equipment involved in Node 11 operations:<br>• WPTT<br>• Waste Package Positioning Room shield door (closed).<br>Additional equipment present during Node 11 operations:<br>• RHS. |
| 12 | 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.<br>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.<br>Equipment involved in Node 12 operations:<br>• RHS<br>• Robotic arms<br>• Weld end effectors<br>• Inspection equipment.<br>Additional equipment present during Node 12 operations:<br>• WPTT<br>• Waste Package Positioning Room shield door (closed). |
| 13 | 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.<br>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.<br>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.)<br>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. |

Table 4. Process Node Descriptions (Continued)

| Node No. | Description |
|---|---|
| 13 Cont'd | 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.<br>Equipment involved in Node 13 operations:<br>• WPTT (with transfer carriage)<br>• Waste Package Positioning Room shield door<br>• TEV<br>• Exit Vestibule inner access door.<br>Additional equipment present during Node 13 operations:<br>Exit Vestibule outer access door. |

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).<br>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.<br>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).<br>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.<br><br>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.<br><br>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.<br><br>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.<br><br>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; ft = feet; in. = inches; MAP = mobile access platform; TAD = transportation, aging, and disposal canister; TEV = transport and emplacement vehicle; WPTT = waste package transfer trolley.

Source: Original

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.

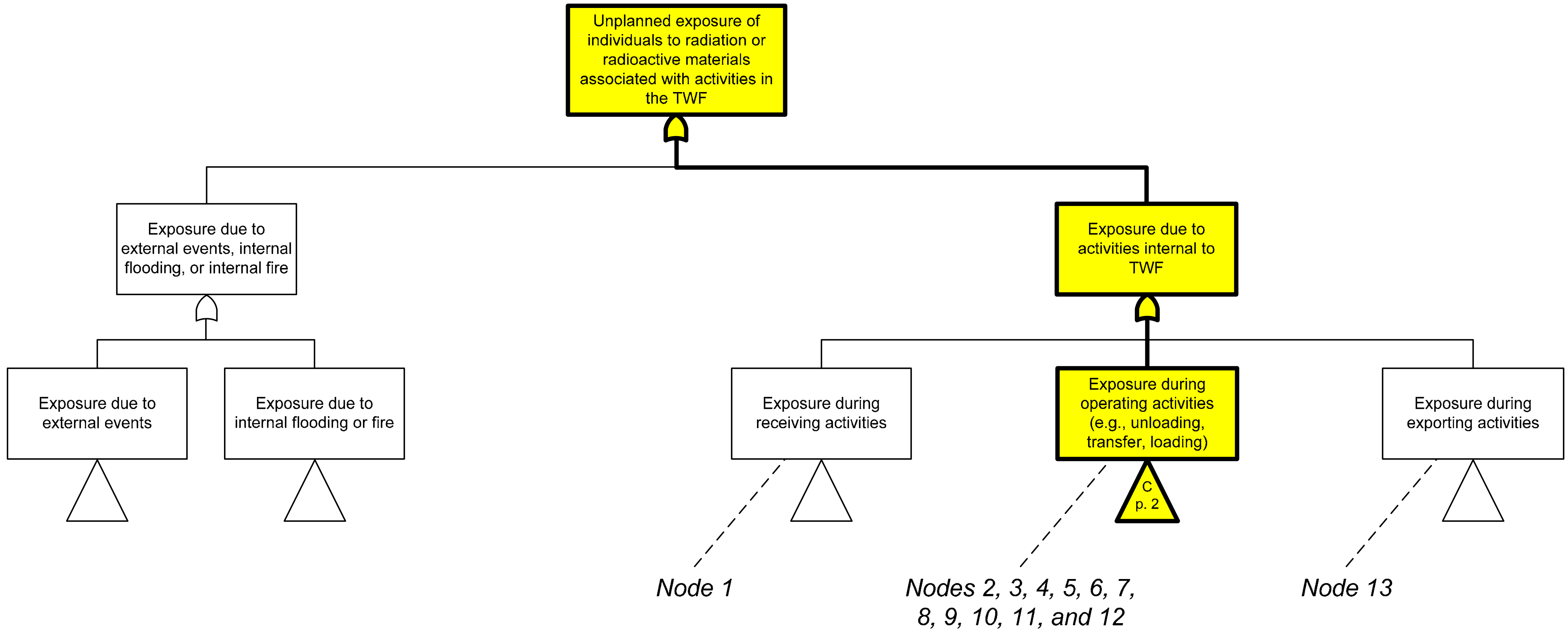
The right branch, "Exposures due to activities internal to the TWF," begins the evaluation of the internal initiators that are not related to fire or flooding, and includes the facility operating activities identified in the PFD. For the TWF, the analyst defines the next level in terms of the PFD operational 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.

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).




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)

- **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.

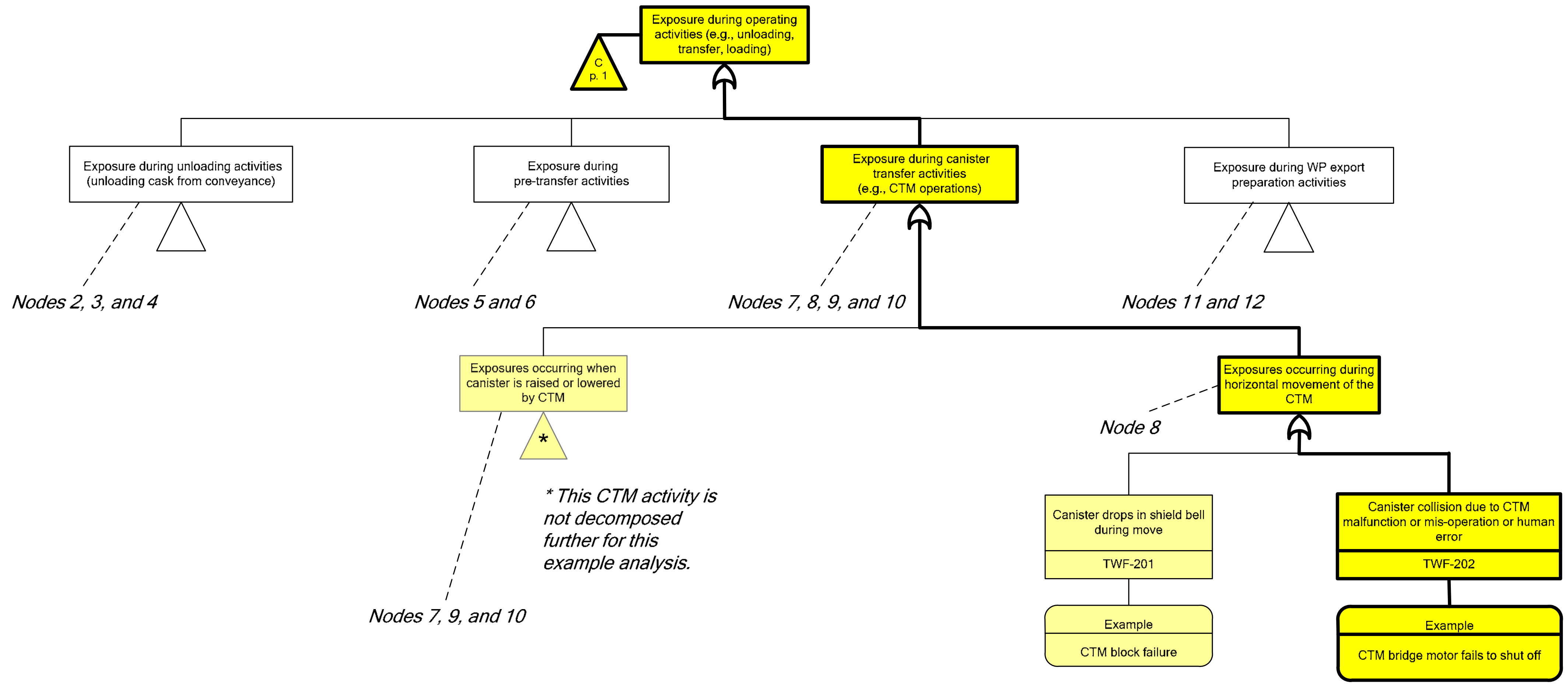
For the purpose of this example and as emphasized in Figure 9, only the failure category related to CTM operations (Nodes 7, 8, 9, and 10) is decomposed further.

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 develops 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).

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 evaluation is used to verify that an accurate and comprehensive list of initiating events and subsidiary failure events is identified.




NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure." CTM = canister transfer machine; RC = railcar.

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)

#### 4.3.4.3 HAZOP Evaluation 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 evaluation (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 evaluation are compared to the results of the MLD development. Any initiating event that is identified in the HAZOP evaluation, 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 evaluation to be included in the ESDs. The HAZOP evaluation 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.

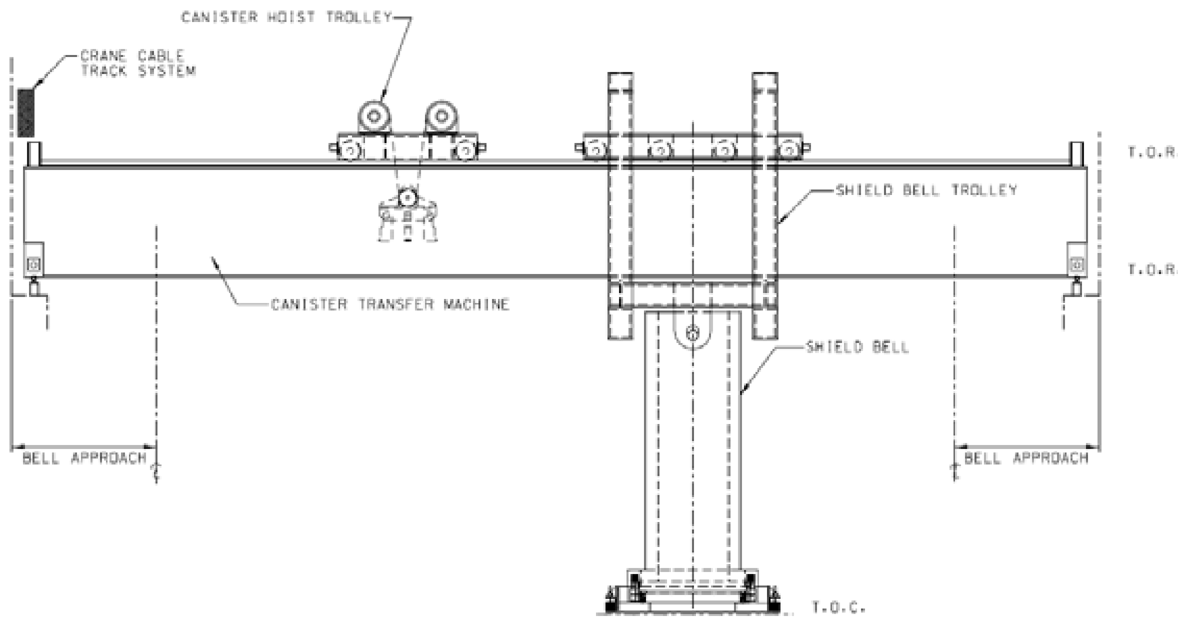
To demonstrate this process for the example facility, TWF, activities involved in the horizontal movement of the CTM are examined (shown on the MLD as “Exposures occurring during horizontal movement of the CTM” (Figure 9). As discussed previously, horizontal movement of the CTM is identified as Node 8 in the PFD and is evaluated discretely from vertical canister movement. The HAZOP evaluation 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., radionuclide release resulting from canister collision), and potential preventive/mitigative design features are identified.

Figure 10 is provided as a conceptual aid for 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 that for other deviations, can be visualized.

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 of the canister 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.




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

Figure 10. Schematic of the Canister Transfer Machine

As shown in Table 6, the "Direction" parameter is analyzed similarly. However, for operations associated with this node, the HAZOP evaluation 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 Evaluation 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**: Radionuclide 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<br>2 – Mechanical failure | Potential collision of canister with internal wall of shield bell leading to radionuclide release | 1 – CTM design<br>2 – Procedures and training | N/A | TWF-202 |
| 8.2 | Speed (CTM) | (No) CTM stuck in middle of room during move | 1 – Human failure<br>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<br>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<br>2 – Mechanical failure | Potential collision of canister with internal wall of shield bell leading to radionuclide release | 1 – CTM design<br>2 – Procedures and training | N/A | TWF-202 |
| 8.5 | Direction (CTM) | (Less) CTM does not move enough | 1 – Human failure<br>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<br>2 – Mechanical failure | Potential collision of canister with internal wall of shield bell leading to radionuclide release | 1 – CTM design<br>2 – Procedures and training | N/A | TWF-202 |
| 8.7 | Direction (CTM) | (Other Than) Bridge impacts end stops | 1 – Human failure<br>2 – Mechanical failure | Potential collision of canister with internal wall of shield bell leading to radionuclide release | 1 – CTM design<br>2 – Procedures and training | N/A | TWF-202 |
| 8.8 | Direction (CTM) | (Other Than) Trolley impacts end stops | 1 – Human failure<br>2 – Mechanical failure | Potential collision of canister with internal wall of shield bell leading to radionuclide release | 1 – CTM design<br>2 – Procedures and training | N/A | TWF-202 |
| 8.9 | Direction (CTM) | (Other Than) Canister Bridge impacts other bridge | 1 – Human failure<br>2 – Mechanical failure | Potential collision of canister with internal wall of shield bell leading to radionuclide release | 1 – CTM design<br>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 radionuclide release | 1 – Facility design<br>2 – Procedures and training | N/A | TWF-202 |
| 8.11 | Miscellaneous (CTM Crane) | (No) Two-blocking of CTM Crane | 1 – Human failure<br>2 – Mechanical failure | Potential canister drop leading to radionuclide release | 1 – CTM design<br>2 – Procedures and training | N/A | TWF-201 |
| 8.12 | Miscellaneous (CTM Crane) | (No) Crane malfunction | 1 – Human failure<br>2 – Mechanical failure | Potential canister drop leading to radionuclide release | 1 – CTM Crane design<br>2 – Procedures and training | N/A | TWF-201 |
| 8.13 | Miscellaneous (Canister Grapple) | (No) Grapple malfunction | 1 – Human failure<br>2 – Mechanical failure | Potential canister drop leading to radionuclide release | 1 – CTM Crane design<br>2 – 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; MLD = master logic diagram; N/A = not applicable; TWF = typical waste-handling facility.

Source: Original

For every operational node, each deviation for each parameter in the HAZOP evaluation 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 evaluation 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 evaluation 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 evaluation 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 evaluation.

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 Evaluation |
|---|---|---|---|---|---|
| TWF-201 | Two-blocking of crane | Human or mechanical failure | Potential canister drop leading to radionuclide release | Y | N/A |
| TWF-201 | Crane malfunction | Human or mechanical failure | Potential canister drop leading to radionuclide release | Y | N/A |
| TWF-201 | Grapple malfunction | Human or mechanical failure | Potential canister drop leading to radionuclide 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 radionuclide release | Y | N/A |
| TWF-202 | CTM stuck | Human or mechanical failure | Potential radionuclide 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 radionuclide 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 Evaluation |
|---|---|---|---|---|---|
| TWF-202 | CTM moves in wrong direction | Human or mechanical failure | Potential collision of canister with internal wall of shield bell leading to radionuclide 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 radionuclide 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 radionuclide 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 radionuclide 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 radionuclide release | Y | N/A |

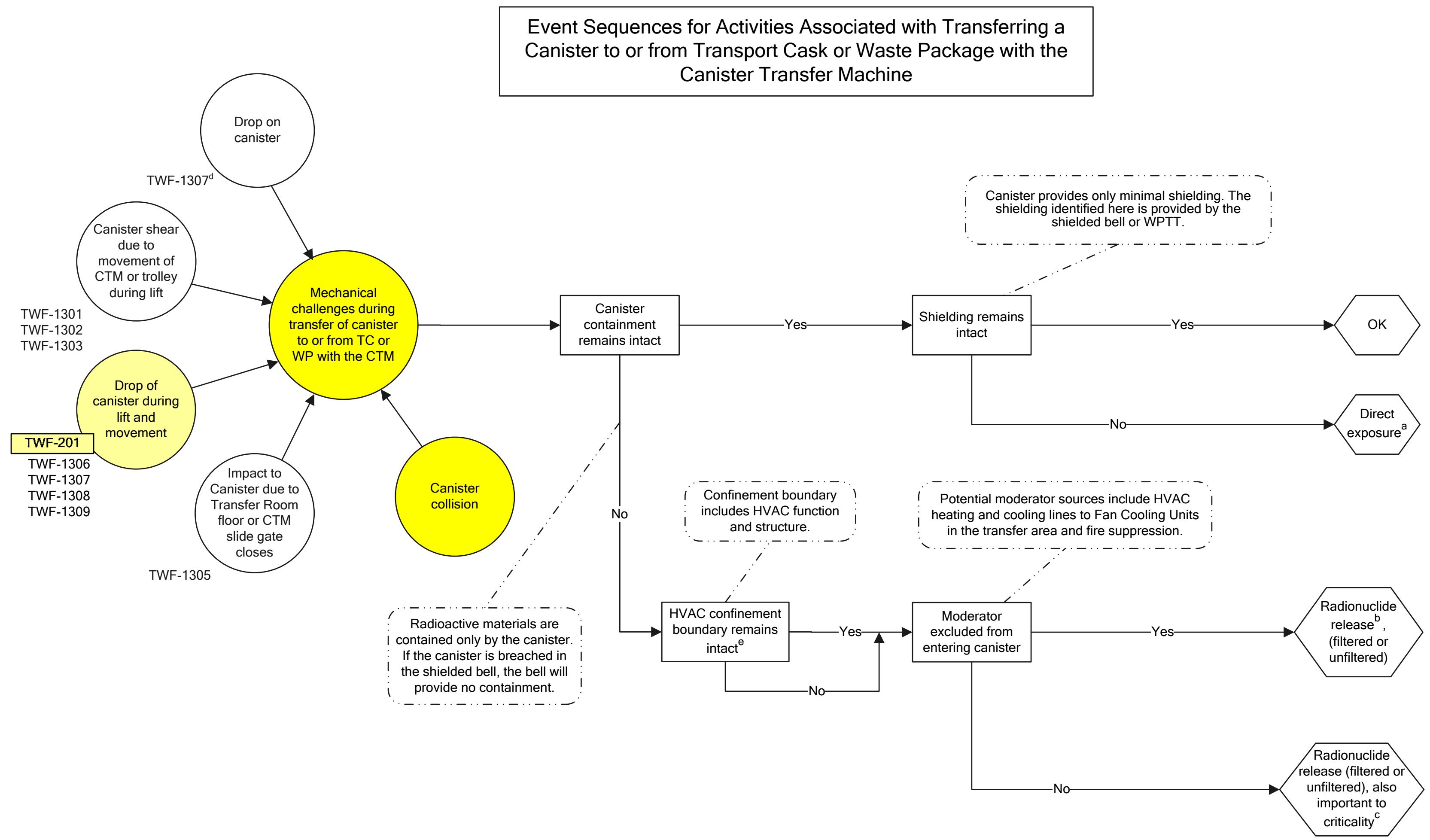
NOTE: CTM = canister transfer machine; HAZOP = hazard and operability; MLD = master logic diagram; N = no; TWF = typical waste-handling facility; Y = yes.

Source: Original

#### 4.3.4.4 Event Sequence Diagram Development

After the HAZOP evaluation 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.

TWF numbers next to the smaller bubbles are references to the TWF MLD.

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.

d Potential for fire analyzed in fire ESDs.

e 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 lift and movement" (Figure 11).

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 *IHF 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 mechanical 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.

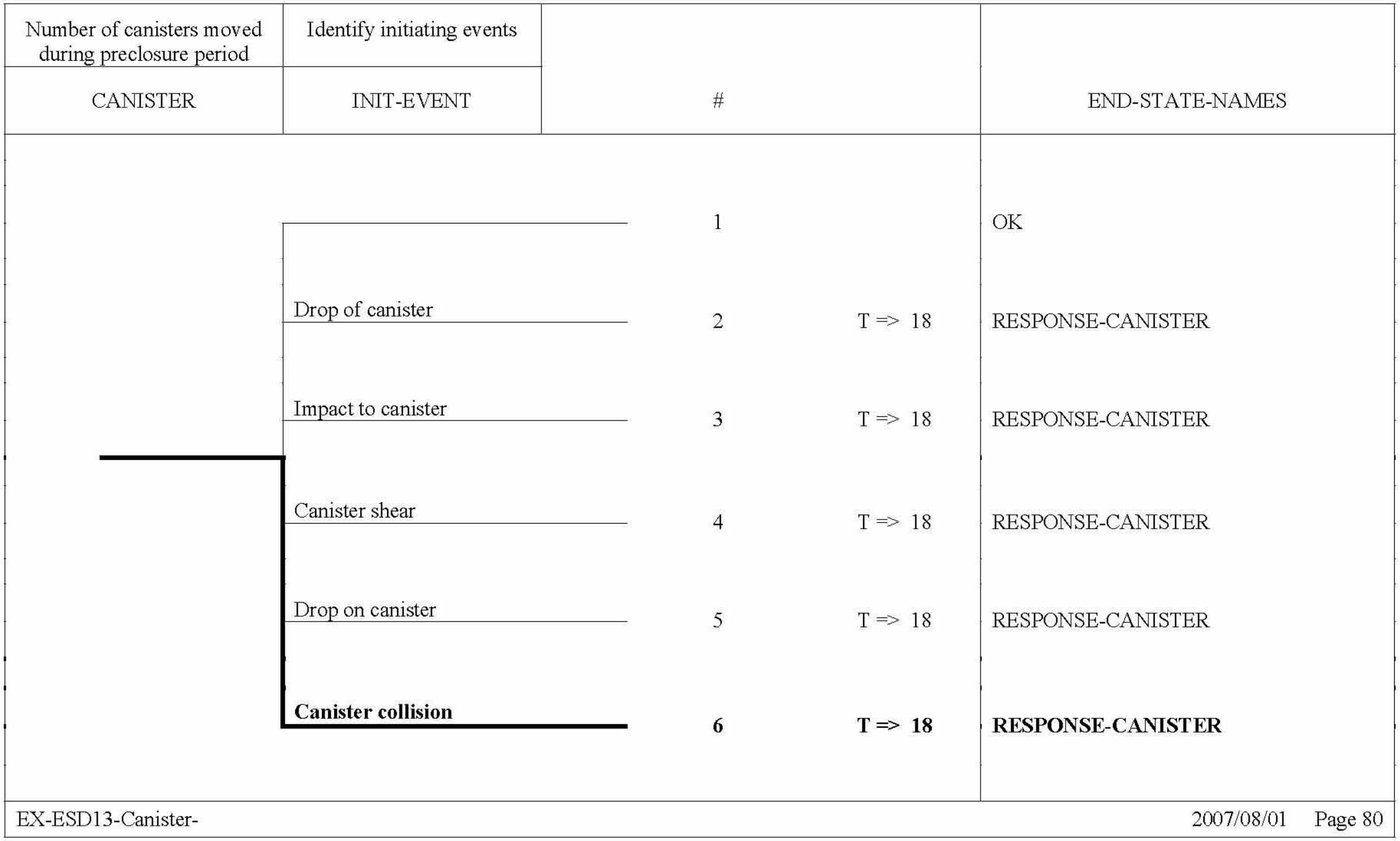
For additional details regarding the development of ESDs and event trees refer to Section 4.3.2.

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<br>Operator error<br>Crane or grapple malfunction. |
| TWF-1306 | CTM wire cable is cut resulting in dropped canister | CTM shield bell slide gates closes on cable<br>Floor slide gate closes on cable. |
| TWF-1307 | Exposures from dropped or impacted canister due to human failure | WP misaligned with port<br>Load too heavy (e.g., CTM lifting more than canister)<br>Canister lifted too high<br>Grapple improperly attached<br>Canister not lifted high enough to clear floor during lifting<br>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<br>Improper crane maintenance. |
| TWF-1309 | Canister drops in shield bell due to brake, cable, or hook malfunction | Mechanical failure<br>Improper crane maintenance. |

NOTE: CTM = canister transfer machine; MLD = master logic diagram; WP = waste package.

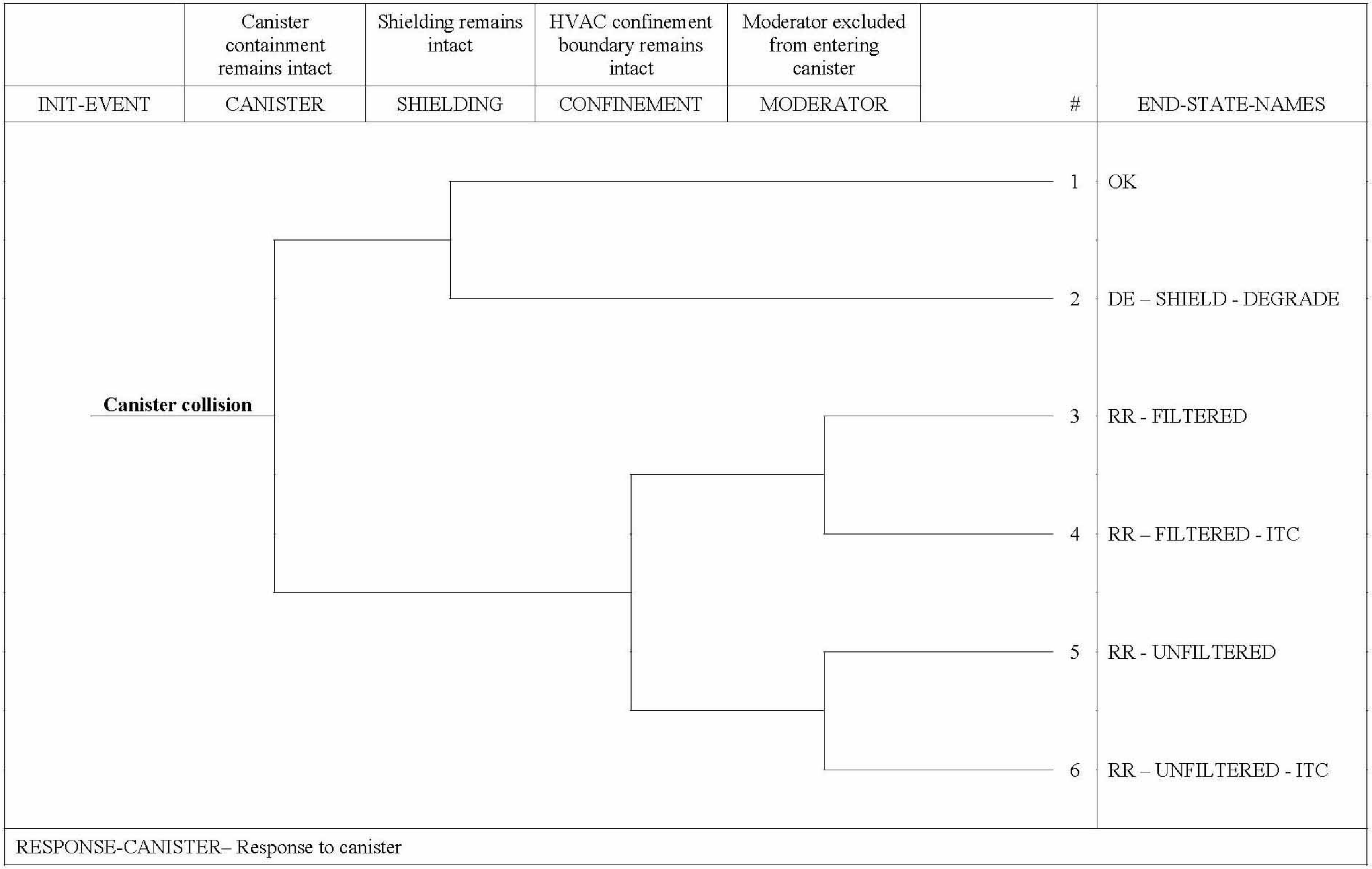
Source: Original




NOTE: INIT = initiating

Source: Original

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




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

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 ANALYSIS

## 6.1 INITIATING EVENT ANALYSIS

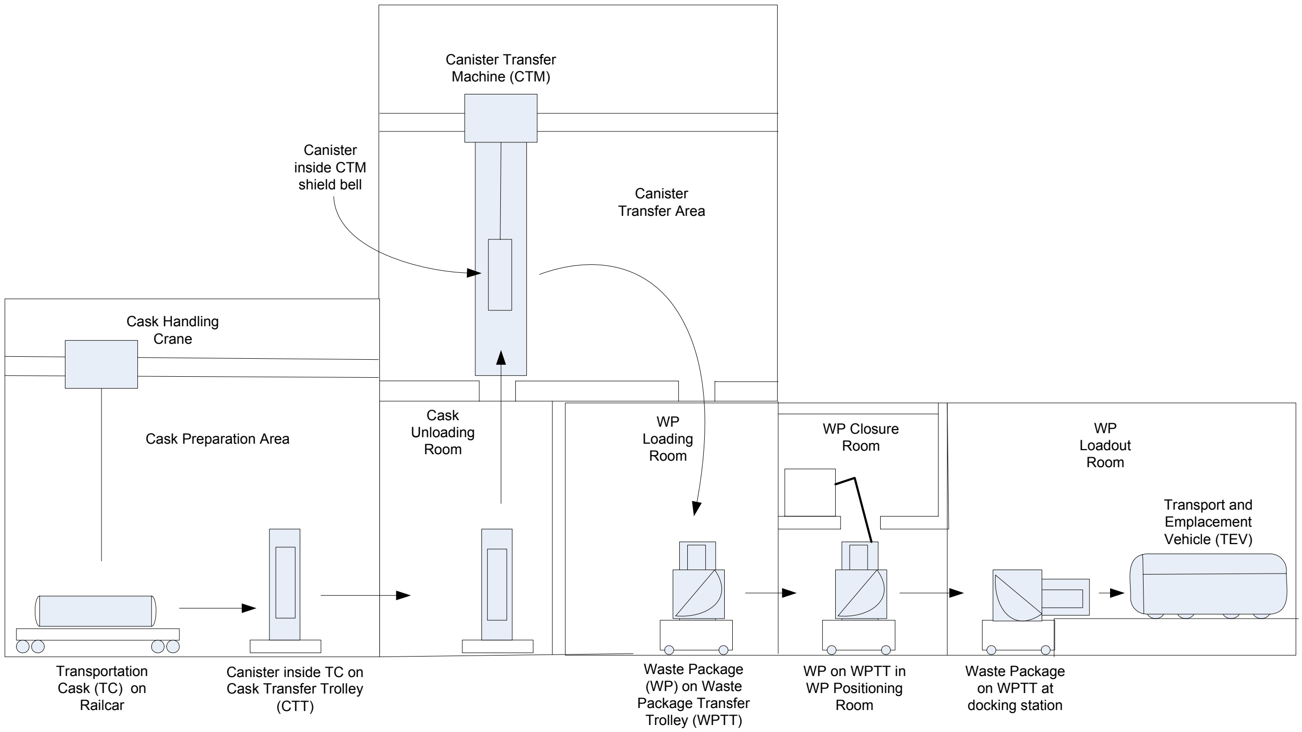
### 6.1.1 Introduction

Initiating events are identified for the Yucca Mountain Project using MLDs that are verified with a HAZOP evaluation as described in Section 4. Each phase of the operations within the IHF 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, including natural phenomena such as tornado, earthquakes, flooding, lightning, and activities external to the GROA such as aircraft crash, nearby industrial facilities (Ref. 2.2.5), 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 Initial Handling 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 IHF 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 evaluation, 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 IHF within the GROA is shown in Attachment C.

The IHF provides handling capability for a portion of the U.S. Department of Energy managed waste stream. The waste stream for the IHF is limited to naval SNF canisters and high-level radioactive waste (HLW) canisters. As illustrated in Figure 14, canisters received in transportation casks by the IHF are transferred into waste packages, which are welded closed and carried out of the IHF by the TEV for emplacement in the repository. The primary mode of receipt of waste into the IHF is rail service. In addition, the IHF is designed to receive trucks (each of which carries a transportation cask loaded with a single HLW canister). Naval SNF is shipped by rail only, while HLW may arrive by rail or truck. For the purposes of this analysis, IHF operations are defined to include operations spanning the receipt of transportation casks on rail or truck conveyances into the Cask Preparation Area of the IHF through the loading of waste packages into the TEV in the Waste Package Loadout Room of the IHF. Transport by the TEV from the Waste Package Loadout Room to the subsurface is covered elsewhere as part of the subsurface analysis. The naval transportation cask and repository interfaces are presented in *Basis of Design for the TAD Canister-Based Repository Design Concept* (Ref. 2.2.7), Section 3.1.1, and in *Integrated Interface Control Document, Volume 1: High-Level Radioactive Waste and U.S. Department of Energy and Naval Spent Nuclear Fuel to the Civilian Radioactive Waste Management System* (Ref. 2.2.64), Section 9.4.




NOTE: This simplified conceptual depiction is not to scale.

Figure 14. Schematic Diagram of Initial Handling Facility Mechanical Handling Operations

The IHF is a multilevel steel structure with concrete cells in the core of the building to shield personnel from radiation exposure during the operations for which a bare canister or waste package may be present in the facility. The concrete cells correspond to the Cask Unloading Room, the Waste Package Loading Room, the Waste Package Positioning Room, and the Waste Package Loadout Room, as illustrated in Figure 14. The portion of the concrete structure that contains the Waste Package Loadout Room protrudes from the steel framed structure and provides radiation protection for nearby personnel outside the building. The elevated concrete operating floor of the Canister Transfer Area 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 Area provide radiation protection when bare canisters or a waste package is present. The roof and exterior walls of the steel-framed portion of the building are metal panels.

The IHF 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 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 IHF. 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 IHF 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 IHF.

#### 6.1.2.1 Node 1: Receive a Loaded Transportation Cask

A loaded transportation cask on a railcar or truck trailer is moved by a prime mover from the rail yard or truck yard to the IHF. (The term "prime mover" generically identifies the truck or tractor that is used to haul the truck trailer or railcar from the rail yard or truck yard to the IHF.) The overhead door to the IHF Cask Preparation Area is opened and the conveyance is parked and secured in the Cask Preparation Area. The Cask Preparation Area is shown in the *Initial Handling Facility General Arrangement Ground Floor Plan* (Ref. 2.2.26). If personnel barriers are present on the transportation cask when the cask is received in the IHF, they are removed at this point using the cask preparation crane.

This node is described in the *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.36).

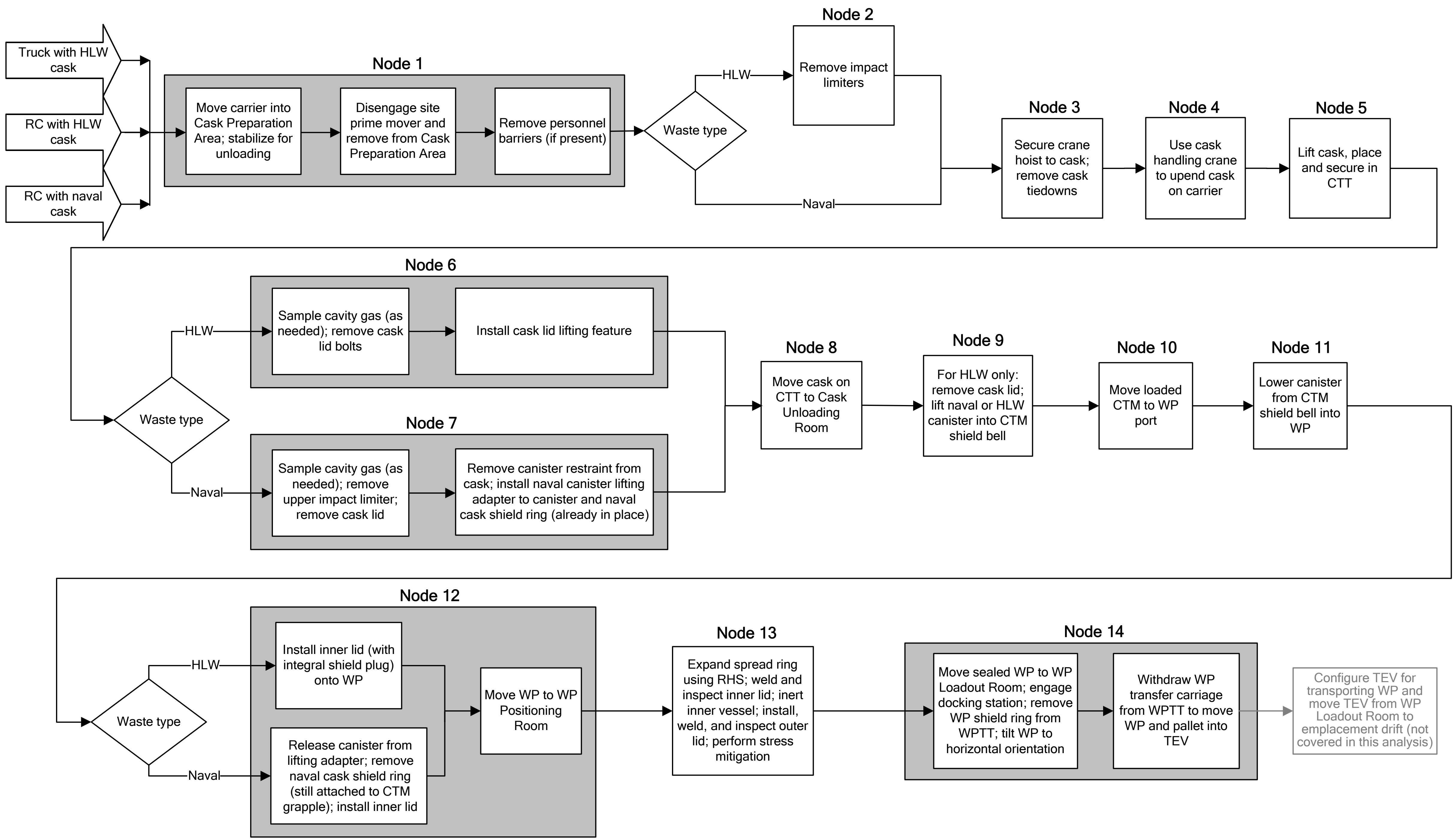
#### 6.1.2.2 Node 2: Remove Impact Limiters from High-Level Waste Transportation Cask

Some cask-handling steps differ for HLW casks and naval casks. For HLW casks, the impact limiters are removed by the cask preparation crane while the cask is still on the truck or rail conveyance. Operators use the MAP in the performance of these operational steps as described in:

- Initial Handling Facility General Arrangement Ground Floor Plan (Ref. 2.2.26)
- Initial Handling Facility General Arrangement Sections C, D, & E (Ref. 2.2.32)
- Initial Handling Facility General Arrangement Sections F, G, H, & J (Ref. 2.2.33).

The MAP allows personnel access to the transportation cask.

The MAP is a rail-mounted structure that bridges over the cask lying on the conveyance as illustrated in the *Initial Handling Facility Mobile Access Platform Mechanical Equipment Envelope* (Ref. 2.2.46). The MAP includes three adjustable platforms to provide access by personnel to different features on the cask (e.g., personnel barriers, impact limiters, etc.). Two of the platforms move vertically up the two legs of the platform. The third platform extends the full width of the rail-mounted structure, and also moves vertically. A jib crane is mounted on the MAP, and provides support for equipment to be used in preparing the cask for removal from the transportation vehicle.




NOTE: CTM = canister transfer machine; CTT = cask transfer trolley; HLW = high-level waste; RC = railcar; TEV = transport and emplacement vehicle; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure 15. Initial Handling Facility Process Flow Diagram

This node is described in the *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 3* (Ref. 2.2.37).

#### 6.1.2.3 Node 3: Prepare to Hoist Transportation Cask

Some of the cask-handling steps in this node differ for HLW casks and naval casks. For the naval cask, a lifting plate is installed and a pivot adapter may need to be installed to facilitate upending of the cask on the conveyance. The applicable yoke or lifting device is attached to the cask handling crane as shown in the *Initial Handling Facility Naval Cask Lift Bail Mechanical Equipment Envelope* (Ref. 2.2.48). For naval and HLW casks, clamps and tie-downs, which secure the cask to the conveyance, are removed using the cask preparation crane. Operators use the mobile access platform in the performance of these operational steps as illustrated in *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 3* (Ref. 2.2.37) and the *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 4* (Ref. 2.2.38).

#### 6.1.2.4 Node 4: Upend Transportation Cask on Its Conveyance

The cask handling crane is used to upend the cask while it is on the conveyance.

This node is described in the *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 3* (Ref. 2.2.37) and in the *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 4* (Ref. 2.2.38).

#### 6.1.2.5 Node 5: Move Transportation Cask to Cask Transfer Trolley

The cask is transferred by the cask handling crane to the CTT in vertical orientation and secured in place. The CTT is an air-based conveyance that floats on an air film (Ref. 2.2.26, Ref. 2.2.37, Ref. 2.2.32 ).

This node is described in the *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 3* (Ref. 2.2.37) and the *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 4* (Ref. 2.2.38).

#### 6.1.2.6 Node 6: Prepare High-Level Waste Transportation Cask for Removal of Cask Lid

For HLW casks, the lid bolts are removed and the cask lid-lift feature (lid adapter) is installed. The lid is left in place until later. Cask cavity gas sampling may be conducted as a prerequisite to removal of cask lid bolts.

This node is described in the *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 3* (Ref. 2.2.37).

#### 6.1.2.7 Node 7: Prepare Naval Transportation Cask and Canister for Removal of Canister

The upper impact limiter (or dome) is removed from the naval cask. Cask cavity gas sampling may be conducted as a prerequisite to removal of cask lid bolts. Lid bolts are removed and then the lid is removed. The installation of the naval canister lifting adapter onto the naval canister is done with the naval cask shield ring left in place. Leaving the shield ring in place protects personnel while they install the lifting adapter from radiation that would otherwise stream from the annulus adjacent to the canister. This operation is illustrated in the *Initial Handling Facility Naval Canister Lifting Adapter Mechanical Equipment Envelope* (Ref. 2.2.47). The naval canister lifting adapter attaches to the canister as well as the naval cask shield ring. This allows the CTM to transfer the shield ring along with the canister to the waste package, where it is called upon for its shielding function.

Some additional steps are required before the naval canister can be removed from the cask by the CTM. The cask shear ring backing ring, closure shear ring, and canister restraint plate are removed. Equipment needed to perform these tasks includes the cask preparation crane, the cask preparation platform, rigging gear, and common tools.

This node is described in the *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 4* (Ref. 2.2.38).

#### 6.1.2.8 Node 8: Move Loaded Cask Transfer Trolley to Cask Unloading Room

The CTT is used to move the loaded transportation cask from the Cask Preparation Area to the Cask Unloading Room. Opening and closing the applicable shield door is required in this node.

This node is described in the *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 3* (Ref. 2.2.37) and in the *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 4* (Ref. 2.2.38).

#### 6.1.2.9 Node 9: Lift Canister into Canister Transfer Machine

For the naval cask, the cask lid has been removed. For the HLW cask, the cask lid is still in place, though its bolts have been removed. In both the naval and HLW 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 as described in the following:

- *CRCF, IHF, RF, and WHF Canister Transfer Machine Mechanical Equipment Envelope* (Ref. 2.2.6)
- *Initial Handling Facility General Arrangement Sections A & B* (Ref. 2.2.31)
- *Initial Handling Facility General Arrangement Sections F, G, H & J* (Ref. 2.2.33)
- *CRCF, IHF, RF, & WHF Port Slide Gate Mechanical Equipment Envelope* (Ref. 2.2.18).

For the HLW waste form, the CTM is used to remove the cask lid. Also, for HLW, the appropriate exchangeable grapple must be attached to the CTM grapple after the cask lid has been removed and staged as illustrated in the *CRCF and IHF WVDP/Hanford HLW Canister Grapple Mechanical Equipment Envelope* (Ref. 2.2.14); and in the *CRCF and IHF DWPF/INL Canister Grapple Mechanical Equipment Envelope* (Ref. 2.2.12). Next, in both cases, the canister is grappled by the CTM, and the canister is 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 and the shield skirt is raised.

The CTM is located on the second floor in the Canister Transfer Area as shown in:

- *CRCF, IHF, RF, and WHF Canister Transfer Machine Mechanical Equipment Envelope* (Ref. 2.2.6)
- *Initial Handling Facility General Arrangement Sections A & B* (Ref. 2.2.31)
- *Initial Handling Facility General Arrangement Sections F, G, H & J* (Ref. 2.2.33).

The CTM is mounted on a pair of rails on top of bridge girders. The primary function of the CTM is to transfer the canister from a transportation cask to a waste package. 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 and shield skirt are 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.

This node is described in the *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 5* (Ref. 2.2.39).

#### 6.1.2.10 Node 10: Move Loaded Canister Transfer Machine to Waste Package Port

This step involves the horizontal movement of the CTM carrying the canister from a position over the cask port to a position above the waste package port. Positioned below the waste package port is an empty waste package in the WPTT. The WPTT is a rail-based conveyance that is designed to carry the waste package in vertical orientation from the waste package port to the Waste Package Positioning Room for closure and then on to the WPTT docking station, where it tilts the waste package to horizontal orientation as described in:

- *CRCF-1 and IHF WP Transfer Trolley Mechanical Equipment Envelope Plan & Elevations - Sh 1 of 2* (Ref. 2.2.10)
- *CRCF-1 and IHF WP Transfer Trolley Mechanical Equipment Envelope Elevation & Detail-Sheet 2* (Ref. 2.2.9)
- *Initial Handling Facility General Arrangement Ground Floor Plan* (Ref. 2.2.26)
- *Initial Handling Facility General Arrangement Sections A & B* (Ref. 2.2.31)

- *Initial Handling Facility General Arrangement Sections C, D, & E* (Ref. 2.2.32)
- *Initial Handling Facility General Arrangement Sections F, G, H, & J* (Ref. 2.2.33).

This node is described in the *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 6* (Ref. 2.2.40).

#### 6.1.2.11 Node 11: Lower Canister into Waste Package

Once the CTM is in position over the waste package port, the shield skirt is lowered, and the CTM slide gate and the waste package port slide gate are opened. Next, the canister is lowered into the waste package, the waste package port slide gate and the CTM slide gate are closed, and the shield skirt is raised. For HLW waste packages, which are loaded with five HLW canisters in the IHF, the steps involved in Nodes 9, 10, and 11 are repeated until all of the canisters have been loaded into the waste package. For HLW canisters arriving one at a time by truck cask, steps beginning with Node 1 must also be repeated. The waste package used for HLW can accommodate an 18-in diameter DOE standardized canister in the center, with five 24-in diameter HLW canisters arrayed around it. Because DOE SNF is not handled in the IHF, and the HLW canisters would not fit in the central location, the center of the waste package is left vacant (Ref. 2.2.20, Ref. 2.2.19).

This node is described in the *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 6* (Ref. 2.2.40).

#### 6.1.2.12 Node 12: Install Inner Lid and Move Waste Package to Waste Package Positioning Room

Before the naval canister is sealed inside the waste package, it is necessary to detach the naval canister lifting adapter from the top of the canister. The naval cask shield ring, which is still atop the canister at this point, protects personnel while they work to detach the lifting adapter. Operators detach the canister lifting device from the top of the canister, but leave the shield ring attached to the lifting adapter. The shield ring is then removed using the CTM.

For both the naval and the HLW waste forms, the inner lid of the waste package is installed by the CTM while the waste package is below the waste package loading port. The spread ring, which is a part of the closure system for the inner lid, is also installed on the waste package by the CTM. After the inner lid and spread ring are in place, the WPTT carries the waste package to the Waste Package Positioning Room. Opening and closing the shield door that separates the Waste Package Loading Room from the Waste Package Positioning Room is required in this node.

This node is described in:

- *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 6* (Ref. 2.2.40)

- *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 7* (Ref. 2.2.41

- *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 10* (Ref. 2.2.44).

#### 6.1.2.13 Node 13: Close Waste Package

The RHS, extending down through the Closure Room opening into the Positioning Room, is used to expand the spread ring for a seal weld. The spread ring is welded to the inner lid and the inner vessel of the waste package. The weld is non-destructively examined and the inner vessel is inerted and leak tested.

The outer lid of the waste package is retrieved and placed on the waste package by the RHS. The outer lid is welded to the waste package outer barrier. The weld is non-destructively examined. Stress mitigation is performed on the outer lid weld.

This node is described in the *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 10* (Ref. 2.2.44).

#### 6.1.2.14 Node 14: Move Waste Package to Transport and Emplacement Vehicle

The sealed waste package is moved from the positioning room to the Waste Package Loadout Room by the WPTT. Opening and closing the shield door between the two rooms is required in this node. The WPTT continues to the waste package transfer carriage docking station where it is locked in place. The waste package handling crane is used to remove the waste package shield ring from the top of the waste package in the WPTT as described in:

- *Initial Handling Facility General Arrangement Second Floor Plan* (Ref. 2.2.30)
- *Initial Handling Facility General Arrangement Sections A & B* (Ref. 2.2.31)
- *Initial Handling Facility General Arrangement Sections C, D, & E* (Ref. 2.2.32).

Before the waste package enters the room on the WPTT, the TEV is moved into position to receive the waste package (Ref. 2.2.26, Ref. 2.2.31). The WPTT tilts the waste package down to a horizontal orientation. The waste package transfer carriage is engaged by a mechanism in the docking station and pulled into the shielded compartment of the TEV where it can be lifted by the TEV into transport position.

This node is described in the *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 11* (Ref. 2.2.45).

### 6.1.3 Identification of Initiating Events

The identification of initiating events is completed by constructing the MLD and supplementing it with a HAZOP evaluation. The methodologies for the MLD and HAZOP evaluation are described in Sections 4.3.1.2 and 4.3.1.3, respectively. The MLD diagram and HAZOP deviations for the IHF are provided in Attachment D and E, respectively. 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 Event Groups

| Identifier | General Event Description |
|---|---|
| IHF-E201 | Exposure due to seismic events |
| IHF-E202 | Non-seismic geologic activity (including landslides, avalanches) |
| IHF-E203 | Volcanic activity |
| IHF-E204 | High winds/tornadoes (including wind effects from hurricanes) |
| IHF-E205 | External floods |
| IHF-E206 | Lightning |
| IHF-E207 | Loss of power events |
| IHF-E208 | Loss of cooling capability event (non-power cause, including biological events) |
| IHF-E209 | Aircraft crash |
| IHF-E210 | Nearby industrial/military facility accidents (including transportation accidents) |
| IHF-E211 | Onsite hazardous materials release |
| IHF-E212 | External fires (including forest fires, grass fires) |
| IHF-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 # |
|---|---|---|---|---|
| IHF-101 | RC derailment leads to rollover | D-1 | E-2 | F-1 |
| IHF-102 | RC collision leads to impact | D-1 | E-2 | F-1 |
| IHF-103 | TT failure leads to rollover or load drop (HLW only) | D-1 | E-2 | F-1 |
| IHF-104 | TT collision leads to impact (HLW only) | D-1 | E-2 | F-1 |
| IHF-I301 | Internal flooding caused by pipe failure | D-3 | | |
| IHF-I302 | Internal flooding caused by actuation of fire protection system | D-3 | | |
| IHF-I305 | Fire affects WP in WP Loadout Room | D-3 | | F-13 |
| IHF-I306 | Fire affects WP in WP Positioning Room | D-3 | | F-13 |
| IHF-I307 | Fire affects WP in WP Loading Room | D-3 | | F-13 |
| IHF-I308 | Fire affects TC in Cask Unloading Room | D-3 | | F-13 |
| IHF-I309 | Fire affects TC on CTT in Cask Preparation Area | D-3 | | F-13 |
| IHF-I310 | Fire affects TC on RC in Cask Preparation Area (diesel) | D-3 | | F-13 |

Table 10. List of Internal Initiating Events (Continued)

| Identifier | General Event Description | MLD Figure # | HAZOP Table # | ESD Figure # |
|---|---|---|---|---|
| IHF-I311 | Fire affects TC on RC in Cask Preparation Area (no diesel) | D-3 | | F-13 |
| IHF-I312 | Fire affects canister in WP | D-3 | | F-13 |
| IHF-I313 | Fire affects TC (diesel) | D-3 | | F-13 |
| IHF-I314 | Fire affects TC (no diesel) | D-3 | | F-13 |
| IHF-I315 | Fire affects canister in CTM | D-3 | | F-13 |
| IHF-I316 | Fire affects canister in Canister Transfer Area | D-3 | | F-13 |
| IHF-I317 | Excessive temperature (excluding internal fire events) | D-3 | | |
| IHF-401 | Cask preparation crane drops load onto HLW TC (HLW only) | D-4 | E-3 | F-2 |
| IHF-402 | Unplanned conveyance movement while MAP crane is attached to HLW TC or conveyance fixtures leading to cask impact (HLW only) | D-4 | | F-2 |
| IHF-403 | Cask preparation crane or cask handling crane failure causes cask impact (HLW only) | D-4 | E-3, E-7 | F-2 |
| IHF-404 | CTM drops object onto canister before grappling canister (HLW only) | D-4 | | F-7 |
| IHF-405 | Impact from MAP operations (HLW only) | D-4 | E-3 | F-2 |
| IHF-501 | Cask handling crane failure causes TC drop | D-5 | E-4, E-5 | F-1, F-2 |
| IHF-502 | Operation of cask handling crane causes unplanned conveyance movement and cask drop | D-5 | | F-1, F-2 |
| IHF-503 | Unplanned conveyance movement while crane is attached to TC or conveyance fixtures causes cask drop | D-5 | | F-1, F-2 |
| IHF-504 | Cask handling crane drops object onto TC | D-5 | E-4 | F-1, F-2 |
| IHF-505 | Unplanned conveyance movement prior to cask clearing pedestal causing cask drop | D-5 | | F-1, F-2 |
| IHF-506 | Cask handling crane drops cask | D-5 | E-5, E-6 | F-1, F-2 |
| IHF-507 | Cask tips and drops after placed onto CTT | D-5 | E-7 | F-1, F-2 |
| IHF-508 | Cask collides with object while being moved by cask handling crane resulting in side impact | D-5 | E-6 | F-1, F-2 |
| IHF-509 | Impact from cask preparation platform operations | D-5 | E-4 | F-1, F-2 |
| IHF-602 | Unplanned movement of CTT during cask lid removal leads to cask impact (naval only) | D-6 | | F-4 |
| IHF-603 | Heavy load dropped into the cask and onto the canister (naval only) | D-6 | E-9 | F-4 |
| IHF-604 | Operation of cask preparation crane leads to cask tipover (naval only) | D-6 | E-9 | F-4 |
| IHF-605 | Heavy object dropped onto the cask before removal of the lid (naval only) | D-6 | | F-2 |
| IHF-606 | Cask preparation crane causes impact to side of cask (naval only) | D-6 | E-9 | F-2, F-4 |
| IHF-607 | Inadvertent displacement of shield ring causes direct exposure (naval only) | D-6 | | F-12 |
| IHF-701 | Operation of cask preparation crane leads to cask tipover (HLW only) | D-7 | | F-3 |

Table 10. List of Internal Initiating Events (Continued)

| Identifier | General Event Description | MLD Figure # | HAZOP Table # | ESD Figure # |
|---|---|---|---|---|
| IHF-702 | Cask preparation crane drops object onto cask (HLW only) | D-7 | | F-3 |
| IHF-703 | Cask impact resulting from unplanned movement of CTT during installation of cask lid lift fixture (HLW only) | D-7 | | F-3 |
| IHF-705 | Cask preparation crane causes impact to side of cask (HLW only) | D-7 | | F-3 |
| IHF-801 | Shield door to Cask Unloading Room, closes against CTT resulting in cask impact | D-8 | E-10 | F-6 |
| IHF-802 | Collision with facility structures or equipment during movement resulting in cask impact | D-8 | E-10 | F-5, F-6 |
| IHF-803 | CTT or cask catches crane hook or rigging during movement resulting in cask impact | D-8 | | F-5 |
| IHF-804 | CTM drops object (e.g., lid) into the cask (HLW only) | D-8 | E-11 | F-7 |
| IHF-805 | Lid binds during removal resulting in dropped cask (HLW only) | D-8 | E-11 | F-7 |
| IHF-806 | Cask impact resulting from unplanned movement of CTT during lid removal (HLW only) | D-8 | | F-7 |
| IHF-901 | Canister drop within CTM | D-9 | | F-7 |
| IHF-902 | Canister collision due to CTM failure leading to an impact | D-9 | E-12 | F-7 |
| IHF-903 | Cask Unloading Room or WP Loading Room shielding loss while the canister is being lifted or lowered | D-9 | E-11, E-13 | F-12 |
| IHF-1001 | Improper configuration of the WP in the WPTT | D-10 | E-14, E-15 | F-12 |
| IHF-1002 | CTM crane drops WP inner lid onto canister during placement | D-10 | E-14, E-15 | F-7 |
| IHF-1003 | RHS drops object on WP | D-10 | E-15 | F-9 |
| IHF-1004 | Welding damages canister | D-10 | | F-9 |
| IHF-1005 | WPTT derails leading to canister impact | D-10 | E-14, E-16 | F-8 |
| IHF-1006 | Collision between WPTT and facility, structures, or equipment leading to a WP or canister impact | D-10 | E-14, E-16 | F-8, F-10 |
| IHF-1007 | Premature tilt-down of WPTT | D-10 | E-14, E-16 | F-8, F-10 |
| IHF-1102 | WPTT moves while WP is being loaded leading to an impact | D-11 | E-13 | F-7 |
| IHF-1103 | CTT moves during cask unloading leading to an impact | D-11 | E-11 | F-7 |
| IHF-1104 | Spurious movement of CTM bridge or trolley leading to an impact | D-11 | | F-7 |
| IHF-1105 | Canister strikes port edge, CTM slide gate, or wall leading to a canister drop | D-11 | E-11, E-13 | F-7 |
| IHF-1106 | Canister crushed during transfer | D-11 | E-11, E-13 | F-7 |
| IHF-1107 | CTM wire rope cut resulting in dropped canister | D-11 | E-11, E-13 | F-7 |
| IHF-1108 | Canister impact or drop caused by CTM motor failure to stop on demand | D-11 | E-11, E-13 | F-7 |
| IHF-1109 | CTM failure leading to canister impact or drop | D-11 | E-11, E-13 | F-7 |
| IHF-1110 | Canister drop in CTM shield bell (with CTM slide gate closed) due to CTM failure | D-11 | E-11, E-13 | F-7 |
| IHF-1202 | WP handling crane drops an object | D-12 | E-16 | F-11 |

Table 10. List of Internal Initiating Events (Continued)

| Identifier | General Event Description | MLD Figure # | HAZOP Table # | ESD Figure # |
|---|---|---|---|---|
| IHF-1203 | Crane interference with TEV or WPTT | D-12 | E-16 | F-11 |
| IHF-1204 | Failure of the WPTT | D-12 | E-16 | F-10, F-11 |
| IHF-1205 | Failure of WP transfer carriage | D-12 | E-16 | F-11, F-12 |
| IHF-1206 | TEV collision | D-12 | | F-11 |
| IHF-1207 | Untimely opening of shield door or personnel door to WP Loadout Room | D-12 | | F-12 |

NOTE: CTM = canister transfer machine; CTT = cask transfer trolley; HLW = high level radioactive waste; MLD = master logic diagram; RC = railcar; RHS = remote handling system; TC = transportation cask; TEV = transport and emplacement vehicle; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

To facilitate ESD development, a unique identification number has been assigned to each initiating event. The numbers consist of "IHF-" 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, "IHF-312" means "initiating event 12 on the page 3 of the MLD" and "IHF-1207" means "initiating event 07 on page 12 of the MLD." A slightly different convention has been used for external events: a prefix "E" has been inserted before the page number. Thus, "IHF-E202" means external initiating event 02 on page 2 of the MLD. For internal initiating events associated with heat or flooding, the prefix "I" has been added to differentiate these from the internal initiating events associated more closely with facility operations. No prefix is used for other internal events.

As noted in Section 1, external event sequences are not developed in this analysis. Their treatment here is limited to identifying initiating events within the MLD. Several categories of external hazard can be identified that encompass the spectrum of potential hazards based on an external event screening as presented in the *Monitored Geologic Repository External Events Hazards Screening Analysis* (Ref. 2.2.5). Regrouping these items, 13 categories of external events are identified as potentially applicable to a repository, as listed in Table 9 and are incorporated into the MLD as shown in Attachment D. Some of these categories can be readily screened from further consideration based on other analyses. Specifically, the two categories are: (1) nearby industrial/military facility accidents (including transportation accidents); and (2) an aircraft crash.

Based on *Industrial/Military Activity-Initiated Accident Screening Analysis* (Ref 2.2.58), no specific industrial or military activity is identified near the repository site that could affect repository operations to induce a release or exposure. Therefore, industrial or military activity is screened from further analysis.

The second category, an aircraft crash, is screened out based on the potential frequency of occurrence during the 50-year emplacement period. An evaluation of the potential for an aircraft crash into repository facilities is presented in *Frequency Analysis of Aircraft Hazards for License Application* (Ref 2.2.21), Section 7. It is noted that Category 2 event sequences are defined in

10 CFR 63.2 (Ref. 2.3.1) as those events that have at least one chance in 10,000 of occurring during the preclosure period. Since the probability of an aircraft crash initiating event is Beyond Category 2, any resultant event sequence is not developed further.

The remaining 11 categories of external events will be examined and developed further, as warranted, in *IHF Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1).

## 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-13). Sections 6.2.2 through 6.2.14 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 IHF-ESD-01: Receipt of Naval Transportation Casks on Railcar or HLW Transportation Casks on Railcar or Truck Trailer in Cask Preparation Area and Transfer of Naval Transportation Cask to Cask Transfer Trolley

#### 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 Area before removal of the impact limiters from the transportation cask (Figure F-1). This includes event sequences that arise during receipt of a transportation cask on railcar or truck trailer, and in the case of a naval cask, during transfer to the CTT by the cask handling crane (Section 6.1.2.1, Node 1). This ESD applies to the following waste forms:

- Naval transportation cask containing a single naval SNF canister and received on railcar
- HLW transportation cask containing five HLW canisters and received by railcar
- HLW transportation cask containing a single HLW canister and received by truck trailer.

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

1. Cask handling crane drops object (such as handling equipment) onto the naval transportation cask

2. Cask handling crane drops naval transportation cask from operational height
3. Cask handling crane drops naval transportation cask from above operational height
4. Railcar derailment
5. HLW truck trailer rollover
6. Railcar or truck trailer collision (for example, with another vehicle)
7. Collision involving naval transportation cask off of railcar (while the cask is being carried by the cask handling crane)
8. Naval transportation cask tipover (after placement into the CTT).

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 Area 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 radionuclide 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 potential direct exposure of personnel 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), the next pivotal event asks whether the canister inside the transportation cask remains intact. 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 canister containment remains intact, radionuclide release is avoided, but a direct exposure occurs due to an implied loss of shielding caused by cask breach. Otherwise, the containment boundaries of both the cask and the canister have been breached and a radionuclide release is inevitable. The subsequent 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 HVAC confinement is maintained. The key elements of HVAC are the exhaust fans and HEPA filters. In addition to whether or not the HVAC system is operating at the time of the release, this question implies maintenance of confinement over a mission time after a radionuclide release and a limitation on the amount of air leakage into the building to that which can be accommodated by the HVAC system. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. 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”). The question of whether moderator intrusion occurs is addressed in this pivotal event rather than a more general question asking about criticality because the design intention is to deny entry of moderator into the canister 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 in the subsequent categorization analysis 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 radionuclide 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 loss of cask shielding causes direct exposure

3. Cask containment fails, the canister containment remains intact, but implied loss 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.

In accordance with the methods explained in Section 4.3.2.2, these event sequences are shown explicitly in the event trees in Attachment G.

### 6.2.3 IHF-ESD-02: Removal of Impact Limiters, Upending and Transfer of HLW Cask to CTT and Removal of Impact Limiters from Naval Transportation Cask

#### 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 Area during removal of impact limiters, upending and transfer of the HLW cask to the CTT, and removal of impact limiters from the naval transportation cask (Figure F-2 and Sections 6.1.2.2, Node 2; 6.1.2.3, Node 3; 6.1.2.4, Node 4; 6.1.2.5, Node 5; and, 6.1.2.6, Node 7). This ESD applies to the following waste forms:

- HLW transportation cask containing five HLW canisters and received by railcar
- HLW transportation cask containing a single HLW canister and received by truck trailer
- Naval transportation cask containing a single naval canister and received by 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. Drop of HLW transportation cask from operational height

2. Drop of HLW transportation cask from above operational height

3. Unplanned conveyance movement causes HLW transportation cask impact due to collision with equipment or structure

4. Collision with equipment or structure involving side impact to HLW or naval transportation cask (during transfer by crane)

5. Drop of heavy object (such as handling equipment) onto the naval or HLW transportation cask

6. HLW transportation cask tipover.

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 Area during removal of impact limiters, upending and transfer of the HLW cask to the CTT, or removal of impact limiters from the naval transportation cask.

#### 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 cask containment boundary remains intact, no radionuclide 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), the next pivotal event asks whether the canister inside the transportation cask remains intact. 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 canister containment remains intact, radionuclide release is avoided, but a direct exposure of personnel occurs due to an implied loss of shielding caused by cask breach. Otherwise, the containment boundaries of both the cask and the canister have been breached and a radionuclide release is inevitable. The subsequent 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 HVAC confinement is maintained. The key elements of HVAC are the exhaust fans and HEPA filters. In addition to whether or not the HVAC system is operating at the time of the release, this question implies maintenance of confinement over a mission time after a radionuclide release and a limitation on the amount of air leakage into the building that can be accommodated by the HVAC system. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. 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 (e.g., 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). The question of whether moderator intrusion occurs is addressed in this pivotal event rather than a more general question asking about criticality because the design intention is to deny entry of moderator into the canister 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 in the subsequent categorization analysis 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 radionuclide 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 loss of cask shielding causes direct exposure

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

4. Cask containment 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.

In accordance with the methods explained in Section 4.3.2.2, these event sequences are shown explicitly in the event trees in Attachment G.

### 6.2.4 IHF-ESD-03: Cask Preparation Activities Associated with Unbolting and Lid Adapter Installation for the HLW Cask

#### 6.2.4.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the HLW transportation cask that occurs in the Cask Preparation Area during cask preparation activities involving the cask preparation crane (Figure F-3 and Section 6.1.2.6, Node 6). This ESD applies to the following waste forms:

- HLW transportation cask containing five HLW canisters
- HLW transportation cask containing a single HLW 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 three groups (represented as little bubbles), as follows:

1. Transportation cask tipover (due to interference with the cask preparation crane)

2. Side impact to transportation cask (due to interference with the cask preparation crane)

3. Drop of heavy object (such as handling equipment associated with the cask preparation crane) onto the transportation cask.

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 HLW transportation cask that occurs in the Cask Preparation Area during cask preparation activities involving the cask preparation 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 radionuclide 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), the next pivotal event asks whether the canister inside the transportation cask remains intact. 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 canister containment remains intact, radionuclide release is avoided, but a direct exposure occurs due to an implied loss of shielding caused by cask breach. Otherwise, the containment boundaries of both the cask and the canister have been breached and a radionuclide release is inevitable. The subsequent 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 HVAC confinement is maintained. The key elements of HVAC are the exhaust fans and HEPA filters. In addition to whether or not the HVAC system is operating at the time of the release, this question implies maintenance of confinement over a mission time after a radionuclide release and a limitation on the amount of air leakage into the building that can be accommodated by the HVAC system. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. 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, i.e., 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 (e.g., 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 radionuclide 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 loss of cask shielding causes direct exposure

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

4. Cask containment 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.

In accordance with the methods explained in Section 4.3.2.2, these event sequences are shown explicitly in the event trees in Attachment G.

### 6.2.5 IHF-ESD-04: Removal of the Naval Cask Lid and Installing the Naval Canister Lifting Adapter

#### 6.2.5.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the naval canister inside the transportation cask associated with removal of the cask lid. This includes event sequences that arise during removal of the lid and other actions to prepare the canister for removal from the cask (Figure F-4 and Section 6.1.2.7, Node 7). This ESD applies to the naval transportation cask containing a single naval SNF canister.

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

1. Side impact to transportation cask (handling equipment collision, for example)
2. Drop of a heavy object (such as handling equipment or the cask lid) onto the canister
3. Transportation cask tips over (after placement into the CTT).

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a structural challenge to the canister inside the transportation cask associated with removal of the cask lid.

#### 6.2.5.3 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 canister remains intact 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 may occur depending on the outcome of the next pivotal event, that is, whether the cask shielding (which includes the naval cask shield ring and the integral shielding associated with the top of the naval canister) remains intact. 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 of personnel to radiation. If the canister containment 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 HVAC confinement is maintained. The key elements of HVAC are the exhaust fans and HEPA filters. In addition to whether or not the HVAC system is operating at the time of the release, this question implies maintenance of confinement over a mission time after a radionuclide release and a limitation on the amount of air leakage into the building that can be accommodated by the HVAC system. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. 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). The question of whether moderator intrusion occurs is addressed in this pivotal event rather than a more general question asking about criticality because the design intention is to deny entry of moderator into the canister 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 in the subsequent categorization analysis 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 four end states:

1. "OK"
2 Direct exposure
3. Radionuclide release
4. Radionuclide release, also important to criticality.

The end states that correspond to radionuclide 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 shielding causes 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.

In accordance with the methods explained in Section 4.3.2.2, these event sequences are shown explicitly in the event trees in Attachment G.

### 6.2.6 IHF-ESD-05: Transfer of a Cask on CTT from the Cask Preparation Area to Cask Unloading Room

#### 6.2.6.1 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 Area to the Cask Unloading Room (Figure F-5 and Section 6.1.2.8, Node 8). This ESD applies to the following waste forms:

- Naval SNF canister in a transportation cask
- HLW canister in a transportation cask.

#### 6.2.6.2 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 impact collision with another vehicle, facility structures, or equipment (except 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 area to the cask unloading room.

#### 6.2.6.3 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 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 radionuclide release occurs. However, there remains the question whether or not the transportation cask shielding remains intact, as posed by the next pivotal event. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is "OK." Otherwise, the event sequence terminates in a direct exposure of personnel 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 HVAC confinement is maintained. The key elements of HVAC are the exhaust fans and HEPA filters. In addition to whether or not the HVAC system is operating at the time of the release, this question implies maintenance of confinement over a mission time after a radionuclide release and a limitation on the amount of air leakage into the building that can be accommodated by the HVAC system. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. 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). The question of whether moderator intrusion occurs is addressed in this pivotal event rather than a more general question asking about criticality because the design intention is to deny entry of moderator into the canister 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 in the subsequent categorization analysis 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 six event sequences. The ESD shows four end states:

1. "OK"
2 Direct exposure
3. Radionuclide release
4. Radionuclide release, also important to criticality.

The end states that correspond to radionuclide 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 shielding causes direct exposure of personnel.

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.

In accordance with the methods explained in Section 4.3.2.2, these event sequences are shown explicitly in the event trees in Attachment G.

### 6.2.7 IHF-ESD-06: Collision of CTT with Cask Unloading Room Shield Door

#### 6.2.7.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the HLW or naval cask in the CTT that occurs during the transfer from the Cask Preparation Area to the Cask Unloading Room (Figure F-6 and Section 6.1.2.8, Node 8). This ESD applies to the following waste forms:

- Naval transportation cask (without a lid) containing a single naval SNF canister in a CTT

- HLW transportation cask (with lid in place but unbolted) containing five HLW canisters in a CTT

- HLW transportation cask (with a lid in place but unbolted) containing a single HLW canister in a CTT.

#### 6.2.7.2 Initiating Events

The initiating event that is identified in the MLD is presented on the ESD as a collision between a CTT carrying a HLW or naval cask and the shield door of the Cask Unloading Room. The collision could result from either the CTT hitting a closed or partially closed Cask Unloading Room shield door or the shield door closing on the CTT while it is moving into the Cask Unloading Room. This initiating event is represented by the big bubble on the ESD.

#### 6.2.7.3 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. Determining whether or not the door remains on 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, the impact to the transportation cask could be more severe than it would be if the shield door remains on its track. 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 radionuclide 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 of personnel 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 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 HVAC confinement is maintained. The key elements of HVAC are the exhaust fans and HEPA filters. In addition to whether or not the HVAC system is operating at the time of the release, this question implies maintenance of confinement over a mission time after a radionuclide release and a limitation on the amount of air leakage into the building that can be accommodated by the HVAC system. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. 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). The question of whether moderator intrusion occurs is addressed in this pivotal event rather than a more general question asking about criticality because the design intention is to deny entry of moderator into the canister 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 in the subsequent categorization analysis 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 twelve event sequences. The ESD shows four end states:

1. “OK”
2 Direct exposure
3. Radionuclide release
4. Radionuclide release, also important to criticality.

The end states that correspond to radionuclide 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 event sequences, except that each event sequence is further delineated depending upon whether the door remains on its tracks. The result is twelve event sequences as follows:

1. Shield door remains on its track, canister containment boundary and transportation cask shielding remain intact (no radiation exposure)
2. Shield door falls off its track and crashes on CTT, canister containment boundary and transportation cask shielding remain intact (no radiation exposure)
3. Shield door remains on its track, canister containment remains intact, but loss of cask shielding causes direct exposure
4. Shield door falls off its track and crashes on CTT, canister containment remains intact, but loss of cask 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 CTT, 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 CTT, 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 CTT, 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 CTT, canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented resulting in an unfiltered radionuclide release, also important to criticality.

In accordance with the methods explained in Section 4.3.2.2, these event sequences are shown explicitly in the event trees in Attachment G.

### 6.2.8 IHF-ESD-07: Transfer of a Canister from a TC to a WP with CTM

#### 6.2.8.1 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 waste package port, and lowering the canister into a waste package (Figure F-7 and Sections 6.1.2.9, Node 9; 6.1.2.10, Node 10; and, 6.1.2.11, Node 11). This ESD applies to the following waste forms:

- Naval SNF canister
- HLW 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 eight groups (represented as little bubbles), as follows:

1. HLW transportation cask impact associated with cask lid removal
2. Canister impact due to movement of the CTM, CTT, or WPTT during lift
3. Drop of an object onto the canister
4. Canister dropped during transfer (drop through a port) from operational height
5. Canister dropped during transfer (drop through a port) from above operational height
6. Canister collision or impact (for example, with the inside of the shield bell)
7. Side impact (due to inadvertent closure of a slide gate)
8. Canister dropped inside the CTM (i.e., not through a port).

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 TC or waste package with the CTM.

#### 6.2.8.3 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 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 radionuclide release occurs. However, there remains the question whether or not the CTM shielding remains intact, as posed by the next pivotal event. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is “OK.” Otherwise, the 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 with respect to HVAC confinement and moderator intrusion. First, a pivotal event asks whether HVAC confinement is maintained. The key elements of HVAC are the exhaust fans and HEPA filters. In addition to whether or not the HVAC system is operating at the time of the release, this question implies maintenance of confinement over a mission time after a radionuclide release and a limitation on the amount of air leakage into the building that can be accommodated by the HVAC system. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. 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). The question of whether moderator intrusion occurs is addressed in this pivotal event rather than a more general question asking about criticality because the design intention is to deny entry of moderator into the canister 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 in the subsequent categorization analysis 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 four end states:

1. "OK"
2 Direct exposure
3. Radionuclide release
4. Radionuclide release, also important to criticality.

The end states that correspond to radionuclide 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 causes 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.

In accordance with the methods explained in Section 4.3.2.2, these event sequences are shown explicitly in the event trees in Attachment G.

### 6.2.9 IHF-ESD-08: WP Transfer from WP Loading Room to Closing Position in WP Positioning Room below WP Closure Room

#### 6.2.9.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the canister or canisters inside the waste package that occurs during the waste package transfer from the Waste Package Loading Room to the closing position in the Waste Package Positioning Room below the Waste Package Closure Room (Figure F-8 and Section 6.1.2.12, Node 12). This ESD applies to the following waste forms:

- Naval SNF canister in waste package
- HLW canisters in waste package.

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

1. WPTT collision with facility structures or facility equipment
2. Impact from WPTT premature tilt-down
3. WPTT derailment

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a structural challenge to the waste package that occurs during the waste package transfer from the Waste Package Loading Room to the closing position in the Waste Package Positioning Room below the Waste Package Closure Room.

#### 6.2.9.3 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 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 radionuclide release occurs. However, there remains the question whether or not the waste package remains within the WPTT shield compartment, as posed by the next pivotal event. If the waste package remains within the shielding, there is no exposure of personnel to radiation and the end state is “OK.” Otherwise, the event sequence terminates in a direct exposure of personnel 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 HVAC confinement is maintained. The key elements of HVAC are the exhaust fans and HEPA filters. In addition to whether or not the HVAC system is operating at the time of the release, this question implies maintenance of confinement over a mission time after a radionuclide release and a limitation on the amount of air leakage into the building that can be accommodated by the HVAC system. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. 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). The question of whether moderator intrusion occurs is addressed in this pivotal event rather than a more general question asking about criticality because the design intention is to deny entry of moderator into the canister 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 in the subsequent categorization analysis 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 four end states:

1. “OK”
2 Direct exposure
3. Radionuclide release
4. Radionuclide release, also important to criticality.

The end states that correspond to radionuclide 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 effective (no radiation exposure).

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

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.

In accordance with the methods explained in Section 4.3.2.2, these event sequences are shown explicitly in the event trees in Attachment G.

### 6.2.10 IHF-ESD-09: Event Sequences Associated with Assembly and Closure of the Waste Package

#### 6.2.10.1 Overall Description

This ESD delineates the event sequences that arise after mishaps during assembly and closure of the waste package that occurs in the Waste Package Positioning Room (Figure F-9). This includes event sequences that arise during the closure of the waste package (Section 6.1.2.13, Node 13). At this point in the handling sequence, the inner lid of the waste package has already been set into place. This ESD applies to the following waste forms:

- Waste package containing a single naval SNF canister in the WPTT
- Waste package containing five HLW canisters in the WPTT.

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

1. Welding damages the canister(s)

2. Remote handling system drops object (such as the waste package outer lid or handling equipment, as applicable) onto the inner lid or outer lid of the waste package.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. This big bubble represents mishaps during assembly and closure of the waste package that occurs in the Waste Package Positioning Room.

#### 6.2.10.3 System Response

After the initiating event 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 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 radionuclide release occurs. However, there remains the question whether or not the shielding associated with the waste package and WPTT remains effective, as posed by the next pivotal event. In the case of the HLW waste package, the inner lid provides shielding. For the naval canister, the canister itself contains integral shielding. In both cases, the WPTT shield ring provides additional shielding. If the shielding remains effective, there is no exposure of personnel to radiation and the end state is "OK." Otherwise, the event sequence terminates in a direct exposure of personnel 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 HVAC confinement is maintained. The key elements of HVAC are the exhaust fans and HEPA filters. In addition to whether or not the HVAC system is operating at the time of the release, this question implies maintenance of confinement over a mission time after a radionuclide release and a limitation on the amount of air leakage into the building that can be accommodated by the HVAC system. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. 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). The question of whether moderator intrusion occurs is addressed in this pivotal event rather than a more general question asking about criticality because the design intention is to deny entry of moderator into the canister 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 in the subsequent categorization analysis 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 six event sequences. The ESD shows four end states:

1. "OK"
2 Direct exposure
3. Radionuclide release
4. Radionuclide release, also important to criticality.

The end states that correspond to radionuclide 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 effective (no radiation exposure).

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

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.

In accordance with the methods explained in Section 4.3.2.2, these event sequences are shown explicitly in the event trees in Attachment G.

#### 6.2.11 IHF-ESD-10: Transfer of the Waste Package from the Waste Package Positioning Room to the Waste Package Transfer Trolley Docking Station

##### 6.2.11.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the waste package that occurs during the transfer of the waste package from the Waste Package Positioning Room to the WPTT Docking Station (Figure F-10 and Section 6.1.2.14, Node 14). This ESD applies to the following waste forms:

- Waste package containing naval SNF
- Waste package containing HLW.

##### 6.2.11.2 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 three groups (represented as little bubbles) as follows:

1. WPTT collision
2. Impact due to improper tilt-down or departure of the WPTT
3. WPTT derailment.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a structural challenge to the waste package that occurs during the transfer of the waste package from the Waste Package Positioning Room to the WPTT Docking Station.

##### 6.2.11.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the containment boundary of the waste package remains intact. Determining whether or not the containment boundary of the waste package remains intact involves uncertainties in both the load imposed on the waste package and the strength of the waste package. If the containment boundary remains intact, no radionuclide release occurs. However, there remains the question whether or not the waste package remains within the WPTT (implying that the WPTT shielding remains intact), as posed by the next pivotal event. If the waste package remains within the WPTT, there is no exposure of personnel to radiation and the end state is ”OK.” Otherwise, the waste package does not remain within the WPTT and the event sequence terminates in a direct exposure to radiation.

If the containment boundary of the waste package does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), the next pivotal event asks whether the canister inside the waste package remains intact. 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 canister remains intact, radionuclide release is avoided, but a direct exposure occurs due to a loss of shielding caused by the waste package breach and the implied failure of the waste package to remain within the WPTT shields. Otherwise, the containment boundaries of both the waste package and the canister have 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 HVAC confinement is maintained. The key elements of HVAC are the exhaust fans and HEPA filters. In addition to whether or not the HVAC system is operating at the time of the release, this question implies maintenance of confinement over a mission time after a radionuclide release and a limitation on the amount of air leakage into the building that can be accommodated by the HVAC system. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. 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). The question of whether moderator intrusion occurs is addressed in this pivotal event rather than a more general question asking about criticality because the design intention is to deny entry of moderator into the canister 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 in the subsequent categorization analysis 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-10 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 radionuclide 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. Waste package containment and WPTT shielding remain intact (no radiation exposure)

2. Waste package containment remains intact, but loss of WPTT shielding causes direct exposure

3. Waste package containment fails; canister containment remains intact, but implied loss of WPTT shielding causes direct exposure

4. Waste package containment fails, canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented resulting in a filtered radionuclide release

5. Waste package containment fails, canister containment fails, HVAC confinement fails, and moderator intrusion is prevented resulting in an unfiltered radionuclide release

6. Waste package 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. Waste package containment fails, canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented resulting in an unfiltered radionuclide release, also important to criticality.

In accordance with the methods explained in Section 4.3.2.2, these event sequences are shown explicitly in the event trees in Attachment G.

### 6.2.12 IHF-ESD-11: Exporting a Waste Package

#### 6.2.12.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the waste package that occurs during the export of a waste package from the IHF. This includes event sequences associated with the waste package handling crane, the waste package transfer carriage, and the TEV (Figure F-11 and Section 6.1.2.14, Node 14). This ESD applies to the following waste forms:

- Naval SNF in a waste package
- HLW in a waste package.

#### 6.2.12.2 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. TEV collision
2. Impact due to object dropped on waste package
3. Crane interference with TEV or WPTT
4. Impact due to malfunction of the WPTT or the waste package transfer carriage.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a structural challenge to the waste package that occurs while exporting a waste package.

#### 6.2.12.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the containment boundary of the waste package remains intact. Determining whether or not the containment boundary of the waste package remains intact involves uncertainties in both the load imposed on the waste package and the strength of the waste package. If the containment boundary remains intact, no radionuclide release occurs. However, there remains the question whether or not the waste package remains within the WPTT (implying that the WPTT shielding remains intact), as posed by the next pivotal event. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is “OK.” Otherwise, the waste package does not remain within the WPTT and the event sequence terminates in a direct exposure to radiation.

If the containment boundary of the waste package does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), the next pivotal event asks whether the canister inside the waste package remains intact. 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 canister remains intact, radionuclide release is avoided, but a direct exposure occurs due to a loss of shielding caused by the waste package breach and the implied failure of the waste package to remain within the WPTT shields. Otherwise, the containment boundaries of both the waste package and the canister have 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 HVAC confinement is maintained. The key elements of HVAC are the exhaust fans and HEPA filters. In addition to whether or not the HVAC system is operating at the time of the release, this question implies maintenance of confinement over a mission time after a radionuclide release and a limitation on the amount of air leakage into the building that can be accommodated by the HVAC system. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. 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). The question of whether moderator intrusion occurs is addressed in this pivotal event rather than a more general question asking about criticality because the design intention is to deny entry of moderator into the canister 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 in the subsequent categorization analysis 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-11 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 radionuclide 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. Waste package containment and WPTT shielding remain intact (no radiation exposure)

2. Waste package containment remains intact, but loss of WPTT shielding causes direct exposure

3. Waste package containment fails; canister containment remains intact, but implied loss of WPTT shielding causes direct exposure

4. Waste package containment fails, canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented resulting in a filtered radionuclide release

5. Waste package containment fails, canister containment fails, HVAC confinement fails, and moderator intrusion is prevented resulting in an unfiltered radionuclide release

6. Waste package 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. Waste package containment fails, canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented resulting in an unfiltered radionuclide release, also important to criticality.

In accordance with the methods explained in Section 4.3.2.2, these event sequences are shown explicitly in the event trees in Attachment G.

### 6.2.13 IHF-ESD-12: Direct Exposure during Various Activities

#### 6.2.13.1 Overall Description

These ESDs delineate direct-exposure event sequences that are not addressed in other ESDs (Figure F-12). This includes event sequences that arise during receipt of a transportation cask on railcar or truck trailer, movement of a canister during operations with the CTM, and the export of a waste package from the IHF. These ESDs apply to the following waste forms:

- Naval SNF in a transportation cask, CTM, or waste package
- HLW in a canister in the CTM or waste package.

#### 6.2.13.2 Initiating Events

These ESDs address initiating events that could not be grouped and included in any of the aggregated ESDs described previously. The individual initiating events that are identified in the MLD are indicated on the ESDs by their initiating event identifiers within one of the three aggregate initiating events addressed in ESD-12 and identified in Section 6.2.13.1.

Three aggregate initiating events are identified:

1. Temporary loss of shielding of the CTM shield bell while the canister is being lifted from a transportation cask (Section 6.1.2.9, Node 9) A loss of shielding could occur if the shield skirt is inadvertently lifted during canister transfer or if canister transfer proceeds before the shield skirt is lowered. A loss of shielding could also occur if the canister is lifted so high that it protrudes from the top of the shield bell. Because the elevation of the shield bell is fixed due to its rigid attachment to the shield bell trolley, it is not possible to cause a loss of shielding by inadvertently lifting the shield bell

2. Inadvertent displacement of the naval cask shield ring from cask or waste package or improper installation of waste package shield ring on waste package

3. Direct exposure during exporting a loaded waste package (Section 6.1.2.14, Node 14).

#### 6.2.13.3 System Response

There are no pivotal events associated with the event sequences. If the initiating event occurs, there is a potential for direct exposure of personnel to radiation. This results in three event sequences, one for each initiating event. In accordance with the methods explained in Section 4.3.2.2, these event sequences are shown explicitly in the event trees in Attachment G.

### 6.2.14 IHF-ESD-13: Events Sequences for Fires Occurring in the IHF

#### 6.2.14.1 Overall Description

This ESD delineates the event sequences that occur when a fire threatens waste forms in the IHF. 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-13). 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 the following waste forms:

- Naval SNF
- HLW.

#### 6.2.14.2 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 seven groups (represented as little bubbles) as follows:

1. Localized fire threatens a waste package in the Waste Package Loadout Room
2. Localized fire threatens a waste package in the Waste Package Loading Room
3. Localized fire threatens a transportation cask in the Cask Unloading Room
4. Localized fire threatens a waste package in the Waste Package Positioning Room
5. Localized fire threatens a transportation cask in the Cask Preparation Area
6. Localized fire threatens a canister in the CTM
7. Large fire threatens waste forms anywhere in the IHF.

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.

#### 6.2.14.3 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 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 a waste package, bare canister), the thermal analysis may consider 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 may be considered in the analysis. The same method may be used to determine a thermal failure of a canister that is contained within a waste package. If the canister remains intact, radionuclide release is avoided. However, there remains the question whether or not the shielding survives the fire intact, as posed by the next pivotal event. The nature of the shielding (transportation cask, WPTT, CTM shield bell, etc.) depends on which initiating event is under consideration. 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 has been breached, 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 HVAC confinement is maintained. The key elements of HVAC are the exhaust fans and HEPA filters. In addition to whether or not the HVAC system is operating at the time of the release, this question implies maintenance of confinement over a mission time after a radionuclide release and a limitation on the amount of air leakage into the building that can be accommodated by the HVAC system. 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 and the consequence analysis may take into account degradation of the filter efficiency. If HVAC confinement is not maintained, the release is considered unfiltered. The remaining pivotal event provides further delineation by asking whether the 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, i.e., 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). The question of whether moderator intrusion occurs is addressed in this pivotal event rather than a more general question asking about criticality because the design intention is to deny entry of moderator into the canister 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 in the subsequent categorization analysis 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-13 delineates six event sequences. The ESD shows four end states:

1. "OK"
2. Direct exposure
3. Radionuclide release
4. Radionuclide release, also important to criticality.

The end states that correspond to radionuclide release are further developed to indicate whether the 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 shielding causes 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.

In accordance with the methods explained in Section 4.3.2.2, these event sequences are shown explicitly in the event trees in Attachment G.

## 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 done because the pivotal event probabilities and the radiological consequences of end states may depend on which waste form is under consideration. 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 IHF and identifies and develops potential event sequences that could occur in the IHF during the preclosure period. The results of this analysis are:

- An MLD for the IHF (Attachment D) that identifies potential initiating events for event sequences
- A set of ESDs for the IHF (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
# 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 to give an idea of the scale of the facility and the sizes of important pieces of equipment. Because the results of this analysis depend only weakly 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 IHF is 385 ft long, including the 135 ft long tongue-like structure on the west side (which contains the Loadout Room), and the 85 ft wide support area on the east. The waste-handling operations take place in the central area of the building, which measures about 160 ft by 123 ft and in the Loadout Room, which is about 106 ft long by 37 ft wide. The main roof deck is 105 ft above the floor of the building. Section 6.1.2 of this analysis provides an operational overview of the IHF. In particular, 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.

- *Initial Handling Facility General Arrangement Legend and General Notes* (Ref. 2.2.27)
- *Initial Handling Facility General Arrangement Ground Floor Plan* (Ref. 2.2.26)
- *Initial Handling Facility General Arrangement Second Floor Plan* (Ref. 2.2.30)
- *Initial Handling Facility General Arrangement Plan at Elevation +73′ -0″* (Ref. 2.2.28)
- *Initial Handling Facility General Arrangement Roof Plan* (Ref. 2.2.29)
- *Initial Handling Facility General Arrangement Plan Sections A & B* (Ref. 2.2.31)
- *Initial Handling Facility General Arrangement Sections C, D, & E* (Ref. 2.2.32)
- *Initial Handling Facility General Arrangement Sections F, G, H & J* (Ref. 2.2.33).

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

- *Initial Handling Facility Mechanical Handling System Block Flow Diagram Level 3 Sheet 1 of 11* (Ref. 2.2.35)
- *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.36)
- *Initial Handling Facility Mechanical Handling System Block Flow Diagram Level 3 Sheet 3* (Ref. 2.2.37)
- *Initial Handling Facility Mechanical Handling System Block Flow Diagram Level 3 Sheet 4* (Ref. 2.2.38)
- *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 5* (Ref. 2.2.39)
- *Initial Handling Facility Mechanical Handling System Block Flow Diagram Level 3 Sheet 6* (Ref. 2.2.40)
- *Initial Handling Facility Mechanical Handling System Block Flow Diagram Level 3 Sheet 7* (Ref. 2.2.41)
- *Initial Handling Facility Mechanical Handling System Block Flow Diagram Level 3 Sheet 8* (Ref. 2.2.42)
- *Initial Handling Facility Mechanical Handling System Block Flow Diagram Level 3 Sheet 9* (Ref. 2.2.43)
- *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 10* (Ref. 2.2.44)
- *Initial Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 11* (Ref. 2.2.45).

## A3.1 CASK PREPARATION AREA

The Cask Preparation Area (Room 1012) is used to receive loaded transportation casks by rail or truck and to export empty ones. Other materials and equipment associated with IHF 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, and removal of the cask lid (for naval casks only) take place in this room as well. This generally open area occupies the south half of the IHF steel structure. Crane rails in this area are supported by dedicated steel columns braced together and to the building structural columns, and the roof truss system.

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

**Cask Handling Crane**

The function of the cask handling crane is to transfer the transportation cask from the railcar or truck trailer 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 300 tons.
- The bridge is about 60 ft long.
- The bridge travel along its rails is about 75 ft, running east and west.
- The elevation of the rail for the bridge is about 65 ft above the floor of the building.

This equipment is shown in *Initial Handling Facility Cask Handling Crane Mechanical Equipment Envelope* (Ref. 2.2.22).

**Cask Handling Yoke or Lift Bail**

The cask handling yoke or lift bail is used by the cask handling crane to transfer HLW or naval casks between the cask conveyance and the CTT. The yoke for HLW casks has an estimated weight of 7.5 tons, and can accommodate a hook load of 200 tons. The yoke has two lifting arms, which connect to the trunnions on the HLW cask. The arm positions are adjustable to accommodate the HLW rail cask and HLW truck cask. The lift bail for naval casks has an estimated weight of 3 tons, and has a required lifting capacity of 285 tons.

This equipment is shown in *CRCF, RF, WHF and IHF Cask Handling Yoke Mechanical Equipment Envelope* (Ref. 2.2.15) and *Initial Handling Facility Naval Cask Lift Bail Mechanical Equipment Envelope* (Ref. 2.2.48).

**Cask Preparation Crane**

The cask preparation crane is used for most of the lifts of loads other than transportation casks that occur in the Cask Preparation Area. The cask preparation crane is a top-running double girder type with a top-running trolley. The cask preparation crane has the following design features:

- The main hoist is rated at 30 tons.
- The bridge is about 60 ft long.
- The bridge travel along its rails is about 80 ft.
- The height of the rail for the bridge is about 87 ft above the floor of the building.

This crane and some related equipment is shown in *Initial Handling Facility Cask Preparation Crane Mechanical Equipment Envelope* (Ref. 2.2.23), *CRCF, RF, WHF & IHF Impact Limiter Lifting Device Mechanical Equipment Envelope* (Ref. 2.2.16), and *CRCF, RF, WHF & IHF Personnel Barrier Lifting Device Mechanical Equipment Envelope* (Ref. 2.2.17).

**Cask Preparation Platform**

The cask preparation platform is a stationary steel structure located in the Cask Preparation Area. The platform provides three elevated working levels for personnel to access the CTT during cask loading and unloading processes. The platform is split down the center to allow placement of the cask into the CTT and passage of the CTT to the Cask Unloading Room. Each level of the platform is accessed by stairs. The upper two levels have movable platform sections to facilitate personnel access and provide radiation shielding for personnel performing cask preparation tasks. The naval cask lid stand and the naval cask canister restraint staging area are located on the top level of the platform.

This equipment is shown in *Initial Handling Facility Cask Preparation Platform Mechanical Equipment Envelope Sheet 1 of 2* (Ref. 2.2.24) and *Initial Handling Facility Cask Preparation Platform Mechanical Equipment Envelope Sheet 2* (Ref. 2.2.25).

**Cask Transfer Trolley**

The CTT is used for moving the transportation cask in vertical orientation between the Cask Preparation Area 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 characteristics:

- The top of the cask when in the CTT is approximately 32 ft 3 inches from the floor.
- 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 265 tons maximum for a loaded transportation cask.
- To elevate the top of the HLW cask to a height just below the ceiling height of the Cask Unloading Room a removable pedestal is placed in the bottom of the CTT. Different pedestals are used to accommodate the different cask types (HLW rail and HLW truck). A removable pedestal is not needed to accommodate the naval cask.

The CTT is described in *Mechanical Handling Design Report for Cask Transfer Trolley.* (Ref. 2.2.50).

**Mobile Access Platform**

The MAP allows personnel access to transportation casks brought in by rail or truck. The platform is a rail-mounted structure that bridges over the cask lying on the carrier. The MAP includes three adjustable platforms to provide access by personnel to different features on the cask (e.g., personnel barriers and impact limiters). Two of the platforms are sized for a single operator, and move vertically up the two legs of the platform. The third platform extends the full width of the MAP, and also moves vertically. A jib crane is mounted on the top-center of the platform, and provides support for an impact wrench, which is used in preparing the cask for removal from the transportation vehicle.

The equipment is shown in *Initial Handling Facility Mobile Access Platform Mechanical Equipment Envelope* (Ref. 2.2.46).

**Naval Canister Lifting Adapter**

The naval canister lifting adapter is a device that is attached to the top of naval canisters and associated naval cask shield ring so that the naval canister, along with the naval cask shield ring, can be lifted out of the transportation cask by the CTM. The adapter is placed on the top of the naval canister by the cask preparation crane, and then bolted on by personnel.

The equipment is shown in *Initial Handling Facility Naval Canister Lifting Adapter Mechanical Equipment Envelope* (Ref. 2.2.47).

**Rail-Cask and Truck-Cask Lid Adapters**

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

This equipment is described in *Nuclear Facilities Rail Cask Lid Adapter Mechanical Equipment Envelope* (Ref. 2.2.53) and *Nuclear Facilities Truck Cask Lid Adapter Mechanical Equipment Envelope* (Ref. 2.2.54).

## A3.2 CASK UNLOADING ROOM

The Cask Unloading Room (Room 1008) provides a shielded location for removal of the canister from the cask. The easternmost room of the concrete cell structure within the IHF 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 IHF 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 Area 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. When closed, the gate provides sufficient shielding to allow operators to be on the deck 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. 2.2.18).

**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 Area. 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. The shielding thickness may be up to 16 in. of steel.

This equipment is described in *Nuclear Facilities Equipment Shield Door-Type 1 Mechanical Equipment Envelope* (Ref. 2.2.51).

## A3.3 CANISTER TRANSFER AREA

The Canister Transfer Area (Room 2005) is the area above both the Cask Unloading Room and the Waste Package Loading Room, and extending all the way up to the main ceiling of the building. The CTM operates in this area, carrying the canister from the cask unloading port to the waste package loading port. The concrete roof slab of the Waste Package Loading Room and the Cask Unloading Room forms the Canister Transfer Area 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 Area:

**Canister Transfer Machine**

The primary function of the CTM is to transfer the canister from the transportation cask to the waste package. The CTM is a specialized bridge crane, which is mounted on a pair of bridge girders that run on rails that are supported by dedicated steel columns braced together and to the building structural elements. 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 has a permanently attached grapple, which is sized to grapple the naval canister lifting adapter. To allow differently designed HLW canisters to be grappled and lifted, the permanent CTM grapple is used to hold an exchangeable grapple, which, in turn, pick ups the HLW canister. 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 Area. 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 WASTE PACKAGE LOADING ROOM

The Waste Package Loading Room (Room 1007) provides a shielded location for placement of the canister into the waste package. The interior dimensions of the room are 46 ft east to west by 33 ft wide, with a ceiling height of 33 ft. The walls and roof are 4 ft thick reinforced concrete. The west wall has a shield door for the WPTT. The floor is the IHF base mat.

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

**Waste Package Port Slide Gate**

The waste package port, which is the opening through which the canister passes from the CTM shield bell into the waste package, is located in the operating deck between the Canister Transfer Area above and the Waste Package 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 on the deck when loaded waste packages are located in the Waste Package Loading 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. 2.2.18).

**Waste Package Shield Rings 1 and 2**

The waste package shield ring sits on top of the WPTT shielded enclosure (while in the vertical position) to provide shielding against radiation streaming upward from the roughly annular region between the waste package and the shielded enclosure of the WPTT. The shield ring surrounds the top of the waste package, which projects through the center of the shield ring a distance of a few inches to accommodate waste package closure operations. Two different shield rings accommodate the two different diameters of waste packages that are handled in the IHF.

This equipment is shown in *CRCF & IHF WP Shield Ring Lift Beam Mechanical Equipment Envelope* (Ref. 2.2.13).

**Waste Package Transfer Trolley**

The WPTT is used to reorient and transport a waste package for receipt of canisters, lid installation, and delivery to the TEV for emplacement. The trolley travels from the Waste Package Loading Room to Waste Package Positioning Room, and on to the Waste Package Loadout Room. The trolley consists of two main parts; the shielded enclosure and the trolley.

The shielded enclosure surrounds the waste package and pallet assembly on all sides, with the exception of the top. The shield ring, which is placed on top of the vertical shielded enclosure, allows the waste package to protrude approximately 3 in. The shield ring shields against radiation shine from the space between the waste package and the shielded enclosure, while accommodating the waste package closure process. The different sized waste packages must be maintained at the same elevation to support closure operations. A pedestal is used on the bottom of the vertical enclosure to hold the top of each waste package at the required height. Note that the waste package pallet and the waste package pedestal are two different pieces of equipment. The primary function of the pallet is to support the horizontally oriented waste package in the emplacement drift. It is placed in the WPTT (where it supports the waste package while the WPTT shielded enclosure is horizontally oriented) and transferred to the TEV (where it supports the waste package during the journey to the emplacement drift) as a convenient way to achieve the final configuration in the emplacement drift. The waste package pedestal, by contrast, supports the vertically oriented waste package in the WPTT and elevates the top of the waste package to the required height for closure operations. The waste package pedestal remains behind in the WPTT when the waste package is transferred to the TEV.

The trolley bears the weight of the shielded enclosure by a support structure and shaft. The shaft on the support structure allows the enclosure to tilt the waste package from vertical to horizontal orientation at the docking station. The enclosure is tilted by electric motor and gear assemblies (one on each side of the enclosure). The trolley travels from the Waste Package Loading Room to the Waste Package Positioning Room, and on to the Waste Package Loadout Room on crane rails. Power is provided to the WPTT by a third rail, which runs between the crane rails.

This equipment is shown in *CRCF-1 and IHF WP Transfer Trolley Mechanical Equipment Envelope Plan & Elevations–Sh 1 of 2* (Ref. 2.2.10) and *CRCF-1 and IHF WP Transfer Trolley Mechanical Equipment Envelope Elevation & Detail–Sheet 2* (Ref. 2.2.9).

## A3.5 WASTE PACKAGE POSITIONING ROOM AND WASTE PACKAGE CLOSURE ROOM

The Waste Package Positioning Room (Room 1006) provides a shielded location where the waste package in the WPTT rests during closure of the waste package. The room measures approximately 33 ft by 33 ft in plan, and the ceiling height is 26 ft 5 in. The walls are 4 ft thick reinforced concrete. The west and east walls have shield doors for the WPTT. The roof is a steel plate with an opening for access to the top of the waste package from the Waste Package Closure Room. The roof of this room is the floor of the Waste Package Closure Room.

The Waste Package Closure Room (Room 2004), houses waste package closure system equipment such as the RHS, remote manipulator arms, and robotic arms.

The following equipment is used in operations performed in the Waste Package Positioning Room or Waste Package Closure Room:

**Remote Handling System**

The RHS is part of the waste package closure system and is used to perform various lifting tasks associated with sealing and testing of the waste package. The RHS features an overhead bridge and a trolley with a telescoping vertical mast. The bridge runs on rails on the closure room walls. The trolley assembly, which runs along the bridge, has a telescoping mast that provides lifting capability. The mast can telescope down to the closure room floor and to the top of the waste package in the room below. The mast assembly has a rated load lifting capacity of 6,000 lbs. A rotary actuator is attached to the bottom of the mast. A tool plate allows the attachment of various tools.

The RHS uses the RHS manipulator arm for some operations. The arm is a standard industrial electromechanical manipulator with six degrees of freedom and a 220 lb payload capacity. It mates to the mast tool plate.

This equipment is described in *Component Design Description: Remote Handling System* (Ref. 2.2.61).

**Robotic Arms 1 and 2**

The robotic arms are the central feature of the robotic radiation-hardened arc-welding system, which is part of the waste package closure system. The robotic arms handle various end effectors to facilitate lid welding and weld inspection. The arms reach through the floor aperture to perform work on the top of the waste package, which rests below in the WPTT. Each arm is mounted on a circular bearing that is attached to the waste package closure room floor plate. The ends of the arms are equipped with quick-release connectors to interface with the various end effectors.

This equipment is described in *Component Design Description: Welding and Inspection System* (Ref. 2.2.74).

**Spread Ring and Spread Ring Expander Tool**

The spread ring is a part of the waste package and provides a means to secure the inner lid to the inner vessel. The spread ring expander tool is placed on the waste package by the RHS, and expands the spread ring by pushing radially outward.

**Waste Package Positioning Room Shield Doors 1 and 2**

The Waste Package Positioning Room shield doors provide personnel shielding and equipment and personnel access from the Waste Package Positioning Room to the Waste Package Loading Room to the east and the Waste Package Loadout Room to the west. The shield doors are dual swing-open type doors. Each door is operated by an electric motor with a worm-gear assembly attached to the door hinges. The shielding thickness may be up to 16 in. of steel.

This equipment is shown in *Nuclear Facilities Equipment Shield Door-Type 3 Mechanical Equipment Envelope* (Ref. 2.2.52).

## A3.6 WASTE PACKAGE LOADOUT ROOM

The Waste Package Loadout Room (Room 1005) provides a shielded location where loaded waste packages are transferred from the WPTT to the TEV. This room comprises the majority of the exterior concrete cell structure (i.e., the cells that are outside of the IHF steel building). The floor of the room steps up from elevation 0 ft to elevation 7 ft near the middle of the room to accommodate the interface between the WPTT and the TEV (the waste package transfer carriage docking station). The walls and roof are composed of 4 ft thick reinforced concrete for personnel shielding. The east wall has a shield door to the Waste Package Positioning Room and west wall has a shield door to the outside to allow access by the TEV and other vehicles. Personnel shield doors in the north and south walls allow access to the outside and to other areas of the building.

The following equipment is used in operations performed in the Waste Package Loadout Room:

**Waste Package Transfer Carriage**

The waste package transfer carriage is a steel plate with rollers on the bottom. When the shielded enclosure of the WPTT is in vertical orientation, the transfer carriage rides inside the enclosure alongside the waste package. When the enclosure is in horizontal orientation, the carriage supports the waste package pallet and waste package within the enclosure of the WPTT. A retrieval arm on the front of the carriage allows the carriage retrieval assembly, which is a component of the docking station, to pull the horizontally oriented carriage and waste package on its pallet out onto the docking station and into the TEV.

This equipment is shown in *CRCF-1 and IHF WP Transfer Trolley Mechanical Equipment Envelope Plan & Elevations–Sh 1 of 2* (Ref. 2.2.10) and *CRCF-1 and IHF WP XFR Carriage Docking Sta Mechanical Equipment Envelope Plan, Elevation, & Section* (Ref. 2.2.11).

**IHF Loadout Platforms 1 and 2**

The IHF loadout platforms are steel structures located in the Waste Package Loadout Room on either side of the rails for the WPTT. The platforms provide a single operating level for operators to access the top of the WPTT shielded enclosure when the trolley shielded enclosure is in the vertical position The function of the loadout platforms is to enable the verification of waste package location and installation of the waste package shield ring on the empty waste package.

This equipment is shown in *Initial Handling Facility Loadout Platform Mechanical Equipment Envelope* (Ref. 2.2.34).

**Waste Package Handling Crane**

The waste package handling crane is used to load empty waste packages onto the waste package transfer carriage, and for waste package loadout preparation operations, notably including removal of the waste package shield ring from atop the WPTT. The waste package handling crane is a top-running double girder bridge crane with a top-running trolley. The main hoist is rated at 100 tons with an auxiliary hook rated at 30 tons.

This equipment is shown in *Initial Handling Facility WP Handling Crane Mechanical Equipment Envelope* (Ref. 2.2.49).

# ATTACHMENT B
# OPERATIONAL SUMMARY

## B1 INTRODUCTION

A summary of IHF operations is presented to provide the context within which the event sequences were developed. The description of operations in Section 6.1 and this attachment 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. The PFD was developed while preparing for the HAZOP evaluation because this is a precondition for conducting a HAZOP evaluation. Furthermore, the specific processes described in Section 6.1 and this attachment emerged during the HAZOP meetings and subsequent discussions among the above parties. This multidisciplinary effort was led by the Preclosure Safety Analysis group and is documented herein.

## B2 FACILITY OVERVIEW

This attachment describes the mechanical handling operation in the IHF from receipt of HLW and naval SNF canisters in a transportation cask to export of canisters in waste packages. These operations are presented according to the nodes of the IHF PFD, Figure 15. The major pieces of mechanical handling equipment, including overhead bridge cranes, the CTT, the 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. Furthermore, all personnel involved in handling transportation casks and their contents have the proper training commensurate with nuclear industry standards. This training is followed by a period of observation until the operator is proficient in assigned duties.

## B3 NODE 1: RECEIPT OF LOADED CASK IN CASK PREPARATION AREA

### Pre-Job Plan

Before the cask and conveyance reach the IHF, a certified crew member is notified of the type of cask and conveyance to expect. According to this information, the crew member determines the appropriate procedures and equipment to use to process this cask type. The crew member also communicates this information to all the crew members involved in the handling of this cask. The set-up activities that are required before arrival of the conveyance are not described here.

### Move Carrier into Cask Preparation Area and Stabilize for Unloading

- Members of the crew are stationed at the entrance of the IHF to facilitate movement of the transportation cask into the IHF. The transportation cask, whether on a railcar or truck, is conveyed to the IHF by the SPM. (The SPM runs on either rail or road.)
- Once the railcar or truck trailer reaches the facility, the crew opens the overhead door and directs the conveyance into the IHF Cask Preparation Area.

- Once the conveyance is in the Cask Preparation Area the crew sets the conveyance brakes and chocks the wheels.

- **Special Additional Procedure Applicable for Naval Casks Only** - After the railcar conveyance carrying the naval spent fuel canister cask is parked in the IHF Cask Preparation Area, the crew stabilizes the conveyance by lowering the hydraulic leveling jacks and securing the tie-downs.

**Remove Site Prime Mover from Cask Preparation Area**

- Once the conveyance brakes are set, the SPM detaches from the railcar or transport truck conveyance and leaves the facility. Once the SPM has departed, the overhead door is closed.

**Remove and Store Personnel Barrier (If Present)**

The personnel barrier, if present, is removed and stored using the cask preparation crane with personnel barrier lifting device, common tools, 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. After the crew members are positioned a safe distance away from the cask conveyance, 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 vertically
- Crane operator moves personnel barrier to position for lowering
- Crane operator lowers personnel barrier and the crew detaches rigging.

## B4 NODE 2: REMOVE IMPACT LIMITERS (HIGH LEVEL RADIOACTIVE WASTE ONLY)

The impact limiters are removed and stored using the cask preparation crane with the impact limiter lifting device, common tools, and the mobile access platform. This procedure is performed twice because each HLW cask has two impact limiters.

In preparation for removal of the impact limiters, the crew attaches the impact limiter lifting device to the cask preparation crane and unbolts the restraining bolts on the impact limiters. The crane operator, using the cask preparation crane, 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 vertically
- Crane operator moves impact limiter to position for lowering
- Crane operator lowers impact limiter and disengages.

## B5 NODES 3-5: CASK UPENDING AND REMOVAL FROM CONVEYANCE

For all waste forms, the cask is upended and placed vertically into the CTT. For this operation, the CTT with proper cask pedestal is pre-staged in the IHF Cask Preparation Area. The naval cask does not require a removable pedestal. HLW casks require a removable pedestal to be fitted into the bottom of the CTT.

### Node 3: Prepare Cask for Upending

To prepare the casks for upending, the naval cask requires several fixtures to be attached to the cask and/or conveyance, including attaching the lifting bail, which is used to upend and lift the cask; the HLW requires the cask handling yoke to be attached to the cask and the cask handling crane. Once the cask is ready to be upended, the crew removes the cask tie-downs. The crew removes all the bolts of the tie-down, with several crew members removing bolts simultaneously. For the naval cask, the clamps are also removed.

- **Special Procedure for Installing Fixtures Necessary for Pivot of Naval Cask**–Using standard crane operations for the cask preparation crane, the crew installs the pivot adapter (if not already installed) and the cask lifting plate. (The qualifier "if not already installed" is used because operational details involving the naval cask are not yet known with certainty.) The crew then uses the cask handling crane to attach the lifting bail to the cask. These operations are performed using the mobile access platform. The specific steps are as follows:

  – Crane operator moves cask preparation crane to pivot adapter position
  – Crane operator aligns crane to pivot adapter and crew attaches rigging
  – Crane operator lifts the pivot adapter vertically
  – Crane operator moves pivot adapter to position over the conveyance
  – Crane operator lowers pivot adapter and disengages
  – Crew fastens pivot adapter to conveyance/cask with pivot pin
  – Crane operator moves cask preparation crane to cask lifting plate position
  – Crane operator aligns crane to cask lifting plate and crew attaches rigging
  – Crane operator lifts the cask lifting plate vertically
  – Crane operator moves cask lifting plate to position over the cask
  – Crane operator lowers cask lifting plate and disengages
  – Crew bolts lifting plate to cask
  – Crane operator switches cranes and moves cask handling crane to lifting bail position
  – Crane operator aligns crane to lifting bail
  – Crew attaches crane to lifting bail
  – Crane operator lifts the lifting bail vertically
  – Crane operator moves lifting bail to position over the cask
  – Crane operator lowers cask lifting plate and, without disengaging from the crane, attaches lifting bail to the cask.

- **Special Procedure for Installing Fixtures Necessary for Pivot of HLW**–To upend the cask containing HLW, the crew uses the mobile access platform to attach the cask handling crane, with cask handling yoke, to the cask 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

**Node 4: Upend Transportation Cask on Conveyance**

The crane operator upends the transportation cask using the 300-ton cask handling crane with yoke (HLW) or lifting bail (naval). As needed, depending on the cask type, the crew then uses common tools and the mobile access platform to unbolt the constraints on the bottom half of the cask so the cask can be lifted.

**Node 5: Move Loaded Cask from Conveyance to CTT in Cask Preparation Area**

The crane operator uses the cask handling crane, which is already attached to the cask, to move the cask from the conveyance to the CTT, which is stationed under the cask preparation platform. Once the cask is properly loaded in the CTT, the crewmember secures the cask to the CTT. Once the cask is secure in the CTT, the crew disengages the cask from the crane.

## B6 NODE 6: HIGH LEVEL RADIOACTIVE WASTE CASK PREPARATION ACTIVITIES (HIGH LEVEL RADIOACTIVE WASTE ONLY)

Preparation of a HLW cask involves gas sampling (if required) and preparation for lid removal by the CTM (remove lid bolts and attach cask lid adapter). (The qualifier "if required" is used because operational details involving the HLW cask are not yet known with certainty.)

**Gas Sampling and Equalization**

Although gas sampling is not anticipated to be required for normal operations, the ability to sample casks cavity gas is included in the design. To sample the cask, a crewmember must plug a hose into the quick-disconnect sampling port and then open the valve to start flow. Once connected, a crew member takes a reading in the Gas Sampling Room of gas that is being removed. After the sample is taken, the remainder of the gas is vented, the valve closed and the hose disconnected and removed. Because this step is not anticipated to be required for normal operations, further details of the sampling operation have not been established.

**Lid Preparation**

The crew uses common tools and the cask preparation platform to remove all the cask lid bolts. Once the bolts are removed, the crane operator and crew use the cask preparation platform, common tools and the cask preparation crane with standard rigging, to retrieve and emplace the proper lid lifting fixture. The following specific steps are involved in lid preparation:

- Crane operator selects and retrieves appropriate lid lift fixture with cask preparation crane. There are two lid lift fixtures available: one for a rail cask and the other for a truck cask

- Crane operator moves lid lift fixture to cask

- Crane operator lowers lid lift fixture and disengages

- Crew members bolt lid lift fixture to cask lid. Using the cask preparation platform and common tools, crewmembers emplace and tighten the fixture bolts.

## B7 NODE 7: NAVAL CASK PREPARATION ACTIVITIES (NAVY ONLY)

Preparation of a naval cask involves removing the upper impact limiter and lifting plate, the cask lid and the canister restraints, and then attaching the canister lift adapter. Gas sampling may also be performed (if required). (The qualifier "if required" is used because operational details involving the naval cask are not yet known with certainty.)

**Remove Upper Impact Limiter with Lifting Plate and Stage on Conveyance**

Without detaching the crane/lifting bail from the lifting plate, the crew unbolts the impact limiter and, using the cask handling crane, removes the upper impact limiter and lifting plate.

**Remove Transportation Cask Lid and Lid on Cask Lid Stand**

The crew uses common tools and the cask preparation platform to remove all the cask lid bolts. Once the bolts are removed, the crew uses the cask preparation crane to remove the transportation cask lid and store it on the lid stand. The following specific steps are performed:

- Crane operator aligns cask preparation crane to cask and engages grapple
- Crane operator lifts the lid vertically
- Crane operator moves lid to staging area.

**Remove Canister Restraints**

Using common tools and the cask preparation platform, the crew removes the canister restraint segments in four steps: 1) retract all shear ring jack bolts; 2) disengage all backing ring fasteners; 3) remove all backing ring segments; and, 4) remove all shear ring segments. The segments are removed as follows:

- Crane operator removes restraint segment. The crane operator lowers the cask handling crane into position over the restraint segment and engages the sling. To remove the canister restrain segments, the crane operator, starting with the middle segment, slides the segment radially inward and then removes the segment

- Crane operator moves restraint segment to staging area. The crane operator moves the segment to its proper location, lowers it, disengages the sling and returns to the cask to retrieve the remaining segments.

**Attach Naval Canister Lifting Adapter to Canister**

The crew uses the cask preparation crane with standard rigging to retrieve and emplace the naval canister lifting device. Once emplaced, the crew bolts (torque) the device to the naval canister and shield ring. These operations are done on the cask preparation platform. The naval transportation cask is received with the naval cask shield ring already installed. The shield ring protects the crew members from direct exposure during this operation.

The steps in moving the lift fixture are as follows:

- Crane operator retrieves naval canister lift fixture with cask preparation crane
- Crane operator moves naval canister lift fixture to cask
- Crane operator lowers naval canister lift fixture and disengages.

## B8 NODE 8: TRANSFER TRANSPORTATON CASK ON CASK TRANSFER TROLLEY FROM CASK PREPARATION AREA TO CASK UNLOADING ROOM

Using the CTT, the crew moves the transportation cask from the Cask Preparation Area to the Cask Unloading Room and positions the cask under the cask port. The steps here are the same for all waste forms. To do this, the crew moves the CTT to the Cask Preparation Room door, opens the shield door, moves the CTT through the door in position under the cask port, disconnects the air hoses, and closes the shield door.

## B9 NODES 9-11: TRANSFER A CANISTER INTO A WASTE PACKAGE WITH THE CANISTER TRANSFER MACHINE

Using the CTM, the crew removes a HLW canister or naval canister from a transportation cask, raises it through the cask port into the CTM, moves it horizontally to the waste package port, and lowers it into a waste package, then prepares the waste package for closure. CTM operations are performed remotely from a control room within the IHF.

**Remove Cask Lid (HLW Only)**

Prior to transferring a HLW canister to the waste package, the lid of the HLW transportation cask must be removed follows:

- Move CTM to cask port and lower the shield skirt.
- Open CTM slide gate and cask port slide gate
- Lift cask lid into CTM and close cask port slide gate
- Bypass the slide gate interlock and lift the skirt in preparation for movement. (The interlock prevents lifting the shield skirt unless the CTM slide gate is closed. It must be bypassed because the cask lid cannot be lifted high enough to allow the CTM slide gate to be closed.)
- Move CTM to CTM maintenance area and place transportation cask lid on transfer staging stand
- Lower lid to lid station, disengage grapple and reengage bypass.

**Move Canister from Transportation Cask to Waste Package**

Using the CTM, the crew raises a HLW canister or naval canister from a transportation cask through the cask port, moves it horizontally to the waste package port, and lowers it into a waste package. Several HLW canisters are necessary to fill a waste package, and so, for HLW, this process of moving canisters from the transportation cask to the waste package must be repeated until the waste package is full. The steps in moving the canister from the transportation cask to the waste package are as follows:

- Install appropriate canister grapple – The CTM operator moves the CTM from the lid station to the CTM Maintenance Area 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 and lower the 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
- Lift shield skirt and move CTM to waste package port

- Lower shield skirt and open CTM slide gate and waste package port slide gate
- Lower canister into waste package
- Close CTM slide gate and waste package port slide gate.

## B10 NODE 12: MOVEMENT OF LOADED WASTE PACKAGE TRANSFER TROLLEY FROM THE WASTE PACKAGE LOADING ROOM TO THE WASTE PACKAGE POSITIONING ROOM

The WPTT carries the loaded waste package from the Waste Package Loading Room to the Waste Package Positioning Room. Prior to moving the waste package, the naval canister lifting device and shield ring must be removed from the naval canister, and the waste package inner lid and spread ring must be inserted into the waste package for both waste forms.

**Remove Naval Canister Lift Device and Shield Ring (Naval Canister Only)**

In order to close the waste package, the shield ring and canister lifting device must be removed from the naval canister using the CTM with the following steps:

- Move CTM away from port gate
- Unbolt the shield ring and lift adapter from naval canister
- Move CTM to waste package port slide gate, lower hoist, engage grapple and remove shield ring/canister lift adapter from waste package
- Close CTM slide gate and waste package port slide gate
- Move CTM to cask port and place lift adapter and shield ring into the empty transportation cask.

**Prepare Waste Package to Leave Waste Package Loading Room**

Once the waste package is loaded, the waste package inner lid and spread ring must be installed before the waste package can be moved out of the transfer cell. The CTM is used to do the following steps:

- Move CTM to waste package inner lid station and open the CTM slide gate
- Lift waste package inner lid and spread ring into CTM and position the CTM over the waste package port
- Open waste package port slide gate and place waste package inner lid and spread ring in waste package
- Close CTM slide gate and waste package port slide gate.

**Move Loaded Waste Package to Waste Package Positioning Room**

The WPTT carries the loaded waste package from the Waste Package Loading Room to the Waste Package Positioning Room. To do this, an operator, stationed remotely in a control room within the IHF, opens the shield door and signals the WPTT to move. The operator can only start the WPTT movement or make it stop. Once the WPTT has cleared the doorway, the operator closes the shield door and the WPTT proceeds to its proper position underneath the Waste Package Closure Room, ready for waste package closure activities.

## B11 NODE 13: CLOSURE OF THE WASTE PACKAGE

The waste package is closed in preparation for emplacement in the repository. Closure activity includes welding the inner lid, inerting the waste package, and installing and welding the outer lid. All closure activities are performed remotely and there are no personnel in the Waste Package Closure Room during these operations.

**Seal the Inner Lid**

The spread ring is expanded for the seal weld using the spread ring expander tool with the RHS and a camera. The spread ring is seal welded to the inner vessel and inner lid. This is followed by a nondestructive evaluation (NDE). Robotic arm operators use the robotic arm to do the actual welding.

**Inert Waste Package and Perform Leak Test at Spread Ring and Purge Port Plug**

The RHS operator remotely retrieves the purge port tool and places it on top of the purge port. The crew uses the tool to evacuate the inner vessel and backfill the vessel with helium.

**Seal Waste Package**

The crew retrieves the purge port cap and places it onto the purge port. The crew then welds the cap in place. Once the cap is welded, the crew dresses the weld.

Once the purge port cap is on, the crew proceeds to install the outer lid. The crew retrieves the lid, engages the lid grapple, moves the lid to the proper position and then disengages the grapple. The crew then welds the outer lid.

## B12 NODE 14: EXPORT LOADED WASTE PACKAGE

**Move Waste Package on WPTT from Positioning Room to Loadout Room**

The waste package is moved from the Waste Package Positioning Room to the Waste Package Loadout Room. This step concludes with the waste package in the Loadout Area, ready to be placed in the TEV for export. This step is performed remotely. The operator opens the Waste Package Positioning Room shield door and moves the WPTT (on rails) to the docking station in the Waste Package Loadout Room. Once the WPTT has cleared the door, an operator closes the Waste Package Positioning Room shield door. At the end of its travel, the WPTT automatically locks into the docking station.

**Remove Waste Package Shield Ring and Move to Waste Package Shield Ring Stand**

Using the waste package handling crane, the operator removes the shield ring from its position surrounding the top of the waste package in the WPTT.

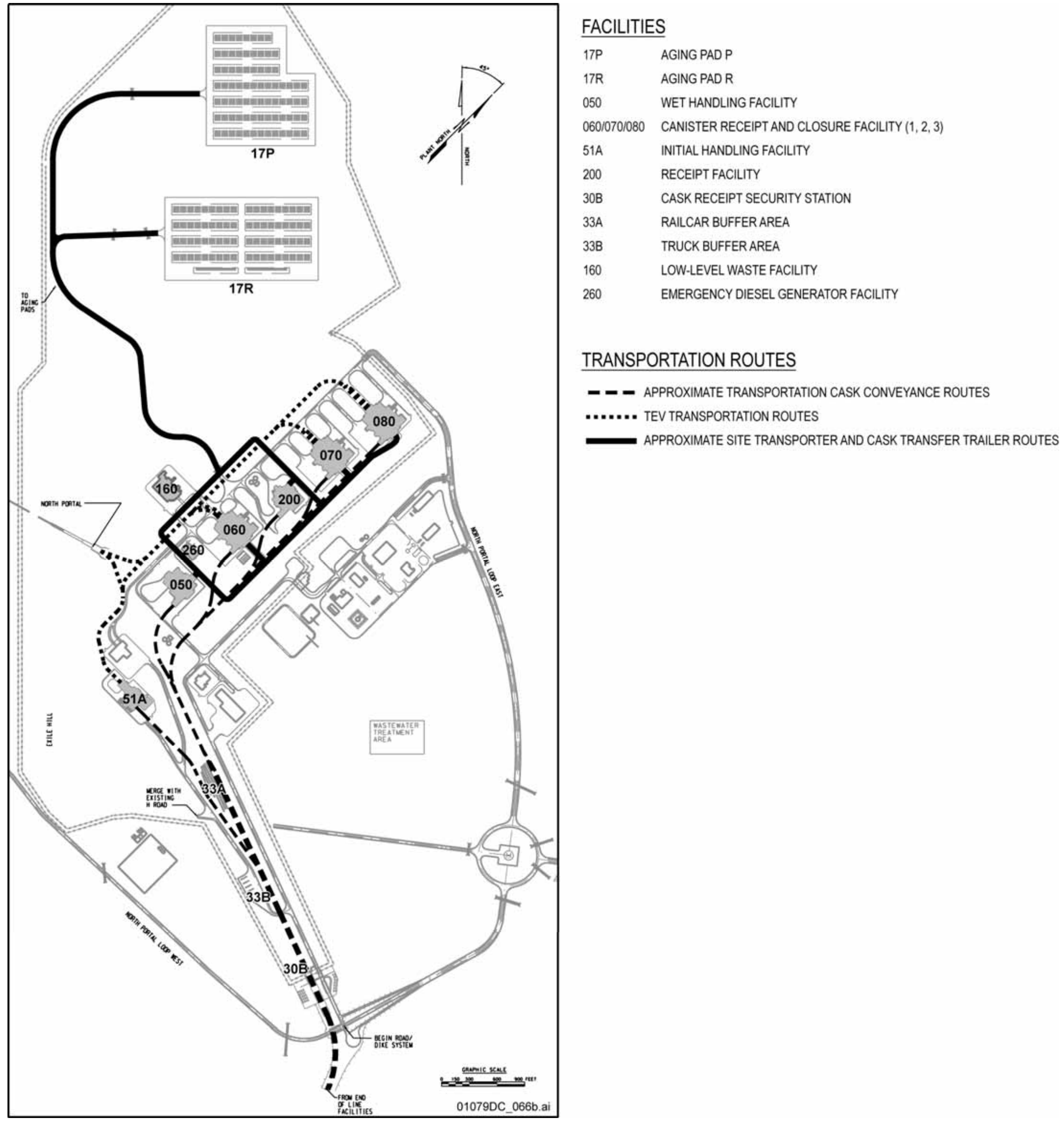
**Rotate WPTT Horizontal and Load Waste Package into TEV**

Because the following steps are performed remotely, the operator must ensure that the Waste Package Loadout Room is clear of personnel before initiating these steps. The TEV is pre-staged in the Loadout Room with its shield doors open, base plate extended and shielded enclosure lowered. The operator signals the WPTT to tilt down the waste package. Tilting down the waste package causes the retrieval assembly within the docking station to engage the waste package transfer carriage. The retrieval assembly then pulls the waste package transfer carriage from the shielded enclosure of the WPTT into the shielded enclosure of the TEV. The waste package is visually inspected via camera for defects while it is loaded into the TEV.

Although the following steps are outside the scope of this analysis (as noted in Section 1), they are provided here to indicate how the IHF interfaces with the subsurface. Once the waste package has been moved completely into the shielded enclosure of the TEV, the operator signals the TEV to pick up the waste package by lifting the shielded enclosure. Once the shielded enclosure is lifted, the TEV base plate retracts and the shield door automatically closes and locks into the base plate. Once the TEV is fully loaded and secured, the operator signals the facility door to open and the TEV to exit the facility.

# ATTACHMENT C
# INITIAL HANDLING FACILITY LOCATION WITHIN THE GEOLOGIC REPOSITORY OPERATIONS AREA

The IHF is one of four waste-handling building types (Ref. 2.2.56). Figure C-1 displays the location of the IHF and other major facilities within the GROA. The IHF is designed to receive naval and HLW transportation casks, remove the waste-bearing canister (or canisters) from the casks, transfer the waste into waste packages, close the waste packages, and send them underground. The IHF is the only one of the waste handling facilities that is designed to receive naval transportation casks. Waste leaves the IHF only in a waste package destined for emplacement underground.




NOTE: TEV = transport and emplacement vehicle.

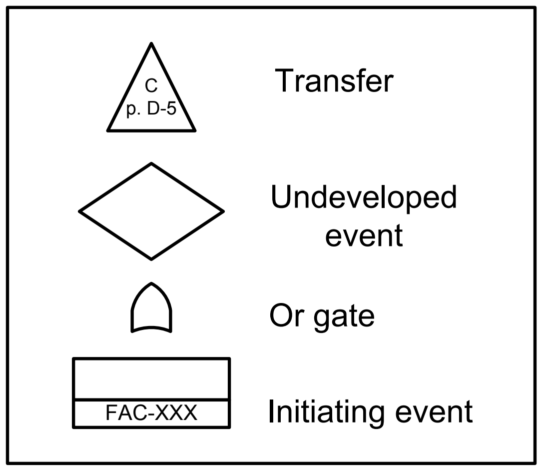
Source: Modified from (Ref. 2.2.56) and (Ref. 2.2.57).

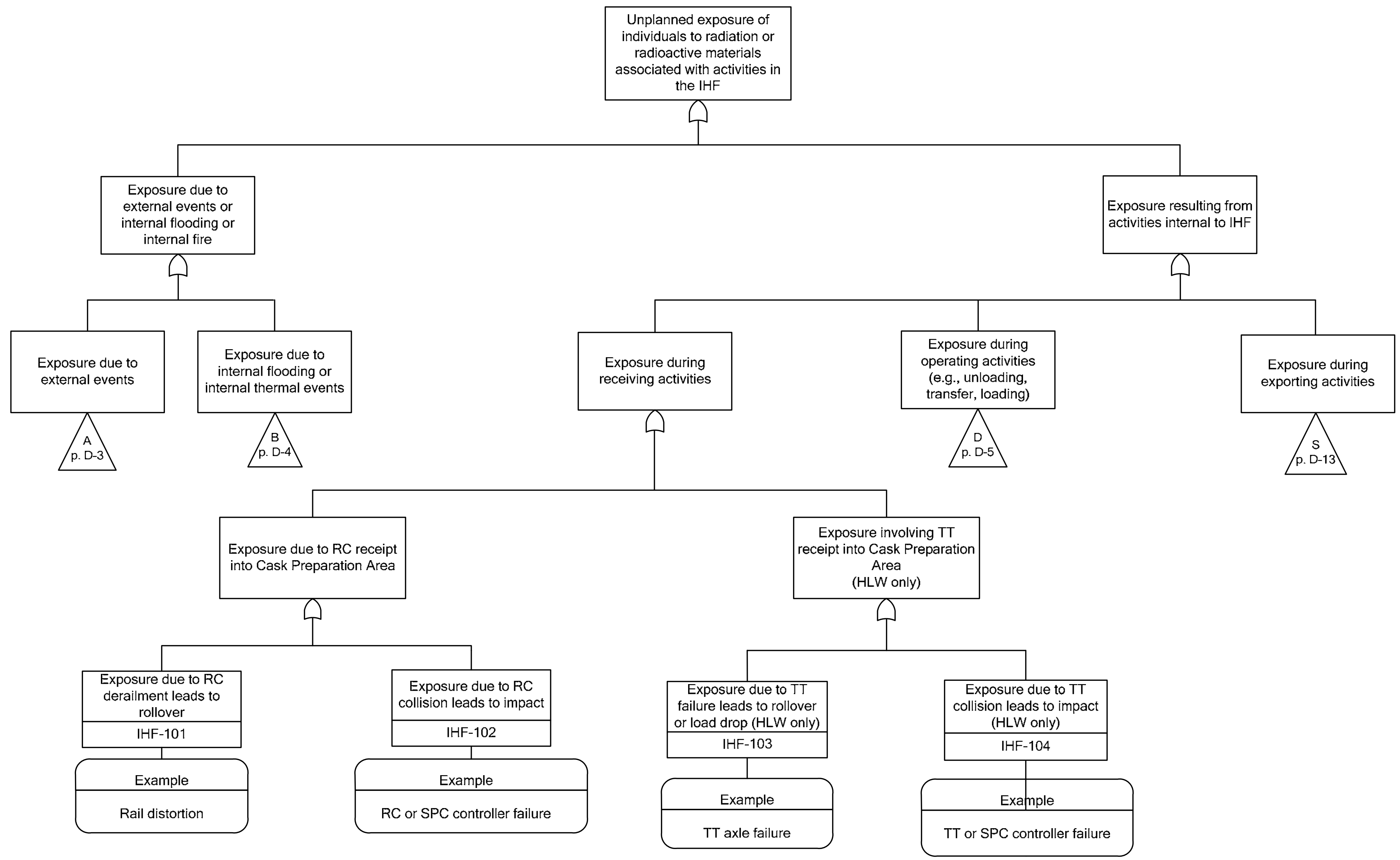
Figure C-1 Facility Locations within the Geologic Repository Operations Area

# ATTACHMENT D
# MASTER LOGIC DIAGRAM

The MLD for the Initial Handling Facility is presented in Figures D-1 through D-12. The legend for the figures is shown below.

Legend

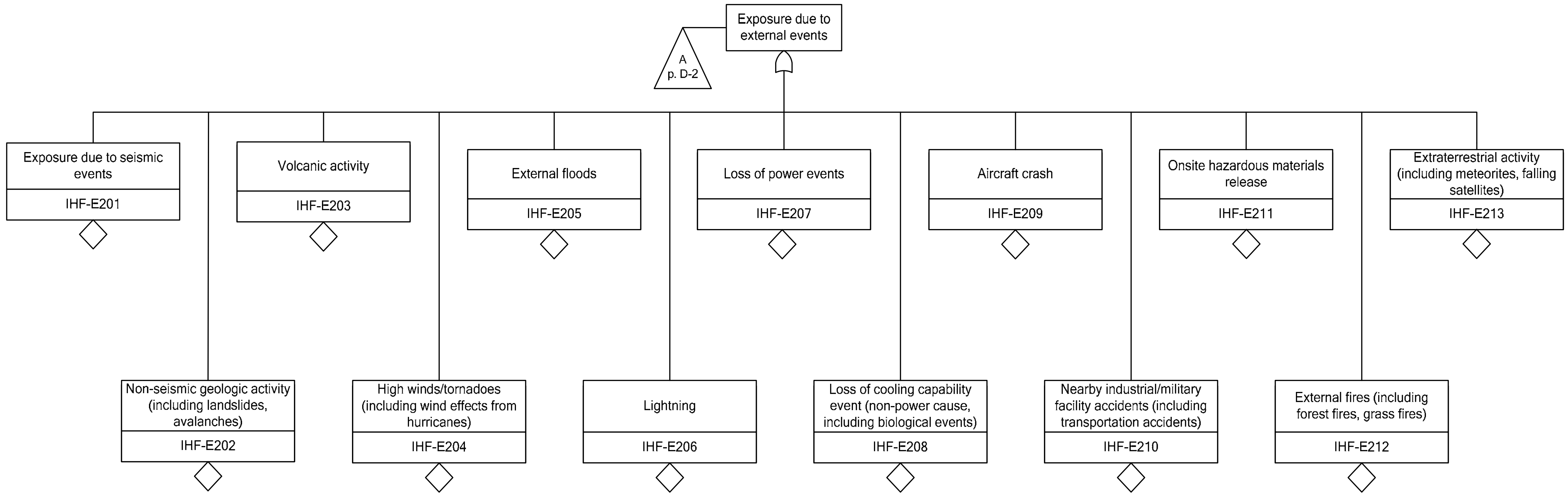





NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
IHF = Initial Handling Facility; MAP = mobile access platform; RC = railcar; TT= truck trailer.

Source: Original

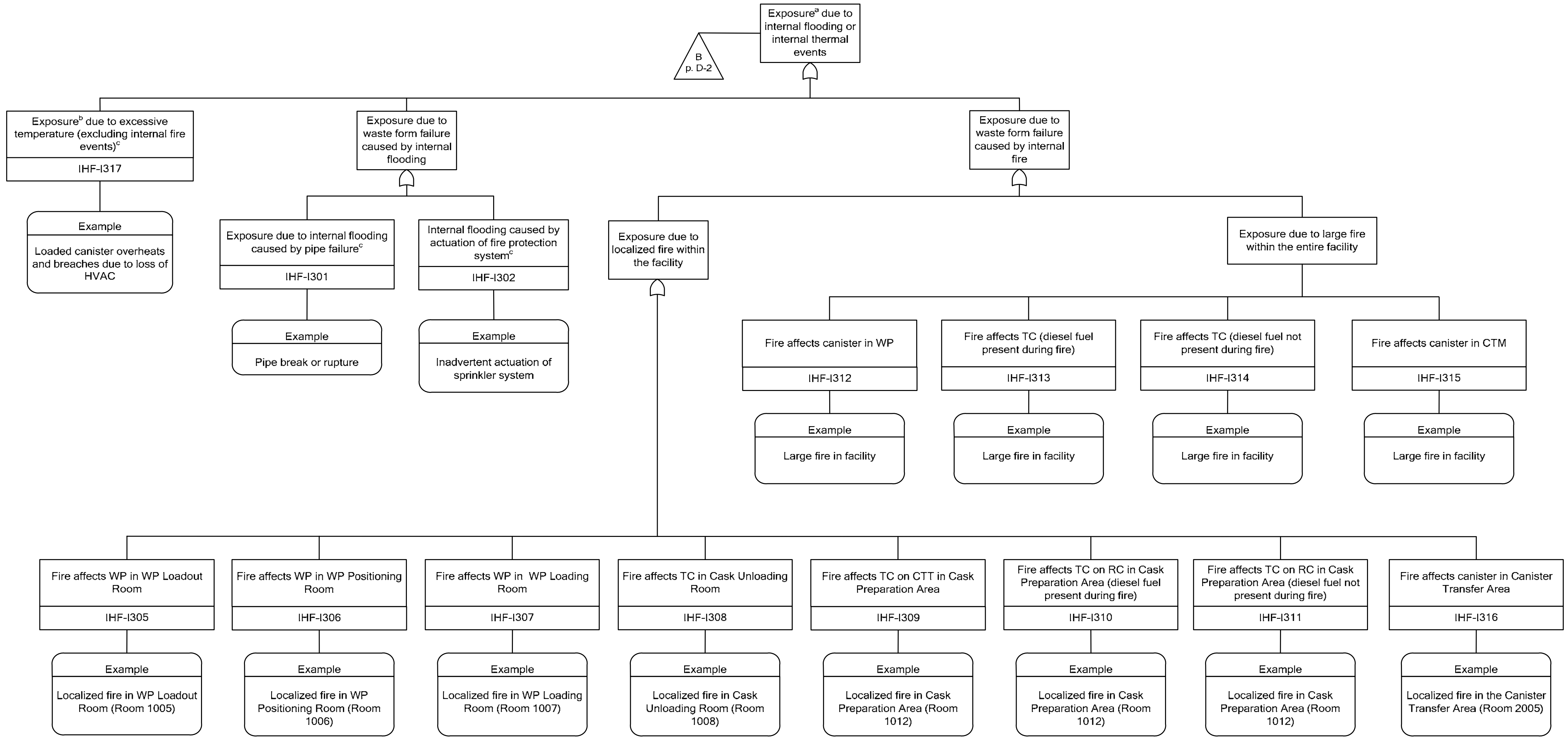
Figure D-1. Unplanned Exposure of Individuals to Radiation or Radioactive Materials Associated with Activities in the IHF




NOTS: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
These external events are analyzed in the *Monitored Geologic Repository External Events Hazards Screening Analysis* (Ref. 2.2.5).
IHF = Initial Handling Facility.

Source: Original

Figure D-2. Exposure Due to External Events




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

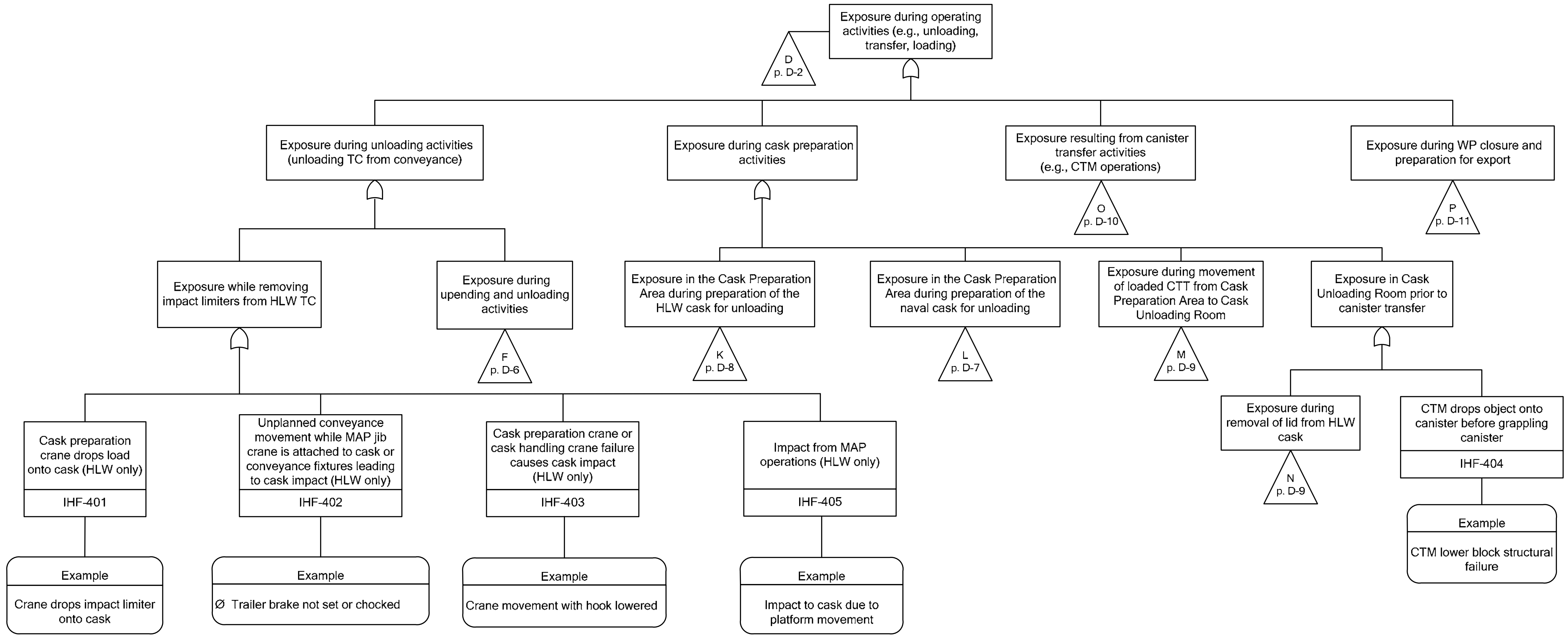
[b] Non-fire thermal event sequences have not been developed because naval or HLW canisters in the IHF experiencing a loss of HVAC flow would not reach a high enough temperature to jeopardize the structural integrity of the canister. A steady-state thermal calculation shows that a loss of ventilation in the IHF would not lead to a naval canister surface temperature in excess of 400 °F (*Canister Temperatures in IHF* (Ref. 2.2.8), Section 7). The surface temperature limit for the naval canisters is intended to protect the naval SNF inside the canister and is far below temperatures that would jeopardize the structural integrity of the canister. The thermal calculation uses 11.8 kW as the thermal output of a naval canister. A limiting thermal output of HLW canisters is 1.5 kW for short and long canisters (*Waste Acceptance System Requirements Document* (Ref. 2.2. 65, Section 4.8.13)). The combined thermal output of five canisters at 1.5 kW each is 7.5 kW. Therefore, the heat output of a cask or waste package containing 5 HLW canisters is less than that of the naval canister modeled in the thermal calculation cited. With lower heat output spread among five canisters in a waste package or cask, it is apparent that the maximum temperature reached by HLW canisters in the IHF would be comparable to the maximum temperature reached by a naval canister and far below temperatures that would jeopardize the structural integrity of the HLW canisters. For normal operations, the vitrified glass waste form in the HLW canisters is limited to 400 °C (*Basis of Design for the TAD Canister-Based Repository Design Concept*, (Ref. 2.2.7), Sections 3.2.2.5.13, 11.2.2.23).

The potential for internal flooding as an initiating event is covered in *IHF Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1).

[c] CTM = canister transfer machine; CTT = cask transfer trolley; HLW = high-level radioactive waste; HVAC = heating, ventilation, and air conditioning; IHF = Initial Handling Facility; RC = railcar; SNF = spent nuclear fuel; TC = transportation cask; WP = waste package.

Source: Original

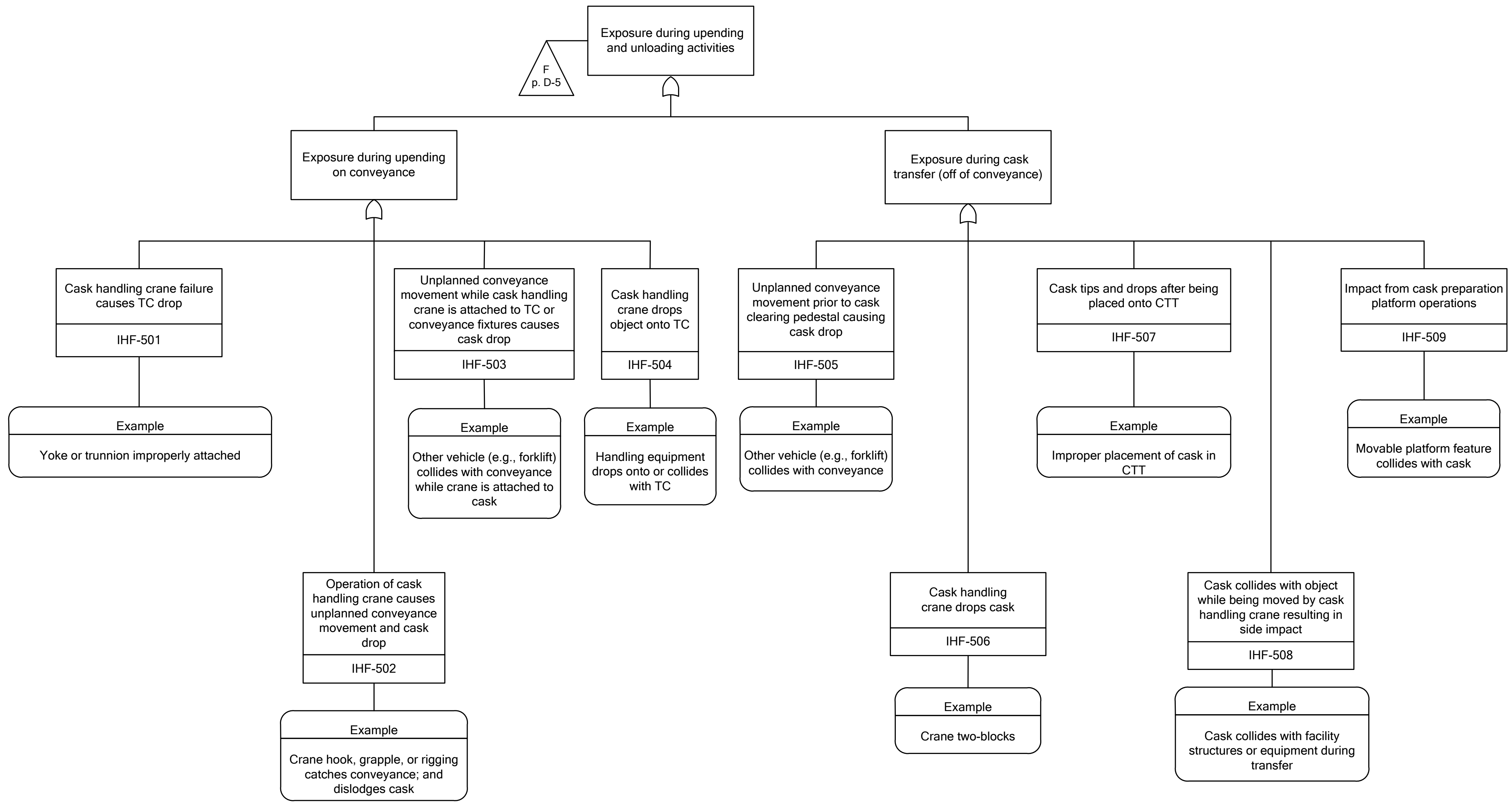
Figure D-3. Exposure Due to Internal Flooding or Internal Thermal Events




NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
CTM = canister transfer machine; CTT = cask transfer trolley; HLW = high-level radioactive waste; IHF = Initial Handling Facility; MAP = mobile access platform; TC = transportation cask; WP = waste package.

Source: Original

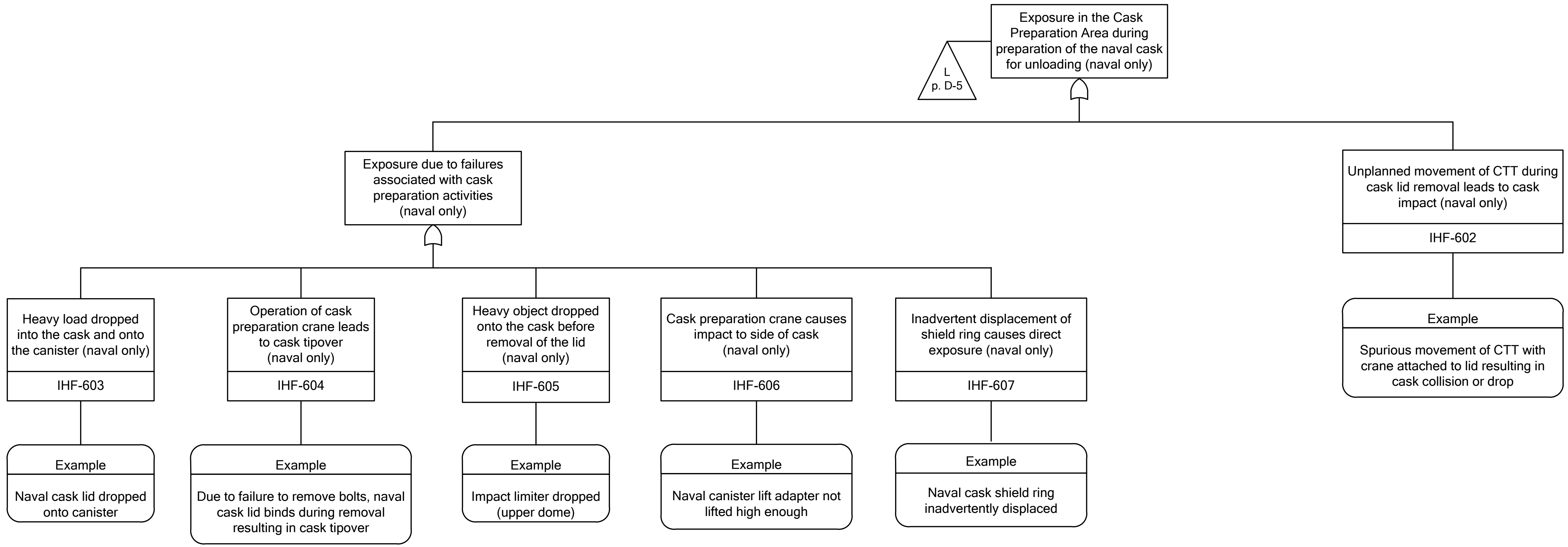
Figure D-4. Exposure during Operating Activities (e.g., unloading, transfer, loading)




NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
CTT = cask transfer trolley; IHF = Initial Handling Facility; MAP = mobile access platform; TC = transportation cask.

Source: Original

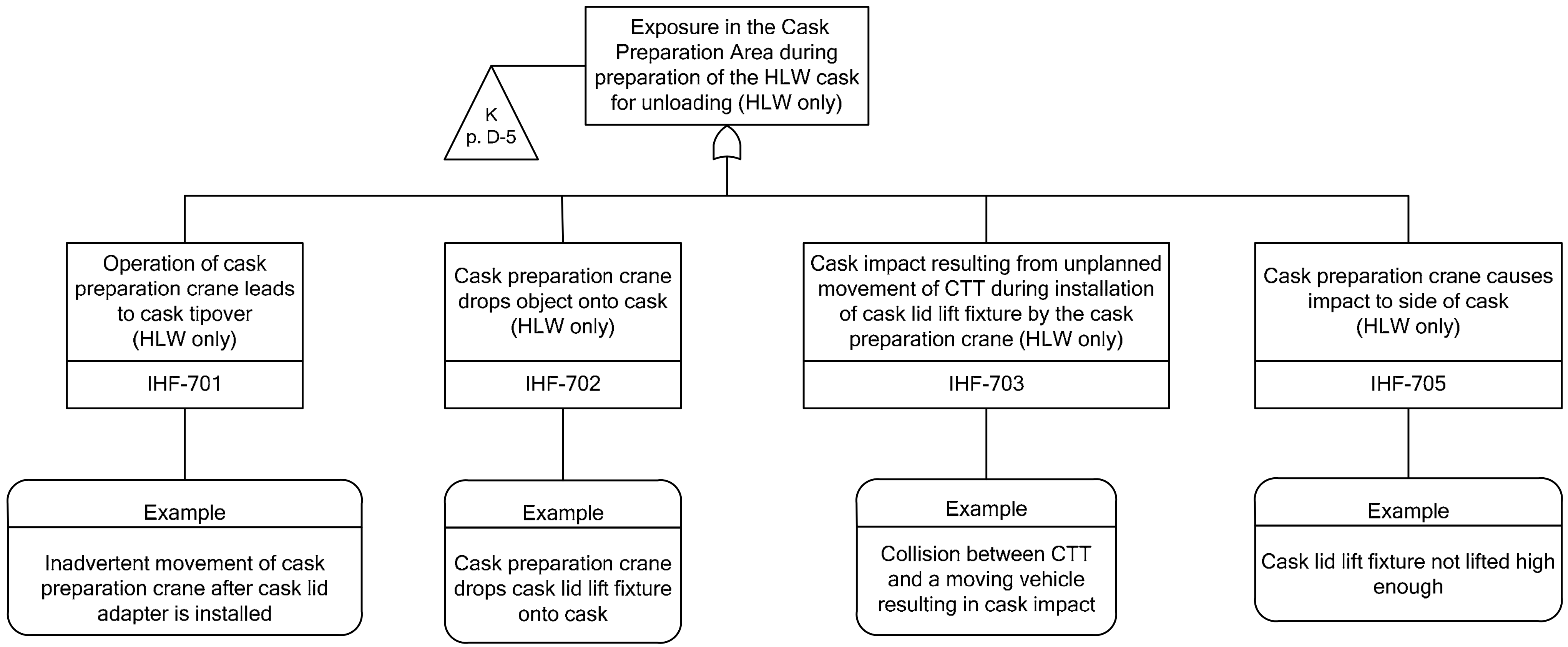
Figure D-5. Exposure during Upending and Unloading Activities




NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
CTT = cask transfer trolley; IHF = Initial Handling Facility.

Source: Original

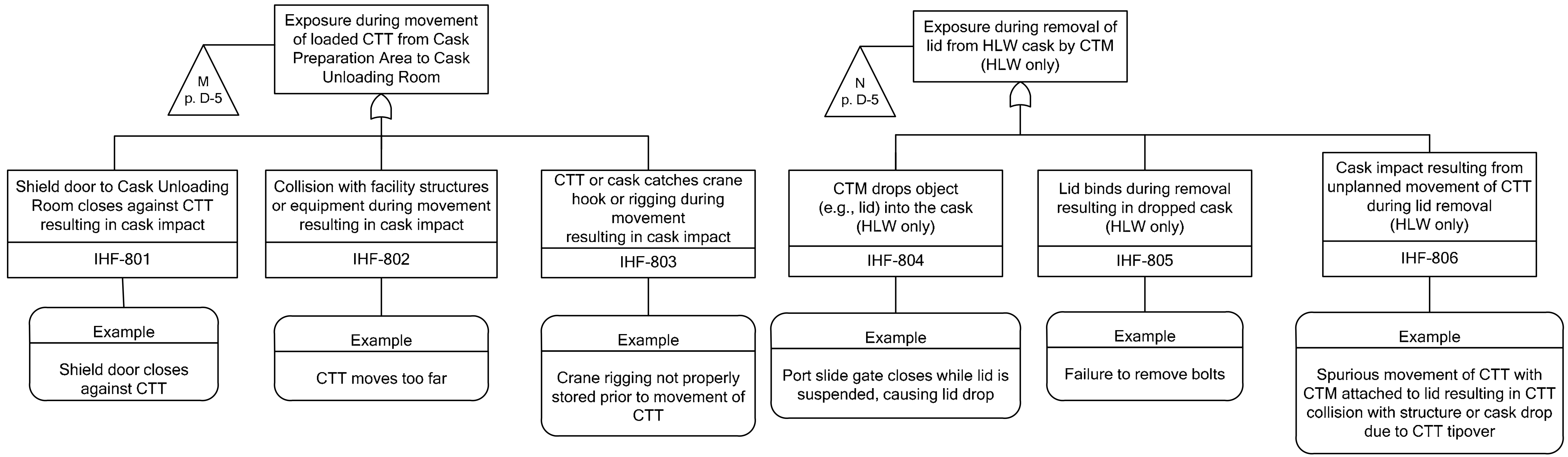
Figure D-6. Exposure in the Cask Preparation Area during Preparation of the Naval Cask for Unloading




NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
CTT = cask transfer trolley; HLW = high-level radioactive waste; IHF = Initial Handling Facility.

Source: Original

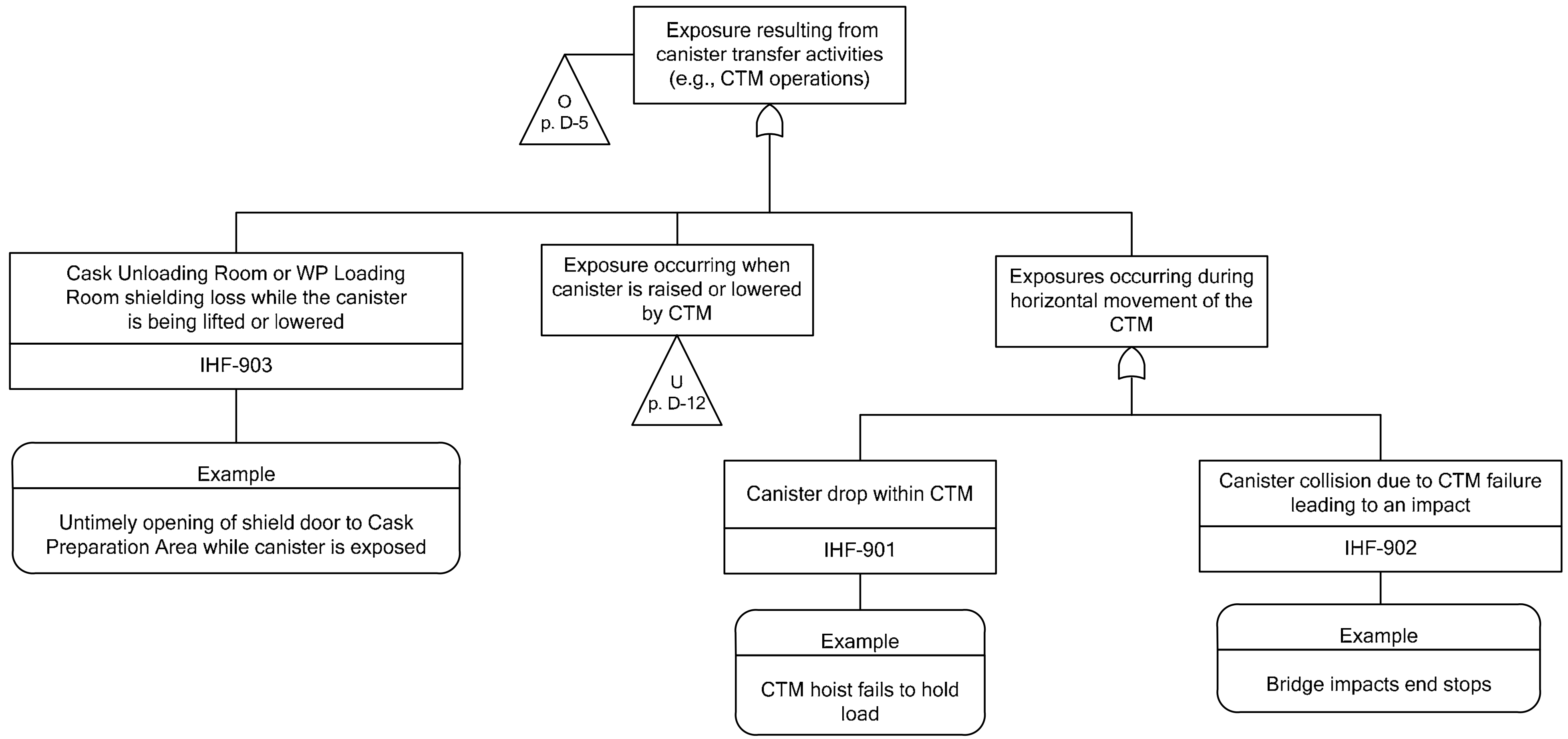
Figure D-7. Exposure in the Cask Preparation Area during Preparation of the HLW Cask for Unloading




NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
CTM = canister transfer machine; CTT = cask transfer trolley; HLW = high-level radioactive waste; IHF = Initial Handling Facility.

Source: Original

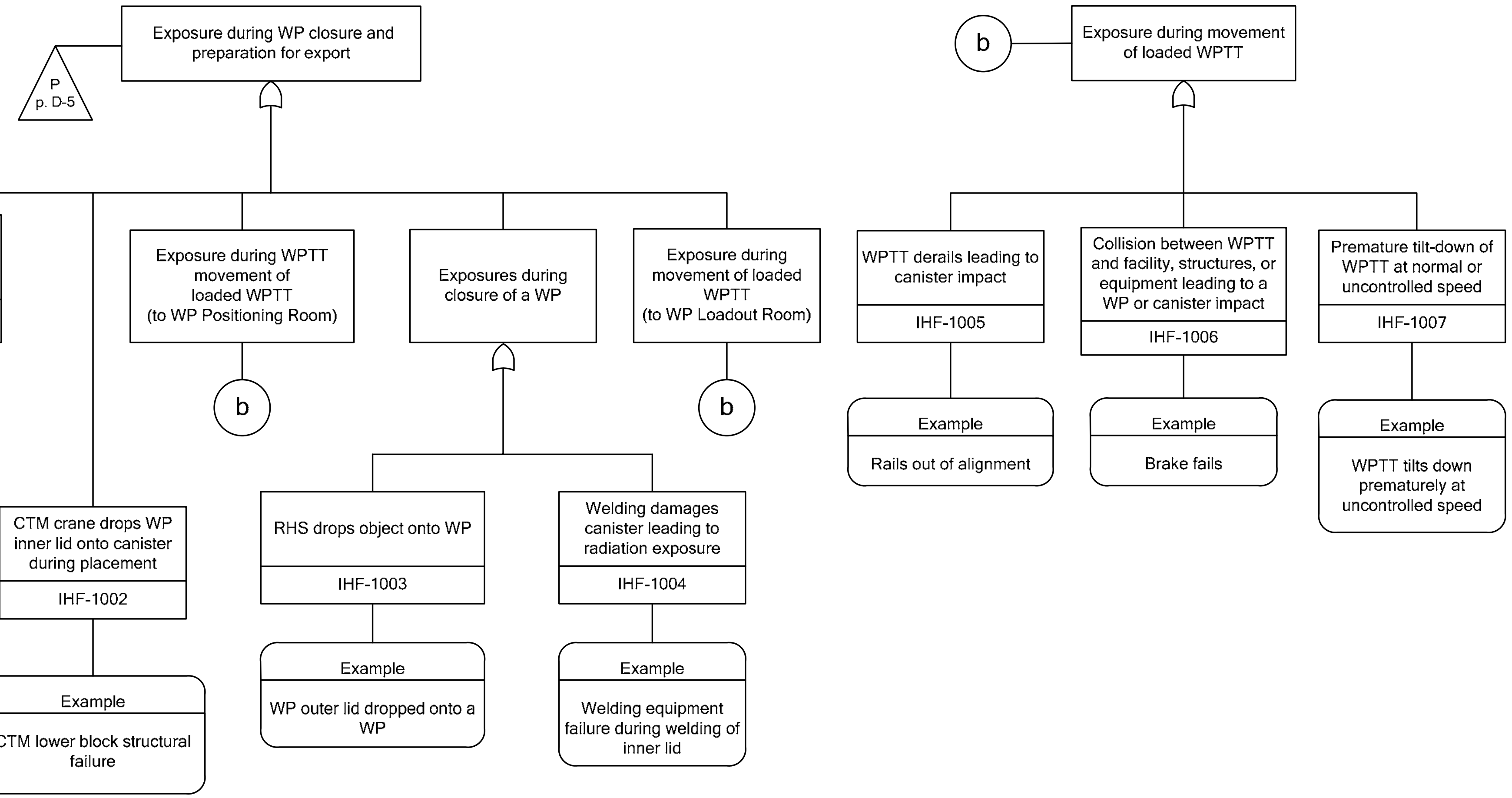
Figure D-8. Exposure during Removal of Lid from HLW Cask




NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
CTM = canister transfer machine; IHF = Initial Handling Facility; WP = waste package.

Source: Original

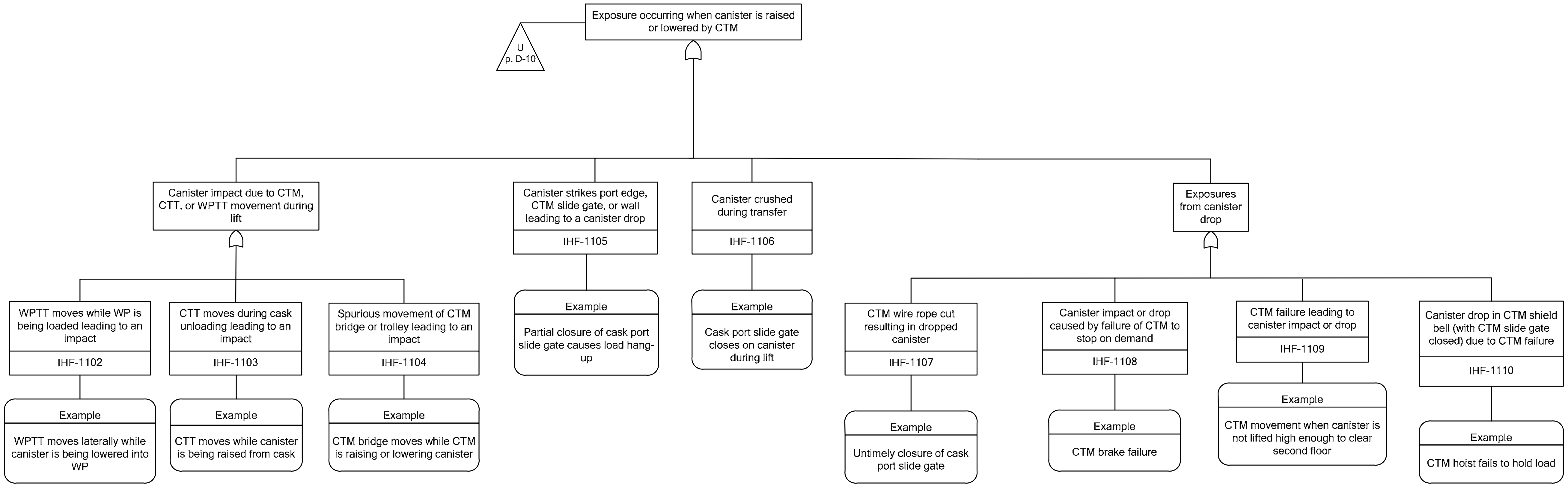
Figure D-9. Exposure Resulting from Canister Transfer Activities (e.g., CTM operations)




NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
CTM = canister transfer machine; IHF = Initial Handling Facility; RHS = remote handling system; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

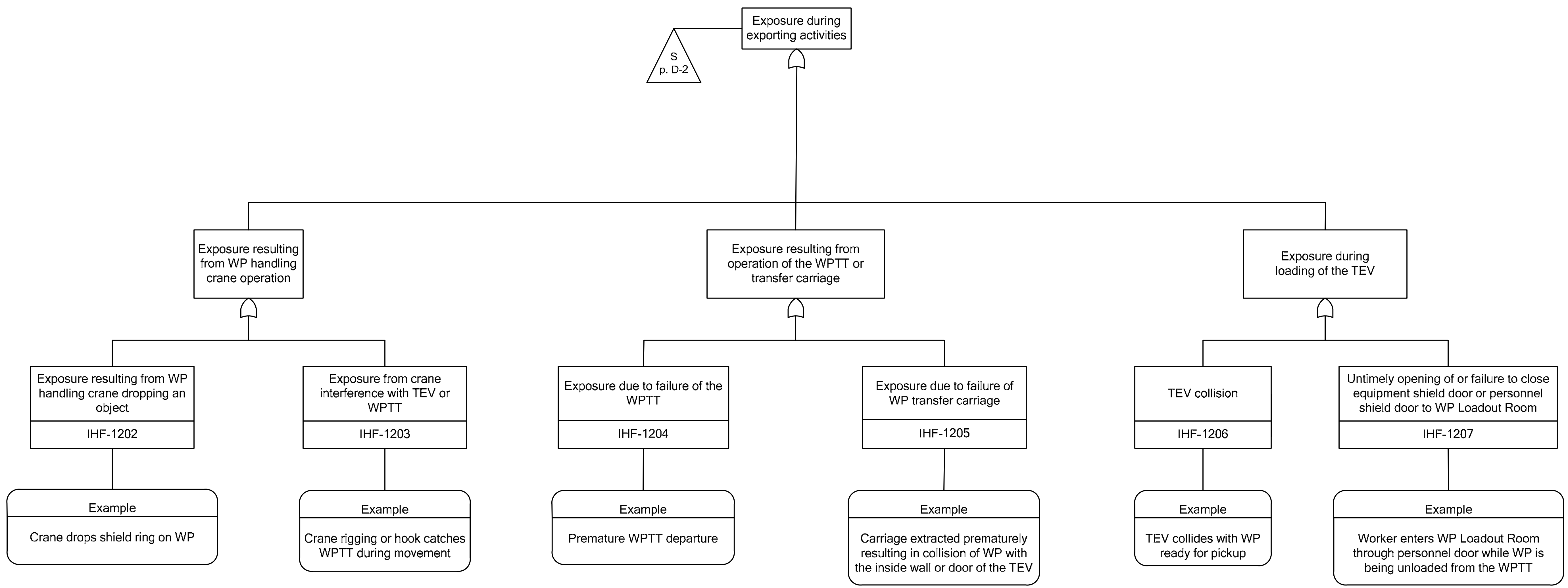
Figure D-10. Exposure during Movement of Loaded WPTT




NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
CTM = canister transfer machine; CTT = cask transfer trolley; IHF = Initial Handling Facility; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure D-11. Exposure Occurring when Canister is Raised or Lowered by CTM




NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
IHF = Initial Handling Facility; TEV = transport and emplacement vehicle; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure D-12. Exposure during Exporting Activities

# ATTACHMENT E
# HAZARD AND OPERABILITY EVALUATION

The results of a hazard and operability (HAZOP) evaluation for the IHF are provided in this attachment. The results presented here are a subset of the results from the HAZOP evaluation for the repository that were conducted in accordance with the process described in Section 4.3.1.3. The HAZOP evaluation was conducted in a series of meetings that lasted from 4 to 8 hours for each facility. The meeting participants and their resumes are provided in this attachment.

# HAZARD AND OPERABILITY EVALUATION

# LIST OF SUBJECT MATTER EXPERT PARTICIPANTS AND THEIR RESUMES

Table E-1 contains the HAZOP evaluation meeting dates and the names, telephone numbers, and employers of the subject matter experts who attended the meetings.

Table E-1. HAZOP Evaluation Meeting Dates and Participants

| **HAZOP Evaluation Meetings** | | |
|---|---|---|
| **Name** | **Telephone Number** | **Employer** |
| **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 |

Table E-1. HAZOP Evaluation Meeting Dates and Participants (Continued)

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

Table E-1. HAZOP Evaluation Meeting Dates and Participants (Continued)

| HAZOP Evaluation Meetings | | |
|---|---|---|
| **Name** | **Telephone Number** | **Employer** |
| **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 Evaluation Meeting Dates and Participants (Continued)

| **HAZOP Evaluation Meetings** | | |
|---|---|---|
| **Name** | **Telephone Number** | **Employer** |
| **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

Brief resumes of the subject matter experts participating in the HAZOP evaluation 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 HAZOP studies 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 HAZOP studies for facilities at the Savannah River Site and the Yucca Mountain Project. For this evaluation, Mr. Garrett served as a representative in the Intra-Site Operations areas for the HAZOP evaluation 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 evaluation, Mr. Graves served as the Preclosure Safety Analysis Lead for the HAZOP evaluation 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 evaluation 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 HAZOP studies ranging from nuclear to chemical processing and food industries. For this evaluation, Mr. Le served as co-leader of the HAZOP evaluation 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 HAZOP studies for various processes, including incineration and hazardous materials handling. For this evaluation, Ms. Loyd served as a participant for subsurface-related HAZOP evaluation sessions.

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

**Kelvin J. Montague**: Mr. Montague is an engineer with over 16 years of experience in safety analysis. Mr. Montague has led numerous HAZOP studies in nuclear industries. For this evaluation, Mr. Montague served as co-leader of the HAZOP evaluation 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 the HAZOP evaluation sessions. Dr. Orvis has participated in the development of human reliability analysis techniques (e.g., SHARP) and conducted measurements of, and analyzed data for, nuclear power plant control room operators during simulated accidents. Dr. Orvis has performed event tree and fault tree analyses of hazardous systems for both internal events and seismic initiators. Dr. Orvis is a former Supervisor of the BSC Preclosure Safety Analysis group.

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

**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 evaluation, 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 HAZOP studies on nuclear facilities. For this evaluation, Mr. Reny served as a representative for the Canister Receipt and Closure Facility for the HAZOP evaluation 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 Evaluation Worksheet for Node 1

| Facility/Operation: IHF | | | | | Process: Receipt and Transfer into Cask Preparation Area | | |
|---|---|---|---|---|---|---|---|
| Node 1: Receive Railcar or Truck Trailer Carrying TC into Cask Preparation Area (see Attachments B and C for node definitions) | | | | | Process/Equipment: SPM, Railcar, Truck Trailer | | |
| Guidewords: 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 Part 71 configuration<br>2 – Procedures and training | Creeping speed | IHF-102 |
| 1.2 | Speed | (More) SPM moves too fast | Collision | Potential loss of control or collision leading to radioactive release | 1 – TC remains in 10 CFR Part 71 configuration<br>2 – Procedures and training | Creeping speed | IHF-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<br>2 – Mechanical failure | No safety consequences | | | |
| 1.5 | Direction | (Reverse) SPM backs up instead of going forward | Collision due to<br>1 – Human failure<br>2 – Mechanical failure | Potential loss of control or collision leading to radioactive release | 1 – TC remains in 10 CFR Part 71 configuration<br>2 – Procedures and training | Potential loss of HVAC boundary if collision with door | IHF-102 |
| 1.6 | Direction | (Other Than) Derailment or rollover of carrier | 1 – Human failure<br>2 – Mechanical failure | Potential collision leading to radioactive release | 1 – TC remains in 10 CFR Part 71 configuration<br>2 – Procedures and training | IHF-101 applies to both waste forms. IHF-103 applies only to HLW. | IHF-101<br>IHF-103 |
| 1.7 | Direction | (Other Than) Derailment of carrier | Rail distortion due to structural failure | Potential drop of TC leading to radioactive release | 1 – TC remains in 10 CFR Part 71 configuration<br>2 – Procedures and training<br>3 – Rail design | | IHF-101 |
| 1.8 | Direction | (Other Than) SPM does not follow designated route and goes to wrong location or problem area | Collision due to<br>1 – Human failure<br>2 – Mechanical failure | Potential loss of control or collision leading to radioactive release | 1 – TC remains in 10 CFR Part 71 configuration<br>2 – Procedures and training | Faulty track or switch indicator, improper directions, or failure to follow directions | IHF-102 |
| 1.9 | Parking | (Other Than) Improper positioning and constraint of cask conveyance | 1 – Human failure<br>2 – Mechanical failure | Potential collision leading to radioactive release | 1 – TC remains in 10 CFR Part 71 configuration<br>2 – Procedures and training<br>3 – Brakes, chocks, and rail stops | Collision caused by unconstrained cask conveyance | IHF-102 |
| 1.10 | Temperature | (More) Exceeds 10 CFR Part 71 temperature design basis | Fire | 1 – Potential radioactive release<br>2 – Potential criticality | 1 – TC remains in 10 CFR Part 71 configuration<br>2 – Procedures and training<br>3 – Combustible materials control | 1 – 10 CFR Part 71 temperature design basis<br>2 – SPM may contain liquid fuel that could feed a fire in the Cask Preparation Area<br>3 – SPM may provide other combustible materials<br>4 – Entrance into facility to be controlled | IHF-I310<br>IHF-I311<br>IHF-I313<br>IHF-I314 |
| 1.11 | Temperature | (Less) Below 10 CFR Part 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 Part 71 configuration<br>2 – Procedures and training<br>3 – Combustible materials control | Includes reduction or complete loss of shielding. IHF-103 and IHF-104 apply only to HLW. | IHF-101<br>IHF-102<br>IHF-103<br>IHF-104 |

NOTE: Guidewords "As Well As" and "Part Of" were not used in this node.
HVAC = heating, ventilation, and air conditioning; IHF = Initial Handling Facility; SPM = site prime mover; TC = transportation cask.

Source: Original; 10 CFR Part 71 (Ref. 2.3.3).

Table E-3. HAZOP Evaluation Worksheet for Node 2

| Facility/Operation: IHF | | | | Process: Unloading TC from Carrier | | | |
|---|---|---|---|---|---|---|---|
| Node 2: Remove Impact Limiters from HLW TC on Carrier (see Attachments B and C for node definitions) | | | | Process/Equipment: Railcar, Truck Trailer, Cask Preparation Crane, Mobile Access Platform | | | |
| Guidewords: 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 | Potential drop of TC leading to radioactive release | 1 – TC design<br>2 – Procedures and training<br>3 – Crane design and below-the-hook devices | Cask preparation crane | IHF-401 |
| 2.2 | Load | (Less) Load lifted too light | | No safety consequences | | | |
| 2.3 | Speed (Crane) | (More) Hook lowered too fast | 1 – Human failure<br>2 – Mechanical failure | Drop of hook leading to radioactive release | 1 – TC design<br>2 – Procedures and training<br>3 – Crane design | | IHF-401 |
| 2.4 | Speed (Crane) | (Less) Hook lowered too slow | | No safety consequences | | | |
| 2.5 | Travel (Crane) | (Other Than) Crane movement with hook lowered | 1 – Human failure<br>2 – Mechanical failure | Potential collision leading to radioactive release | 1 – TC design<br>2 – Procedures and training<br>3 – Crane design | | IHF-403 |
| 2.6 | Travel (Crane) | (More) Crane moves past desired position for activity | 1 – Human failure<br>2 – Mechanical failure | No safety consequences | | | |
| 2.7 | Travel (Crane) | (Less) Crane does not move into desired position for activity | 1 – Human failure<br>2 – Mechanical failure | No safety consequences | | | |
| 2.8 | Travel (Crane) | (Reverse) Travels in wrong direction | 1 – Human failure<br>2 – Mechanical failure | Potential collision leading to radioactive release | 1 – TC design<br>2 – Procedures and training<br>3 – Crane design | | IHF-403 |
| 2.9 | Motor | (More) Motor temperature too high | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | Potential fire scenario | N/A |
| 2.10 | Maintenance | (No) Improper maintenance of crane | Human failure | | Maintenance program | Considered in event sequence development (event tree/FTA/HRA) | |
| 2.11 | Controls (PLC) | (Other Than) Improper signal generated | | | | Considered in event sequence development (event tree/FTA/HRA) | N/A |
| 2.12 | Vision/ Communication | (Other Than) Unclear communication | Poor operating environment | | 1 – Crane operator training program<br>2 – Human factor evaluation<br>3 – Industrial hygiene standards | Considered in HRA | N/A |
| 2.13 | Alignment | (Other Than) Improper alignment | See 2.5 through 2.8 above | | | | N/A |
| 2.14 | Mobile Access Platform Operations | (Other Than) Impact from operational activities | 1 – Human failure<br>2 – Mechanical failure | Potential impact leading to radioactive release | 1 – TC design<br>2 – Procedures and training<br>3 – Platform and tool design | | IHF-405 |

NOTE: Guidewords “As Well As” and “Part Of” were not used in this node.
FTA = fault-tree analysis; HLW = high-level radioactive waste; HRA = human-reliability analysis; IHF = Initial Handling Facility; PLC = programmable logic controller; TC = transportation cask.

Source: Original

Table E-4. HAZOP Evaluation Worksheet for Node 3

| Facility/Operation: IHF | | | | | | | Process: Unloading TC from Carrier |
|---|---|---|---|---|---|---|---|
| Node 3: Attach Lift Yoke to TC on Railcar or Truck Trailer (see Attachments B and C for node definitions) | | | | | | | Process/Equipment: Railcar, Truck Trailer, Cask Handling Crane, Lift Yoke, Trunnions (as required) |
| Guidewords: 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 lowered too fast | 1 – Human failure<br>2 – Mechanical failure | Potential collision leading to radioactive release | 1 – Procedures and training<br>2 – Crane design | TC design may mitigate event, depending on passive equipment failure analysis | IHF-504 |
| 3.2 | Speed (Crane) | (Less) Yoke lowered too slow | | No safety consequences | | | |
| 3.3 | Travel (Crane) | (Other Than) Crane movement with yoke lowered | 1 – Human failure<br>2 – Mechanical failure | Potential collision leading to radioactive release | 1 – Procedures and training<br>2 – Crane design | TC design may mitigate event, depending on passive equipment failure analysis | IHF-501 |
| 3.4 | Motor | (More) Motor temperature too high | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | Potential fire scenario | N/A |
| 3.5 | Maintenance | (No) Improper maintenance of crane | Human failure | | Maintenance program | Considered in event sequence development (event tree/FTA/HRA) | N/A |
| 3.6 | Controls (PLC) | (Other Than) Improper signal generated | | | | Considered in event sequence development (event tree/FTA/HRA) | N/A |
| 3.7 | Vision/ Communication | (Other Than) Unclear communication | Poor operating environment | | 1 – Crane operator training program<br>2 – Human factor evaluation<br>3 – Industrial hygiene standards | Considered in HRA | N/A |
| 3.8 | Mobile Access Platform Operations | (Other Than) Impact from operational activities | 1 – Human failure<br>2 – Mechanical failure | Potential impact leading to radioactive release | 1 – TC design<br>2 – Procedures and training<br>3 – Platform and tool design | | IHF-509 |
| 3.9 | Engagement (Yoke) | (More) Yoke arm over-travel | 1 – Human failure<br>2 – Mechanical failure | Potential drop of TC leading to radioactive release | 1 – Positioning interlocks<br>2 – Yoke adjustment motor design<br>3 – Pin alignment<br>4 – Procedures and training | | IHF-501 |
| 3.10 | Engagement (Yoke) | (Less) Yoke arm under-travel | 1 – Human failure<br>2 – Mechanical failure | Potential drop of TC leading to radioactive release | 1 – Positioning interlocks<br>2 – Yoke adjustment motor design<br>3 – Pin alignment<br>4 – Procedures and training | Potential partial yoke engagement | IHF-501 |
| 3.11 | Engagement (Yoke) | (No) Failed to engage | N/A?? | No safety consequences | | | |
| 3.12 | Yoke | (Other Than) Trunnion installed incorrectly | 1 – Human failure<br>2 – Mechanical failure | Potential drop of TC leading to radioactive release | 1 – Procedures and training<br>2 – Trunnion design | As required for certain casks | IHF-501 |

NOTE: Guidewords "Reverse," "As Well As," and "Part Of" were not used in this node.
FTA = fault-tree analysis; HRA = human-reliability analysis; IHF = Initial Handling Facility; PLC = programmable logic controller; TC = transportation cask.

Source: Original

Table E-5. HAZOP Evaluation Worksheet for Node 4

| Facility/Operation: IHF | | | | | Process: Unloading TC from Carrier | | |
|---|---|---|---|---|---|---|---|
| Node 4: Upright TC on Railcar (see Attachments B and C for node definitions) | | | | | Process/Equipment: Railcar, Truck Trailer, Cask Handling Crane | | |
| Guidewords: 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 | Potential drop of TC leading to radioactive release | 1 – Procedures and training<br>2 – Crane design | 1 – Cask handling crane main hook<br>2 – TC design may mitigate event, depending on passive equipment failure analysis | IHF-501 |
| 4.2 | Load | (Less) Load lifted too light | | No safety consequences | | | N/A |
| 4.3 | Speed (Crane and Hook) | (More or Less) Hook and crane speed not matched during lifting motion | 1 – Human failure<br>2 – Mechanical failure | Potential drop of TC leading to radioactive release | 1 – Procedures and training<br>2 – Crane design and below-the-hook design | TC design may mitigate event, depending on passive equipment failure analysis | IHF-501 |
| 4.4 | Travel (Crane) | (Reverse) Travels in wrong direction | 1 – Human failure<br>2 – Mechanical failure | Potential drop of TC leading to radioactive release | 1 – Procedures and training<br>2 – Crane design and below-the-hook design | 1 – TC design may mitigate event, depending on passive equipment failure analysis<br>2 – Crane feature to prevent rapid rundown needs to be subjected to FTA | IHF-501 |
| 4.5 | Motor | (More) Motor temperature too high | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | Potential fire scenario | N/A |
| 4.6 | Motor Motive Force | (Less or No) Loss of motive force allows rapid rundown | 1 – Human failure<br>2 – Mechanical malfunction | Potential drop of TC leading to radioactive release | | 1 – TC design may mitigate event, depending on passive equipment failure analysis<br>2 – Crane feature to prevent rapid rundown needs to be subjected to FTA | IHF-501 |
| 4.7 | Maintenance | (No) Improper maintenance of crane | Human failure | Potential drop of TC leading to radioactive release | Maintenance program | Considered in event sequence development (event tree/FTA/HRA) | IHF-501 |
| 4.8 | Controls (PLC) | (Other Than) Improper signal generated | | | | Considered in event sequence development (event tree/FTA/HRA) | N/A |
| 4.9 | Vision/ Communication | (Other Than) Unclear communication | Poor operating environment | | 1 – Crane operator training program<br>2 – Human factor evaluation<br>3 – Industrial hygiene standards | Considered in HRA | N/A |
| 4.10 | Alignment | (Other Than) Improper alignment | 1 – Human failure<br>2 – Mechanical failure | No safety consequences | | | N/A |
| 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<br>2 – Procedures and training | | IHF-506 |

NOTE: Guidewords “As Well As” and “Part Of” were not used in this node.
FTA = fault-tree analysis; HRA = human-reliability analysis; IHF = Initial Handling Facility; PLC = programmable logic controller; TC = transportation cask.

Source: Original

Table E-6. HAZOP Evaluation Worksheet for Node 5

| Facility/Operation: IHF | | | | | Process: Unloading TC from Carrier | | |
|---|---|---|---|---|---|---|---|
| Node 5: Transfer TC from Railcar or Truck Trailer to CTT (see Attachments B and C for node definitions) | | | | | Process/Equipment: Railcar, Cask Handling Crane, CTT | | |
| Guidewords: 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 | Lift | (More) Attempting to lift cask too high (i.e., two-blocking) | 1 – Human failure<br>2 – Mechanical malfunction | Potential drop of TC leading to radioactive release | 1 – Crane design<br>2 – Procedures and training | 1 – TC design may mitigate event, depending on passive equipment failure analysis<br>2 – 20-ft or greater drop considered | IHF-506 |
| 5.2 | Lift | (Less) Not lifted high enough to clear other structures or equipment | 1 – Human failure<br>2 – Mechanical malfunction | Potential drop of TC leading to radioactive release | Procedures and training | | IHF-506<br>IHF-508 |
| 5.3 | Lift | (No) Not lifted | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | | |
| 5.4 | Lift | (Reverse) Rapid rundown | 1 – Human failure<br>2 – Mechanical malfunction | Potential drop of TC leading to radioactive release | 1 – Crane design<br>2 – Procedures and training | TC design may mitigate event, depending on passive equipment failure analysis | IHF-506 |
| 5.5 | Speed (Crane) | (More) Crane moves faster than allowed by procedures | 1 – Human failure<br>2 – Mechanical failure | Potential collision of TC leading to radioactive release | 1 – Crane design<br>2 – Procedures and training | TC design may mitigate event, depending on passive equipment failure analysis | IHF-508 |
| 5.6 | Speed (Crane) | (Less) Crane moves too slow | 1 – Human failure<br>2 – Mechanical failure | N/A | Procedures and training | Prolonged exposure time for sequence initiation | N/A |
| 5.7 | Speed (Crane) | (Other Than) Abrupt stop | 1 – Human failure<br>2 – Mechanical failure | Potential TC impact leading to radioactive release | 1 – Crane design<br>2 – Procedures and training | TC design may mitigate event, depending on passive equipment failure analysis | IHF-508 |
| 5.8 | Alignment (CTT) | (No) Improper alignment | Human failure | No safety consequences | | | |

NOTE: Guidewords “As Well As” and “Part Of” were not used in this node.
CTT = cask transfer trolley; IHF = Initial Handling Facility; TC = transportation cask.

Source: Original

Table E-7. HAZOP Evaluation Worksheet for Step-By-Step Evaluation of Nodes 1 Through 5

| Facility/Operation: IHF | | | | Process: Step-By-Step Evaluation of TC Receipt | | | |
|---|---|---|---|---|---|---|---|
| Nodes 1 Through 5: Receive TC on Railcar and Transfer to CTT | | | | Process/Equipment: Various As Needed | | | |
| Guidewords: 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** |
| S.1 | N/A | Wrong cask pedestal selected | Human failure | Potential drop of TC leading to radioactive release | 1 – Procedures and training<br>2 – Pedestal design | 1 – Human factors<br>2 – Scheduling by campaigns may minimize occurrence | IHF-507 |
| S.2 | N/A | Cask handling crane used to remove impact limiters instead of cask preparation crane | Human failure | Potential drop of TC leading to radioactive release | 1 – Procedures and training<br>2 – Hook design | Applies to HLW only | IHF-403 |
| S.3 | N/A | Yoke selection not consistent with canister | Human failure | No safety consequences | | Prevented by design of lifting devices, which would preclude connection to wrong type of cask | |

NOTE: No Guidewords were used in this node.
CTT = cask transfer trolley; IHF = Initial Handling Facility; TC = transportation cask.

Source: Original

Table E-8. HAZOP Evaluation Worksheet for Node 6

| Facility/Operation: IHF | | | | Process: TC Preparation | | | |
|---|---|---|---|---|---|---|---|
| Node 6: Preparation Operations for HLW Casks (see Attachments B and C for node definitions) | | | | Process/Equipment: Preparation Station, Common Tools | | | |
| Guidewords: 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 | Sample Line Hookup | (Other Than) Improper hookup | Human failure | Potential release of materials in cask canister annulus to environment | 1 – Procedures and training<br>2 – Connection design | | |
| 6.2 | Sample Line Hookup | (Other Than) Line breaks | 1 – Human failure<br>2 – Equipment failure | Potential release of materials in cask canister annulus to environment | 1 – Procedures and training<br>2 – Sample system design | | |
| 6.3 | Taking Sample | (Other Than) Incorrect or inadequate sample or false negative | 1 – Human failure<br>2 – Equipment failure | Potential release of materials in cask canister annulus to environment | 1 – Procedures and training<br>2 – Sample system design | | |
| 6.4 | Jib Crane Load | (More) Too much load for crane | 1 – Human failure<br>2 – Equipment failure | No safety consequences | | Possible mitigation of event by TC, depending on passive equipment failure analysis | N/A |
| 6.5 | Jib Crane Load | (Less) Too light | | No safety consequences | | | N/A |
| 6.6 | Loosen/Remove Bolts | (Other Than) Failure to remove | Human failure | No safety consequences | | Potential precursor[a] to overloading CTM | N/A |
| 6.7 | Loosen/Remove Bolts | (Reverse) Tightens bolts instead of loosening | 1 – Human failure<br>2 – Equipment failure | No safety consequences | | Potential precursor[a] to overloading CTM | N/A |
| 6.8 | Attach TC Lid Lift Fixture | (Other Than) Improper attachment | 1 – Human failure<br>2 – Equipment failure | No safety consequences | 1 – Procedures and training<br>2 – Potentially precluded by design | Precursor[a] to drop of lid back onto canister<br>N/A | N/A |

NOTE: Guidewords “No,” “As Well As,” and “Part Of” were not used in this node.
CTM = canister transfer machine; DOE = U.S. Department of Energy; HLW = high-level radioactive waste; IHF = Initial Handling 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.”

N/A

Source: Original

N/A

Table E-9. HAZOP Evaluation Worksheet for Node 7

| Facility/Operation: IHF | | | | Process: TC Preparation | | | |
|---|---|---|---|---|---|---|---|
| Node 7: Preparation Operations for Naval Casks (see Attachments B and C for node definitions) | | | | Process/Equipment: Preparation Station, Cask Shield Ring, Cask Preparation Crane | | | |
| Guidewords: 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 | Sample Line Hookup | (Other Than) Improper hookup | Human failure | Potential release of materials in cask canister annulus to environment | 1 – Procedures and training<br>2 – Connection design | | |
| 7.2 | Sample Line Hookup | (Other Than) Line breaks | 1 – Human failure<br>2 – Equipment failure | Potential release of materials in cask canister annulus to environment | 1 – Procedures and training<br>2 – Sample system design | | |
| 7.3 | Taking Sample | (Other Than) Incorrect or inadequate sample or false negative | 1 – Human failure<br>2 – Equipment failure | Potential release of materials in cask canister annulus to environment | 1 – Procedures and training<br>2 – Sample system design | | |
| 7.4 | Jib Crane Load | (More) Too much load for crane | | No safety consequences | | | N/A |
| 7.5 | Jib Crane Load | (Less) Too light | | No safety consequences | | | N/A |
| 7.6 | 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<br>2 – Precursor[a] to cask drop if remaining bolts overloaded | N/A |
| 7.7 | Loosen/Remove Bolts | (Reverse) Tightens bolts instead of loosening | 1 – Human failure<br>2 – Equipment failure | No safety consequences | | Potential precursor[a] to cask drop if remaining bolts overloaded<br>N/A | N/A |
| 7.8 | Attach TC Lid Lift Fixture | (Other Than) Improper attachment | 1 – Human failure<br>2 – Equipment failure | No safety consequences | 1 – Procedures and training<br>2 – Potentially precluded by design | Potential precursor[a] to cask lid drop | N/A |
| 7.9 | Remove TC Lid | (More) Attempting to lift more than the lid alone | Human failure | Potential drop of TC leading to radioactive release | 1 – Procedures and training<br>2 – Crane design features | N/A<br>Model crane overload protection features and failure modes | IHF-604 |
| 7.10 | Remove TC Lid | (More) Attempting to lift lid too high (i.e., two-blocking) | Human failure | Potential impact to TC leading to radioactive release | 1 – Procedures and training<br>2 – Crane design features | N/A | IHF-603 |
| 7.11 | Remove TC Lid | (Less) Not lifting lid high enough to clear cask | Human failure | Potential drop of TC leading to radioactive release | Procedures and training | | IHF-606 |
| 7.12 | Remove TC Lid | (Other Than) Lift with fixture improperly attached (see 7.8 above) | Human failure | Potential impact to TC leading to radioactive release | Procedures and training | | N/A |
| 7.13 | Remove Closure Shear Ring and Shear Ring Backing Ring | (See 7.9 through 7.12 above) | Human failure | Potential impact to TC leading to radioactive release | Procedures and training | | N/A |
| 7.14 | Install Shield Ring | (More) Lift too high | 1 – Human failure<br>2 – Equipment failure | Potential impact to TC leading to radioactive release | Procedures and training | Operations have changed since the HAZOP evaluation was performed. The naval cask shield ring is left in place. This step is no longer applicable. | N/A |
| 7.15 | Install Shield Ring | (Less) Lift not high enough to clear cask | Human failure | Potential impact to TC leading to radioactive release | Procedures and training | This step is no longer applicable. | N/A |
| 7.16 | Install Shield Ring | (No) No installation | Human failure | Direct exposure | Procedures and training | This step is no longer applicable. | N/A |

Table E-9. HAZOP Evaluation Worksheet for Node 7 (Continued)

| Facility/Operation: IHF | | | | Process: TC Preparation | | | |
|---|---|---|---|---|---|---|---|
| Node 7: Preparation Operations for Naval Casks (see Attachments B and C for node definitions) | | | | Process/Equipment: Preparation Station, Cask Shield Ring, Cask Preparation Crane | | | |
| Guidewords: 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** |
| 7.17 | Install Shield Ring | (Other Than) Improperly installed | Human failure | Direct exposure | Procedures and training | Operations have changed since the HAZOP evaluation was performed. The naval cask shield ring is left in place. This step is no longer applicable. | N/A |
| 7.18 | Install Canister Lift Fixture | (More) Lift too high | 1 – Human failure<br>2 – Equipment failure | Potential impact to TC leading to radioactive release | Procedures and training | This step is no longer applicable. | N/A |
| 7.19 | Install Canister Lift Fixture | (Less) Lift not high enough to clear cask | Human failure | Potential impact to TC leading to radioactive release | Procedures and training | This step is no longer applicable. | N/A |
| 7.20 | Install Canister Lift Fixture | (Other Than) Improperly attached to crane for movement to installation position | Human failure | Potential impact to TC leading to radioactive release | Procedures and training | This step is no longer applicable. | N/A |
| 7.21 | Install Canister Lift Fixture | (Other Than) Improperly installed | Human failure | No safety consequences | Procedures and training | Precursor[a] to drop of canister during lift | |
| 7.22 | Remove and Store Shield Ring | (More) Lift too high | 1 – Human failure<br>2 – Equipment failure | Potential impact to TC leading to radioactive release | Procedures and training | This step is no longer applicable. | N/A |
| 7.23 | Remove and Store Shield Ring | (Less) Lift not high enough to clear cask | Human failure | Potential impact to TC leading to radioactive release | Procedures and training | This step is no longer applicable. | N/A |
| 7.24 | Remove and Store Shield Ring | (No) No removal | Human failure | No safety consequences | Procedures and training | Precursor[a] to drop of or impact to canister during CTM lift | |

NOTE: Guidewords “As Well As” and “Part Of” were not used in this node.
CTM = canister transfer machine; IHF = Initial Handling 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-10. HAZOP Evaluation Worksheet for Node 8

| Facility/Operation: IHF | | | | Process: TC Preparation | | | |
|---|---|---|---|---|---|---|---|
| Node 8: Move Loaded CTT to Cask Unloading Room (see Attachments B and C for node definitions) | | | | Process/Equipment: TC Trolley | | | |
| Guidewords: 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 | CTT Lift | (More) Too much lift | No cause identified | | | | |
| 8.2 | CTT Lift | (Less) Not enough lift | 1 – Lack of air pressure<br>2 – Cone malfunction | No safety consequences | | | |
| 8.3 | CTT Lift | (Other Than) Uneven lift | Cone malfunction | No safety consequences | | Unable to lift more than 5/16-inch over longest dimension | |
| 8.4 | CTT Lift | (Other Than) Drops | Loss of air | No safety consequences | | | |
| 8.5 | CTT Movement | (More) Moves too far | 1 – Human failure<br>2 – Mechanical malfunction | Potential collision leading to radioactive release | 1 – Procedures and training<br>2 – CTT design<br>3 – TC design | Shield door open, leading to collision with facility structure | IHF-802 |
| 8.6 | CTT Movement | (More) Moves too far | 1 – Human failure<br>2 – Mechanical malfunction | Potential collision leading to radioactive release | 1 – Procedures and training<br>2 – CTT design<br>3 – TC design | Shield door closed, leading to collision with shield door | IHF-802 |
| 8.7 | CTT Movement | (Less) Does not move enough | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | | |
| 8.8 | CTT Movement | (Reverse) Moves in opposite (wrong) direction | 1 – Human failure<br>2 – Mechanical malfunction | Potential collision leading to radioactive release | 1 – Procedures and training<br>2 – CTT design<br>3 – TC design | | IHF-802 |
| 8.9 | CTT Movement | (Other Than) Sideways movement | 1 – Human failure<br>2 – Mechanical malfunction | Potential collision leading to radioactive release | 1 – Procedures and training<br>2 – CTT design<br>3 – TC design | | IHF-802 |
| 8.10 | Shield Door Movement | (Other Than) Spurious closure of shield door | 1 – Human failure<br>2 – Mechanical malfunction | Potential collision leading to radioactive release | 1 – Procedures and training<br>2 – Design of shield-door controls<br>3 – TC design | | IHF-801 |
| 8.11 | Preparation Platform Position | (Other Than) Out of position leading to platform collision with CTT frame | 1 – Human failure<br>2 – Mechanical malfunction | Potential collision leading to radioactive release | 1 – Procedures and training<br>2 – CTT design<br>3 – TC design | | IHF-802 |

NOTE: Guidewords “No,” “As Well As,” and “Part Of” were not used in this node.
CTT = cask transfer trolley; IHF = Initial Handling Facility; TC = transportation cask.

Source: Original

Table E-11. HAZOP Evaluation Worksheet for Node 9

| Facility/Operation: IHF | | | | | | | Process: CTM Operation |
|---|---|---|---|---|---|---|---|
| Node 9: Lift Canister from TC into CTM (see Attachments B and C for node definitions) | | | | | | | Process/Equipment: CTM |
| 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** |
| 9.1 | Shield Door Movement | (Other Than) Failure to close shield door | 1 – Human failure<br>2 – Mechanical malfunction | Direct exposure | 1 – Procedures and training<br>2 – Design of shield-door controls | Must be concurrent with canister removal | IHF-903 |
| 9.2 | Shield Door Movement | (Other Than) Spurious opening of shield door | 1 – Human failure<br>2 – Mechanical malfunction | Direct exposure | 1 – Procedures and training<br>2 – Design of shield-door controls | Must be concurrent with canister removal | IHF-903 |
| 9.3 | Shield Door Movement | (Other Than) Failure to evacuate personnel prior to door closure | 1 – Human failure<br>2 – Mechanical malfunction | Direct exposure | 1 – Procedures and training<br>2 – Design of shield-door controls | Must be concurrent with canister removal | IHF-903 |
| 9.4 | Port Slide Gate | (Other Than) Failure to open slide gate | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | | |
| 9.5 | Port Slide Gate | (Other Than) Failure to close slide gate | 1 – Human failure<br>2 – Mechanical malfunction | Potential direct exposure to personnel on second floor when CTM moved | 1 – Procedures and training<br>2 – Design of slide-gate controls | | IHF-903 |
| 9.6 | Port Slide Gate | (Other Than) Untimely opening of port slide gate | 1 – Human failure<br>2 – Mechanical malfunction | Potential direct exposure to personnel on second floor when CTM moved | 1 – Procedures and training<br>2 – Design of slide-gate controls | | IHF-903 |
| 9.7 | Port Slide Gate | (Other Than) Closure while lifting canister | 1 – Human failure<br>2 – Mechanical malfunction | Potential release | 1 – Procedures and training<br>2 – Design of slide-gate controls | Examine rope and canister closures | IHF-1106 |
| 9.8 | CTM Slide Gate | (Other Than) Failure to open slide gate | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | | |
| 9.9 | CTM Slide Gate | (Other Than) Failure to close slide gate | 1 – Human failure<br>2 – Mechanical malfunction | Potential direct exposure to personnel on second floor when skirt lifted | 1 – Procedures and training<br>2 – Design of slide-gate controls | | IHF-903 |
| 9.10 | CTM Slide Gate | (Other Than) Untimely opening of CTM slide gate | 1 – Human failure<br>2 – Mechanical malfunction | Potential direct exposure to personnel on second floor when skirt lifted | 1 – Procedures and training<br>2 – Design of slide-gate controls | | IHF-903 |
| 9.11 | CTM Slide Gate | (Other Than) Closure while lifting canister | 1 – Human failure<br>2 – Mechanical malfunction | Potential release | 1 – Procedures and training<br>2 – Design of slide-gate controls | Examine rope and canister closures | IHF-1106 |
| 9.12 | Lid Grapple Engagement | (Other Than) Improper attachment | 1 – Human failure<br>2 – Equipment failure | No safety consequences | 1 – Procedures and training<br>2 – Potentially precluded by design | Potential precursor[a] to cask lid drop | |
| 9.13 | Remove HLW TC Lid | (More) Attempting to lift lid when bolts have not been removed (see Node 6, Items 6.6 and 6.7) | Human failure | Potential drop of TC leading to radioactive release | 1 – Procedures and training<br>2 – Crane design features | Model crane overload protection features and failure modes | IHF-805 |
| 9.14 | Remove HLW TC Lid | (More) Attempting to lift lid too high (i.e., two-blocking) | Human failure | Potential impact to canister leading to radioactive release | 1 – Procedures and training<br>2 – Crane design features | Does not apply to naval canisters | IHF-804 |
| 9.15 | Remove HLW TC Lid | (Less) Not lifting lid high enough to clear cask | Human failure | Potential impact to canister leading to radioactive release | Procedures and training | Does not apply to naval canisters | IHF-804 |
| 9.16 | Remove HLW TC Lid | (Other Than) Lift with grapple improperly attached (see 9.12 above) | Human failure | Potential impact to canister leading to radioactive release | Procedures and training | Does not apply to naval canisters | IHF-804 |
| 9.17 | Canister Grapple Engagement | (Other Than) Improper attachment | 1 – Human failure<br>2 – Equipment failure | No safety consequences | 1 – Procedures and training<br>2 – Potentially precluded by design | Potential precursor[a] to canister drop | |

Table E-11. HAZOP Evaluation Worksheet for Node 9 (Continued)

| Facility/Operation: IHF | | | | Process: CTM Operation | | | |
|---|---|---|---|---|---|---|---|
| Node 9: Lift Canister from TC into CTM (see Attachments B and C for node definitions) | | | | Process/Equipment: CTM | | | |
| 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** |
| 9.18 | Lift | (More) Attempting to lift more than a canister (i.e., load hang-up) | Human failure | Potential drop of canister leading to radioactive release | 1 – Procedures and training<br>2 – CTM design features | Model CTM overload protection features and failure modes | IHF-1105 |
| 9.19 | Lift | (More) Attempting to lift canister too high (i.e., two-blocking) | Human failure | 1 – Potential drop of canister leading to radioactive release<br>2 – Direct exposure if lifted above top of shield bell | 1 – Procedures and training<br>2 – CTM design features | | IHF-1109 |
| 9.20 | Lift Canister | (Less) Not lifting canister high enough to clear floor | Human failure | Potential shear of canister leading to radioactive release | Procedures and training | | IHF-1109 |
| 9.21 | Lift Canister | (Other Than) Movement of CTT during lift of canister | Human failure | Potential shear of canister leading to radioactive release | 1 – Procedures and training<br>2 – CTT design features | | IHF-1103 |
| 9.22 | Lift Canister | (Other Than) Miscellaneous mechanical failures | Mechanical malfunction | Potential drop of canister leading to radioactive release | CTM design features | Maintenance program | IHF-1107<br>IHF-1108<br>IHF-1109<br>IHF-1110 |
| 9.23 | Lift Canister | (Other Than) Lift with grapple improperly attached (see 9.17 above) | 1 – Human failure<br>2 – Mechanical malfunction | Potential drop of canister leading to radioactive release | Procedures and training | | IHF-1109 |

NOTE: Guidewords “No,” “Reverse,” “As Well As,” and “Part Of” were not used in this node.
CTM = canister transfer machine; CTT = cask transfer trolley; HLW = high-level radioactive waste; IHF = Initial Handling Facility; TC = transportation cask.

Source: Original

Table E-12. HAZOP Evaluation Worksheet for Node 10

| Facility/Operation: IHF | | | | | Process: CTM Operation | | |
|---|---|---|---|---|---|---|---|
| Node 10: Move CTM from Cask Port to WP Port (see Attachments B and C for node definitions) | | | | | Process/Equipment: CTM | | |
| 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** |
| 10.1 | Speed (CTM) | (More) CTM moves faster than allowed by procedures | 1 – Human failure<br>2 – Mechanical failure | Potential collision with canister leading to radioactive release | 1 – CTM design<br>2 – Procedures and training | | IHF-902 |
| 10.2 | Speed (CTM) | (No) CTM stuck in middle of room during move | 1 – Human failure<br>2 – Mechanical failure | Potential radioactive release due to heat-up, etc. | | | N/A |
| 10.3 | Speed (CTM) | (Less) CTM moves too slow | 1 – Human failure<br>2 – Mechanical failure | No safety consequences | | | |
| 10.4 | Speed (CTM) | (Other Than) Abrupt stop | 1 – Human failure<br>2 – Mechanical failure | Potential collision with canister leading to radioactive release | 1 – CTM design<br>2 – Procedures and training | | IHF-902 |
| 10.5 | Direction (CTM) | (More) CTM moves too far | 1 – Human failure<br>2 – Mechanical failure | Potential collision with canister leading to radioactive release | 1 – CTM design<br>2 – Procedures and training | | IHF-902 |
| 10.6 | Direction (CTM) | (Less) CTM does not move enough | 1 – Human failure<br>2 – Mechanical failure | No safety consequences | | | |
| 10.7 | Direction (CTM) | (Other Than) Moves in wrong direction | 1 – Human failure<br>2 – Mechanical failure | Potential collision with canister leading to radioactive release | 1 – CTM design<br>2 – Procedures and training | | IHF-902 |
| 10.8 | Miscellaneous (CTM) | (Other Than) Moves over lid not properly stored | Human failure | Potential collision with canister leading to radioactive release | 1 – Facility design<br>2 – Procedures and training | | IHF-902 |

NOTE: Guidewords "Reverse," "As Well As," and "Part Of" were not used in this node.
CTM = canister transfer machine; IHF = Initial Handling Facility; WP = waste package.

Source: Original

Table E-13. HAZOP Evaluation Worksheet for Node 11

| Facility/Operation: IHF | | | | | Process: CTM Operation | | |
|---|---|---|---|---|---|---|---|
| Node 11: Lower Canister from CTM into WP (see Attachments B and C for node definitions) | | | | | Process/Equipment: CTM, WP | | |
| Guidewords: 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<br>2 – Mechanical malfunction | Direct exposure | 1 – Procedures and training<br>2 – Design of shield-door controls | Must be concurrent with canister lowering | IHF-903 |
| 11.2 | Shield Door Movement | (Other Than) Spurious opening of shield door | 1 – Human failure<br>2 – Mechanical malfunction | Direct exposure | 1 – Procedures and training<br>2 – Design of shield-door controls | Must be concurrent with canister lowering | IHF-903 |
| 11.3 | Shield Door Movement | (Other Than) Failure to evacuate personnel prior to door closure | 1 – Human failure<br>2 – Mechanical malfunction | Direct exposure | 1 – Procedures and training<br>2 – Design of shield-door controls | Must be concurrent with canister lowering | IHF-903 |
| 11.4 | Port Slide Gate | (Other Than) Failure to open slide gate | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | | |
| 11.5 | Port Slide Gate | (Other Than) Failure to close slide gate | 1 – Human failure<br>2 – Mechanical malfunction | Potential direct exposure to personnel on second floor when CTM moved | 1 – Procedures and training<br>2 – Design of slide-gate controls | After canister lowered into WP | IHF-903 |
| 11.6 | Port Slide Gate | (Other Than) Inadvertent opening of port slide gate | 1 – Human failure<br>2 – Mechanical malfunction | Potential direct exposure to personnel on second floor when CTM moved | 1 – Procedures and training<br>2 – Design of slide-gate controls | After canister lowered into WP | IHF-903 |
| 11.7 | Port Slide Gate | (Other Than) Closure while lowering canister | 1 – Human failure<br>2 – Mechanical malfunction | Potential release | 1 – Procedures and training<br>2 – Design of slide-gate controls | Examine rope and canister closures | IHF-1106 |
| 11.8 | CTM Slide Gate | (Other Than) Failure to open slide gate | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | | |
| 11.9 | CTM Slide Gate | (Other Than) Failure to close slide gate | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | | |
| 11.10 | CTM Slide Gate | (Other Than) Opening of CTM slide gate | 1 – Human failure<br>2 – Mechanical malfunction | Potential direct exposure to personnel on second floor when skirt lifted | 1 – Procedures and training<br>2 – Design of slide-gate controls | | IHF-903 |
| 11.11 | CTM Slide Gate | (Other Than) Closure while lowering canister | 1 – Human failure<br>2 – Mechanical malfunction | Potential release | 1 – Procedures and training<br>2 – Design of slide-gate controls | | IHF-1106 |
| 11.12 | Lowering of Canister | (Less) Not lowering canister enough to clear bottom of second floor | Human failure | Potential shear of canister leading to radioactive release | Procedures and training | | IHF-1109 |
| 11.13 | Lowering of Canister | (Other Than) Movement of WPTT during lowering of canister | Human failure | Potential shear of canister leading to radioactive release | 1 – Procedures and training<br>2 – WPTT design features | Includes inadvertent movement of WPTT tilting mechanism | IHF-1102 |
| 11.14 | Lowering of Canister | (Other Than) Miscellaneous mechanical failures | Mechanical malfunction | Potential drop of canister leading to radioactive release | CTM design features | Maintenance program | IHF-1107<br>IHF-1108<br>IHF-1109<br>IHF-1110 |
| 11.15 | Lowering of Canister | (Other Than) Lowering canister without WP below | 1 – Human failure<br>2 – Mechanical malfunction | Potential direct exposure | Procedures and training | | IHF-903 |
| 11.16 | Lowering of Canister | (Other Than) Misalignment of CTM and port | 1 – Human failure<br>2 – Mechanical malfunction | Potential drop of or impact to canister leading to radioactive release | Procedures and training | Potential of catching ledge and dropping into hole | IHF-1105 |

NOTE: Guidewords “No,” “More,” “Reverse,” “As Well As,” and “Part Of” were not used in this node.
CTM = canister transfer machine; CTT = cask transfer trolley; IHF = Initial Handling Facility; TC = transportation cask; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Table E-14. HAZOP Evaluation Worksheet for Node 12

| Facility/Operation: IHF | | | | | Process: WP Operation | | |
|---|---|---|---|---|---|---|---|
| Node 12: Install WP Inner Lid and Move WP to WP Positioning Room (see Attachments B and C for node definitions) | | | | | Process/Equipment: CTM, WP, WPTT | | |
| 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** |
| 12.1 | WPTT Preparation | (Other Than) Improper positioning of empty WP in WPTT | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | Precursor[a] to WP loading mishaps | |
| 12.2 | WPTT Preparation | (Other Than) Pedestal not loaded or improper pedestal loaded | Human failure | No safety consequences | | Precursor[a] to WP loading mishaps | |
| 12.3 | WPTT Preparation | (Other Than) Improper alignment of WP to vertical axis when bringing upright | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | Precursor[a] to WP loading mishaps | |
| 12.4 | WPTT Preparation | (Other Than) WP shield ring not installed | Human failure | | | Could cause overexposure of personnel in IHF control room and subject welding equipment to exposure greater than design | IHF-1001 |
| 12.5 | WPTT Preparation | (Other Than) Wrong WP used for waste form to be loaded | Human failure | No safety consequences | | Precursor[a] to WP loading mishaps | |
| 12.6 | WPTT Movement with Empty WP | (Other Than) Impact or derailment | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | Precursor[a] to WP loading mishaps | |
| 12.7 | WPTT Movement with Empty WP | (Other Than) Misalignment of WP and port | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | Precursor[a] to WP loading mishaps | |
| 12.8 | Lid Grapple Engagement | (Other Than) Improper attachment | 1 – Human failure<br>2 – Equipment failure | No safety consequences | | Potential precursor[a] to cask lid drop (WP requires multiple lids) | |
| 12.9 | Install Lid | (Other Than) Install wrong lid or no lid | Human failure | Potential direct exposure | Procedures and training | | IHF-1001 |
| 12.10 | Install Lid | (Reverse) Attempting to lift lid too high (i.e., two-blocking) | Human failure | Potential impact to canister leading to radioactive release | 1 – Procedures and training<br>2 – Crane design features | | IHF-1002 |
| 12.11 | Install Lid | (Other Than) Lift with grapple improperly attached (see 12.8 above) | Human failure | Potential impact to canister leading to radioactive release | Procedures and training | | IHF-1002 |
| 12.12 | WPTT Movement with Loaded WP | (Other Than) Impact or derailment | 1 – Human failure<br>2 – Mechanical malfunction | Potential drop of or impact to WP leading to radioactive release | 1 – Procedures and training<br>2 – Maintenance | Impacts include premature tilting | IHF-1005<br>IHF-1006<br>IHF-1007 |
| 12.13 | Shield Door Movement | (Other Than) Failure to open shield door | 1 – Human failure<br>2 – Mechanical malfunction | Potential collision with WP leading to radioactive release | 1 – Procedures and training<br>2 – Design of shield-door controls | | IHF-1006 |
| 12.14 | Shield Door Movement | (Other Than) Closure on WPTT during transit | 1 – Human failure<br>2 – Mechanical malfunction | Potential collision with WP leading to radioactive release | 1 – Procedures and training<br>2 – Design of shield-door controls | | IHF-1006 |

NOTE: Guidewords “No,” “More,” “Less,” “As Well As,” and “Part Of” were not used in this node.
CTM = canister transfer machine; IHF = Initial Handling Facility; WP = waste package; WPTT = waste package transfer trolley.
[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-15. HAZOP Evaluation Worksheet for Node 13

| Facility/Operation: IHF | | | | Process: WP Operation | | | |
|---|---|---|---|---|---|---|---|
| Node 13: Close WP (see Attachments B and C for node definitions) | | | | Process/Equipment: Closure Equipment, WP, WPTT, Inner and Outer Lids | | | |
| 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** |
| 13.1 | WPTT Alignment | (Other Than) Greater than 1-inch deviation from expected position | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | Positioning monitored by camera | |
| 13.2 | Placement of Inner Lid | | | | | Inner lid will be placed by CTM for all waste forms | |
| 13.3 | Welding Process Temperature | (More) Greater than expected temperature | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | | |
| 13.4 | Welding Process Temperature | (Less) Less than expected temperature | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | | |
| 13.5 | Welding Process Material | (Other Than) Wrong welding material | Human failure | No safety consequences | | | |
| 13.6 | Welding Process Material | (More) More than expected amount | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | | |
| 13.7 | Welding Process Material | (Less) Less than expected amount | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | | |
| 13.8 | Welding Process Inerting Blanket | (No or Less) Loss of inerting blanket | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | | |
| 13.9 | Welding Process Inerting Blanket | (Other Than) Flammable gas substituted for inerting gas | Human failure | No safety consequences | | | |
| 13.10 | Weld Cooling | (More) Too much cooling | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | | |
| 13.11 | Weld Cooling | (Less) Localized temperature exceeds limits | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | | |
| 13.12 | Install Lid | (Other Than) Install wrong lid or no lid | Human failure | Potential direct exposure | Procedures and training | | IHF-1001 |
| 13.13 | Install Lid | (Reverse) Attempting to lift lid too high (i.e., two-blocking) | Human failure | Potential drop of lid onto WP | 1 – Procedures and training<br>2 – RHS design features | | IHF-1002 |
| 13.14 | Install Lid | (Other Than) Lift with grapple improperly attached | Human failure | Potential impact to WP leading to radioactive release | Procedures and training | | IHF-1003 |

NOTE: Guidewords "As Well As" and "Part Of" were not used in this node.
IHF = Initial Handling Facility; RHS = remote handling system; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Table E-16. HAZOP Evaluation Worksheet for Node 14

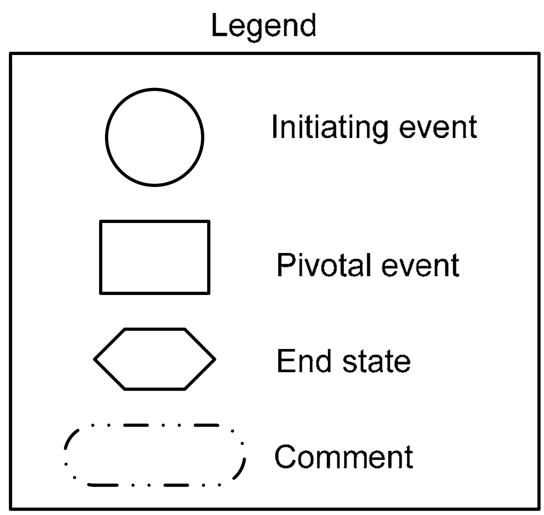
| Facility/Operation: IHF | | | | | Process: WP Operation | | |
|---|---|---|---|---|---|---|---|
| Node 14: Move WP to TEV (see Attachments B and C for node definitions) | | | | | Process/Equipment: WP, WPTT, TEV | | |
| Guidewords: No, More, Less, Other Than, Reverse, As Well As, Part Of | | | | | 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** |
| 14.1 | WPTT Movement with Loaded WP | (Other Than) Impact or derailment | 1 – Human failure<br>2 – Mechanical malfunction | Potential drop of or impact to WP leading to radioactive release | 1 – Procedures and training<br>2 – Maintenance | | IHF-1005<br>IHF-1006<br>IHF-1007<br>IHF-1204 |
| 14.2 | Shield Door Movement | (Other Than) Failure to open shield door | 1 – Human failure<br>2 – Mechanical malfunction | Potential collision leading to radioactive release | 1 – Procedures and training<br>2 – Design of shield door-controls<br>3 – WP design | | IHF-1006 |
| 14.3 | Shield Door Movement | (Other Than) Closure on WPTT during transit | 1 – Human failure<br>2 – Mechanical malfunction | Potential collision leading to radioactive release | 1 – Procedures and training<br>2 – Design of shield-door controls<br>3 – WP design | | IHF-1006 |
| 14.4 | WPTT Engagement | (Other Than) Failure to secure WPTT to docking station prior to shield ring removal or WP transfer | 1 – Human failure<br>2 – Mechanical malfunction | Potential drop of or impact to WP leading to radioactive release | 1 – Procedures and training<br>2 – WPPT/docking station design | Potential displacement of WPTT during tilt-down or shield ring removal | IHF-1204 |
| 14.5 | Shield Ring Removal | (Other Than) Not removed | Human failure | No safety consequences | | | |
| 14.6 | Shield Ring Removal | (Other Than) Drops onto WP during removal | 1 – Human failure<br>2 – Mechanical malfunction | Potential impact to WP leading to radioactive release | 1 – Procedures and training<br>2 – Crane design | Includes installation of grapple | IHF-1202 |
| 14.7 | Shield Ring Removal | (Other Than) Shield ring binds with WP during shield removal | 1 – Human failure<br>2 – Mechanical malfunction | Potential drop of WP leading to radioactive release | 1 – Procedures and training<br>2 – Crane design | Partial lift of WP with drop of WP | IHF-1203 |
| 14.8 | Shield Ring Removal | (Less) Shield ring fails to clear WPTT or WP during shield removal | 1 – Human failure<br>2 – Mechanical malfunction | Potential drop of or impact to WP leading to radioactive release | 1 – Procedures and training<br>2 – Crane design | Tip-over of WPTT | IHF-1203 |
| 14.9 | Down-Ending of WP in WPTT | (More) Rapid tilting rundown | 1 – Human failure<br>2 – Mechanical malfunction | Potential impact to WP leading to radioactive release | 1 – Procedures and training<br>2 – WPTT design | Potential ejection of WP and pallet | IHF-1204 |
| 14.10 | Down-Ending of WP in WPTT | (Less or No) Stuck in mid-travel during tilting | 1 – Human failure<br>2 – Mechanical malfunction | No safety consequences | | | |
| 14.11 | Extract WP and Pallet from WPTT | (Less or No) WP and pallet stuck in WPTT | 1 – Human failure<br>2 – Mechanical malfunction | Direct exposure | 1 – Procedures and training<br>2 – WPTT design | Interface point with TEV and subsurface operations | IHF-1204 |
| 14.12 | Extract WP and Pallet from WPTT | (More) WP and pallet extracted too rapidly from WPTT | 1 – Human failure<br>2 – Mechanical malfunction | Potential impact to WP leading to radioactive release | 1 – Procedures and training<br>2 – WPTT design | 1 – Interface point with TEV and subsurface operations<br>2 – Potential collision if TEV not ready to receive | IHF-1205 |
| 14.13 | Extract WP and Pallet from WPTT | (More) WP and pallet extracted before TEV doors open | 1 – Human failure<br>2 – Mechanical malfunction | Potential impact to WP leading to radioactive release | 1 – Procedures and training<br>2 – WPTT/TEV design | 1 – Interface point with TEV and subsurface operations<br>2 – Potential collision if TEV not ready to receive | IHF-1205 |

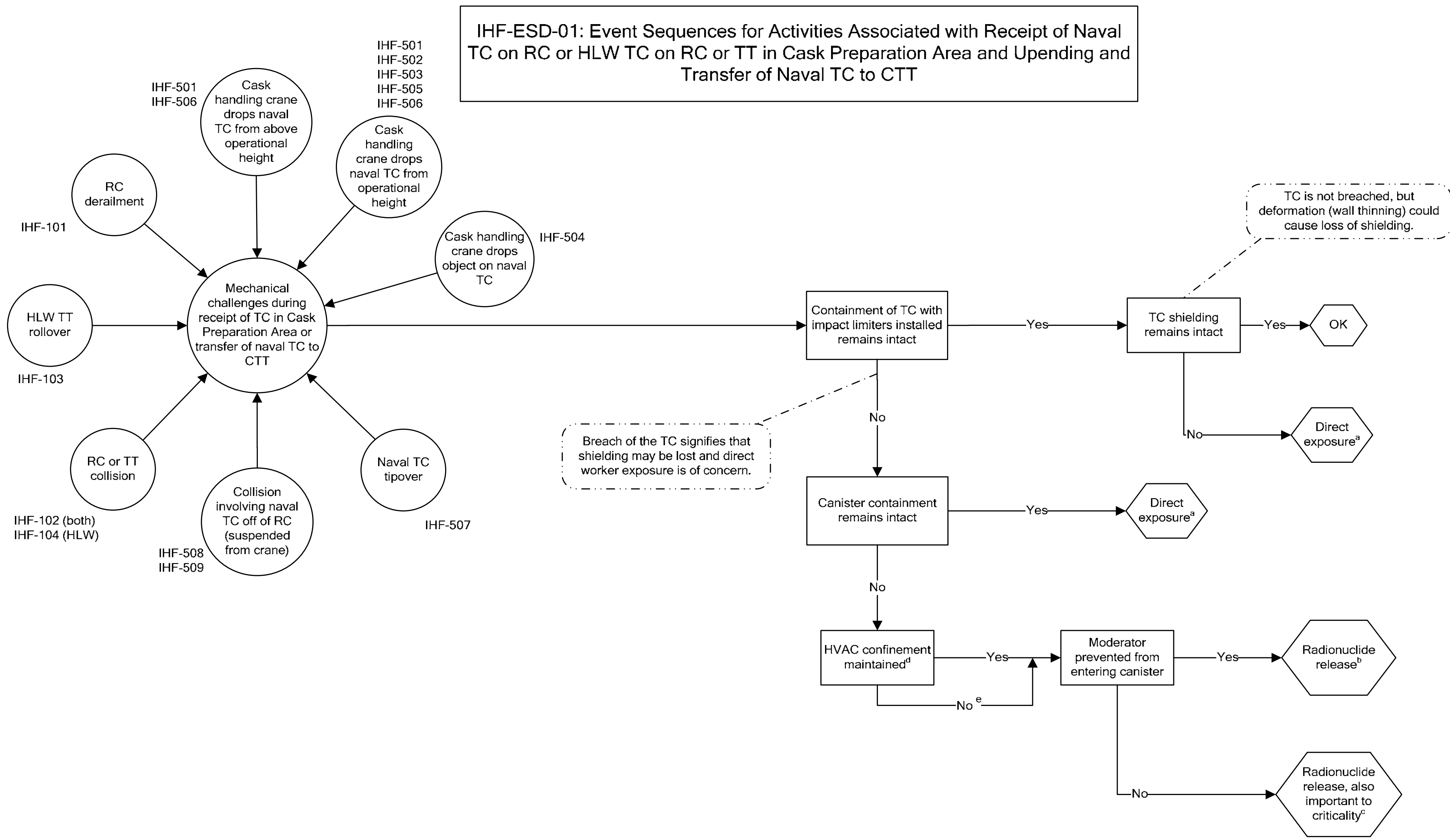
NOTE: Guidewords “Reverse,” “As Well As,” and “Part Of” were not used in this node.
IHF = Initial Handling Facility; TEV = transport and emplacement vehicle; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

# ATTACHMENT F
# EVENT SEQUENCE DIAGRAMS

Event Sequence Diagrams for the Initial Handling Facility are presented in Figures F-1 through F-13. 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 radionuclide release.

[b] Radionuclide release describes a condition where radioactive material has been released 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.

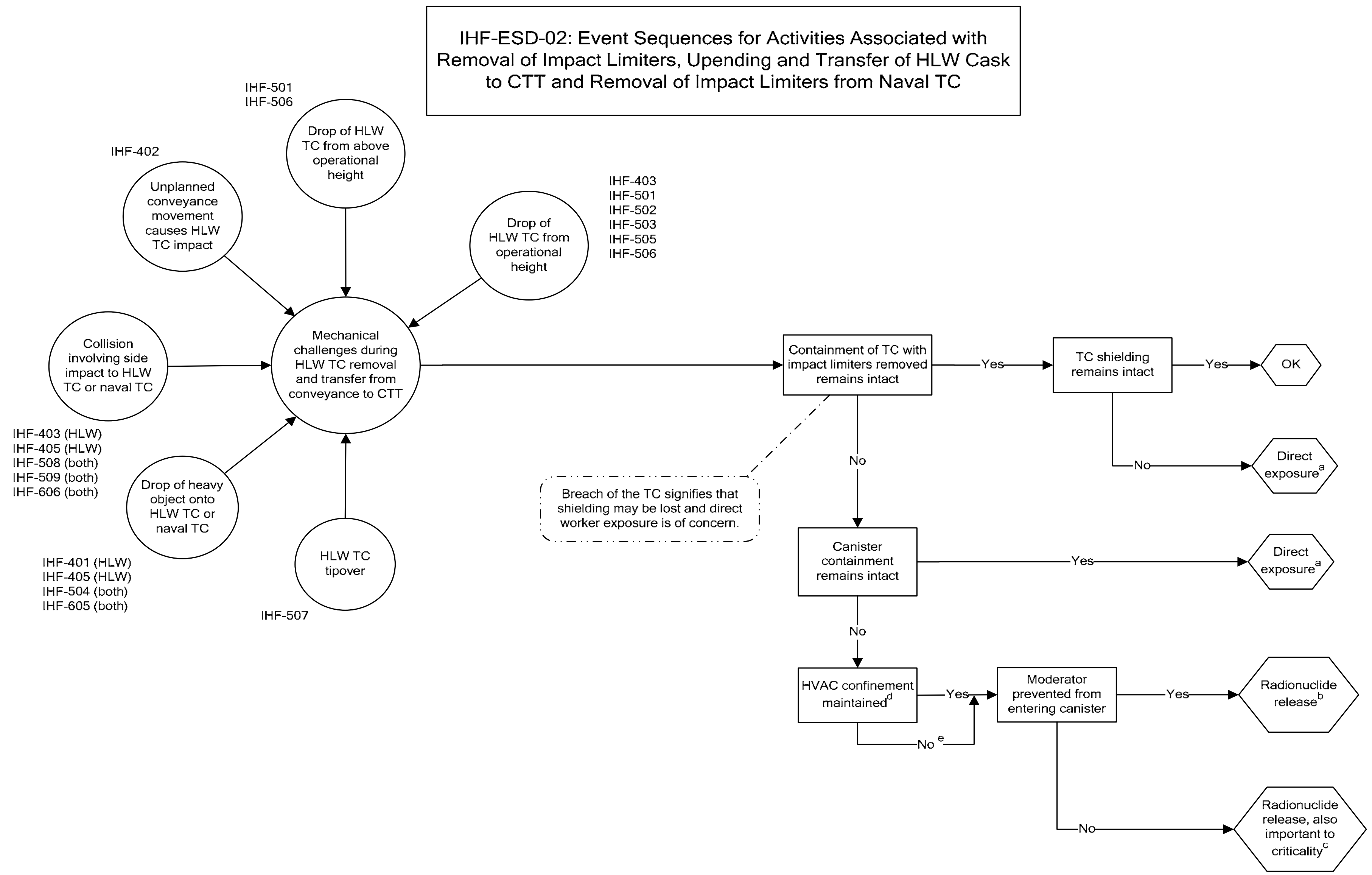
[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

This ESD applies to naval TCs and HLW TCs with impact limiters still in place. Where applicability of initiating events contributing to a small bubble is limited to one or the other waste form, the waste form applicability is indicated after the initiating event identifier as "(HLW)", "(naval)," or "(both)".

CTT = cask transfer trolley; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation and air conditioning; IHF = Initial Handling Facility; RC = railcar; TC = transportation cask; TT = truck trailer.

Source: Original

Figure F-1. IHF-ESD-01: Event Sequences for Activities Associated with Receipt of Naval TC on RC or HLW TC on RC or TT in Cask Preparation Area and Upending and Transfer of Naval TC to CTT




NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a radionuclide release.

[b] Radionuclide release describes a condition where radioactive material has been released 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.

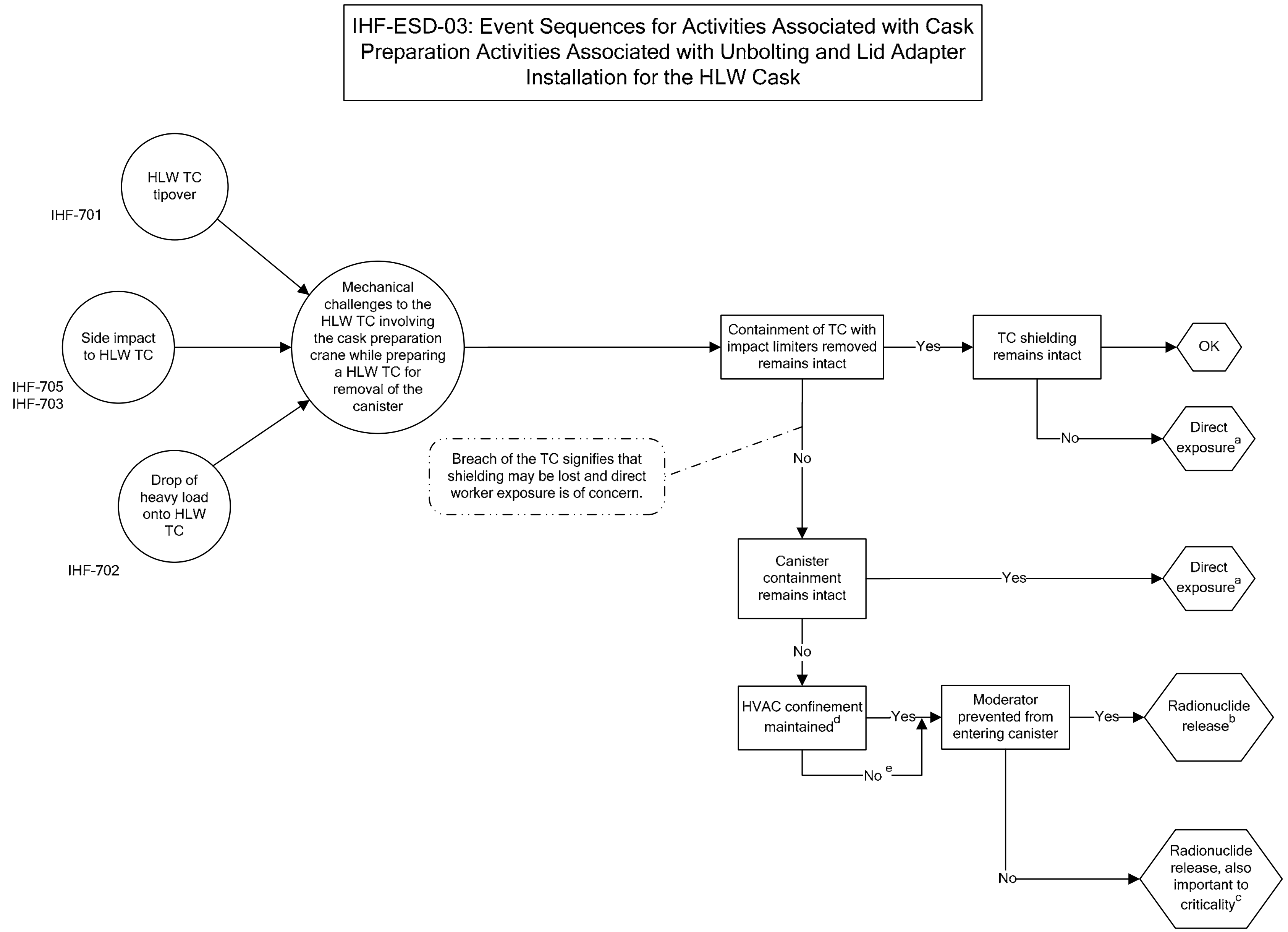
[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

This ESD applies to naval TCs and HLW TCs with impact limiters removed. Where applicability of initiating events contributing to a small bubble is limited to one or the other waste form, the waste form applicability is indicated after the initiating event identifier as “(HLW)”, “(naval),” or “(both)”.

CTT = cask transfer trolley; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation and air conditioning; IHF = Initial Handling Facility; TC = transportation cask.

Source: Original

Figure F-2. IHF-ESD-02: Event Sequences for Activities Associated with Removal of Impact Limiters, Upending and Transfer of HLW Cask to CTT, and Removal of Impact Limiters from Naval TC




NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a radionuclide release.

Radionuclide release describes a condition where radioactive material has been released 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.

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.

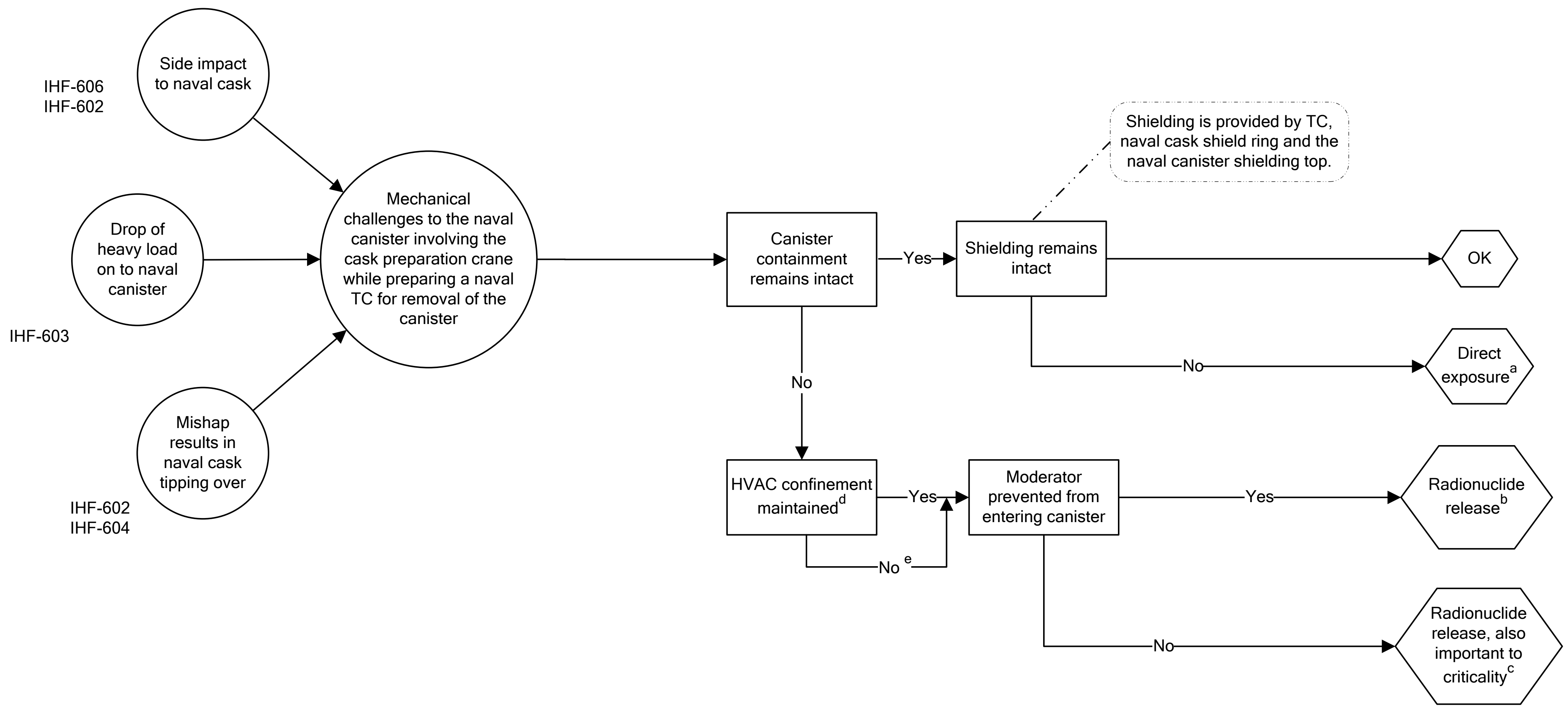
[d] This ESD applies to HLW TCs with impact limiters removed.

[e] ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation and air conditioning; IHF = Initial Handling Facility; TC = transportation cask.

Source: Original

Figure F-3. IHF-ESD-03: Event Sequences for Activities Associated with Cask Preparation Activities Associated with Unbolting and Lid Adapter Installation for the HLW Cask

# IHF-ESD-04: Event Sequences for Activities Associated with Removal of the Naval Cask Lid and Installing the Naval Canister Lifting Adapter




NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a radionuclide release.

Radionuclide release describes a condition where radioactive material has been released 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
[b] moderator is available to enter a breached container.

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

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.

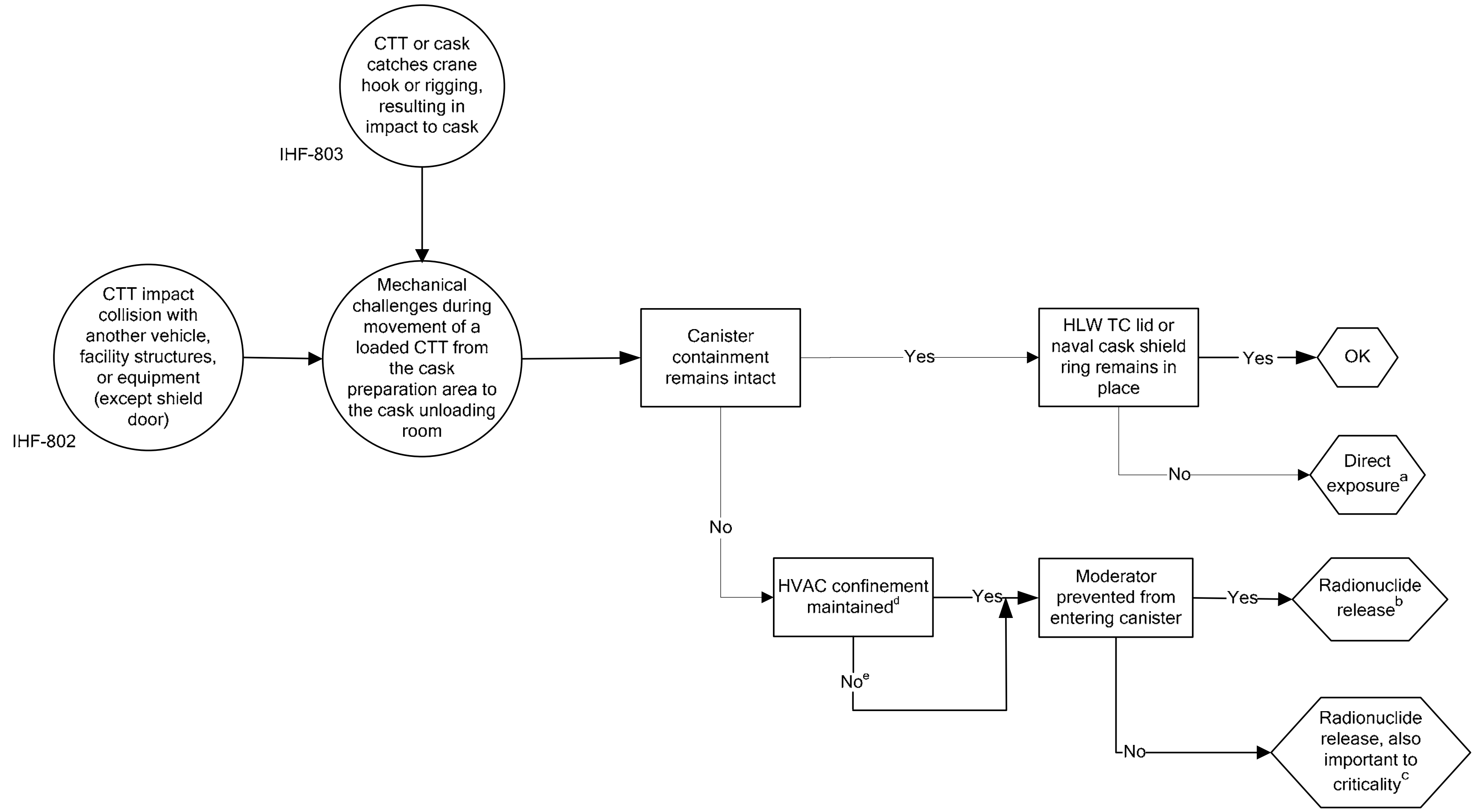
[d] This ESD applies to naval TCs with the upper impact limiter removed.

[e] ESD = event sequence diagram; HVAC = heating, ventilation and air conditioning; IHF = Initial Handling Facility; TC = transportation cask.

Source: Original

Figure F-4. IHF-ESD-04: Event Sequences for Activities Associated with Removal of the Naval Cask Lid and Installing the Naval Canister Lifting Adapter

IHF-ESD-05: Event Sequences for Activities Associated with Transfer of a Cask on CTT from Cask Preparation Area to Cask Unloading Room




NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a radionuclide release.

[b] Radionuclide release describes a condition where radioactive material has been released 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.

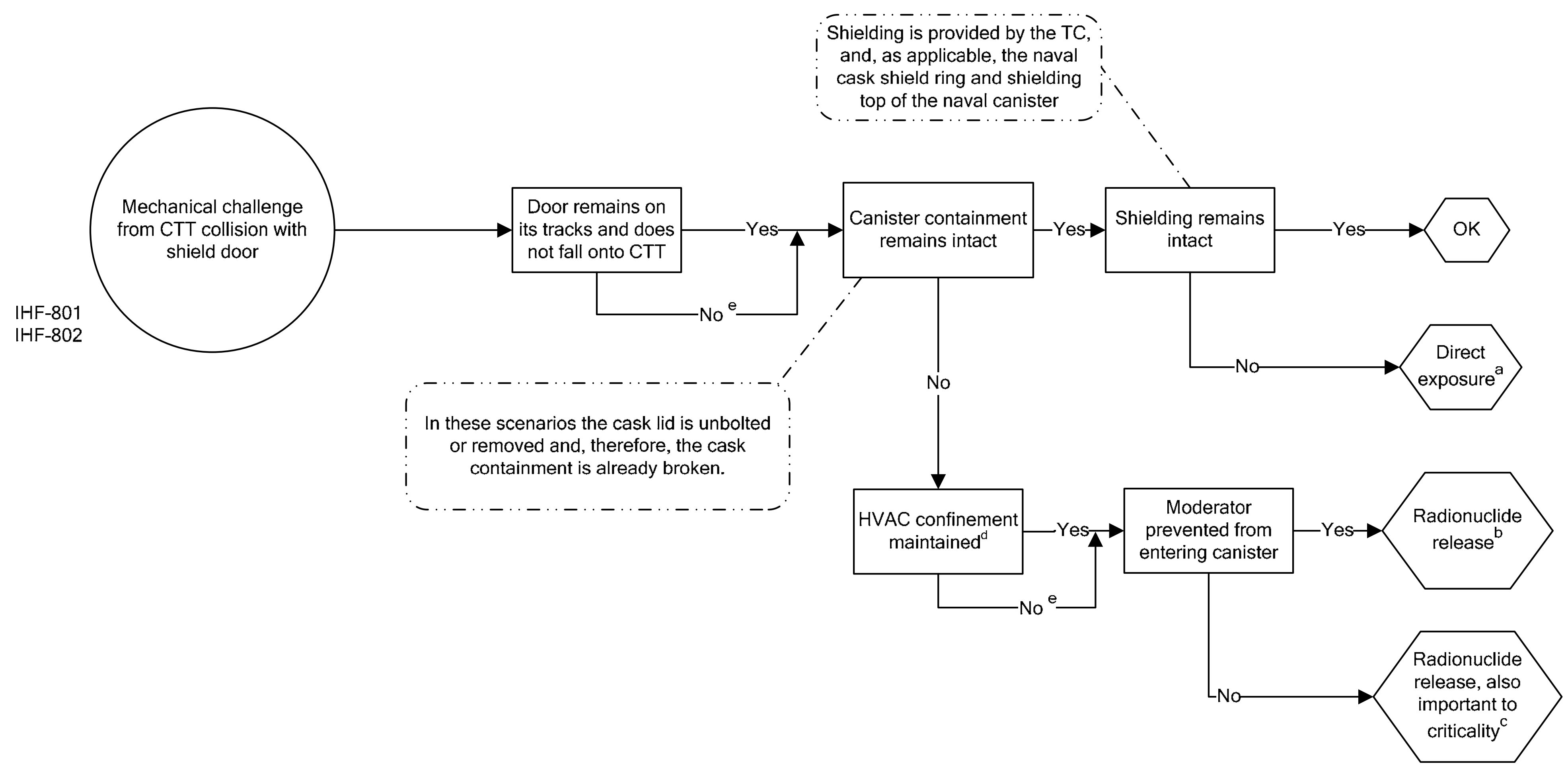
This ESD applies to naval and HLW waste forms.

CTT = cask transfer trolley; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation and air conditioning; IHF = Initial Handling Facility; TC = transportation cask.

Source: Original

Figure F-5. IHF-ESD-05: Event Sequences for Activities Associated with Transfer of a Cask on CTT from Cask Preparation Area to Cask Unloading Room

# IHF-ESD-06: Event Sequences for Activities Associated with Collision of CTT with Cask Unloading Room Shield Door




NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a radionuclide release.

Radionuclide release describes a condition where radioactive material has been released 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

[b] moderator is available to enter a breached container.

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

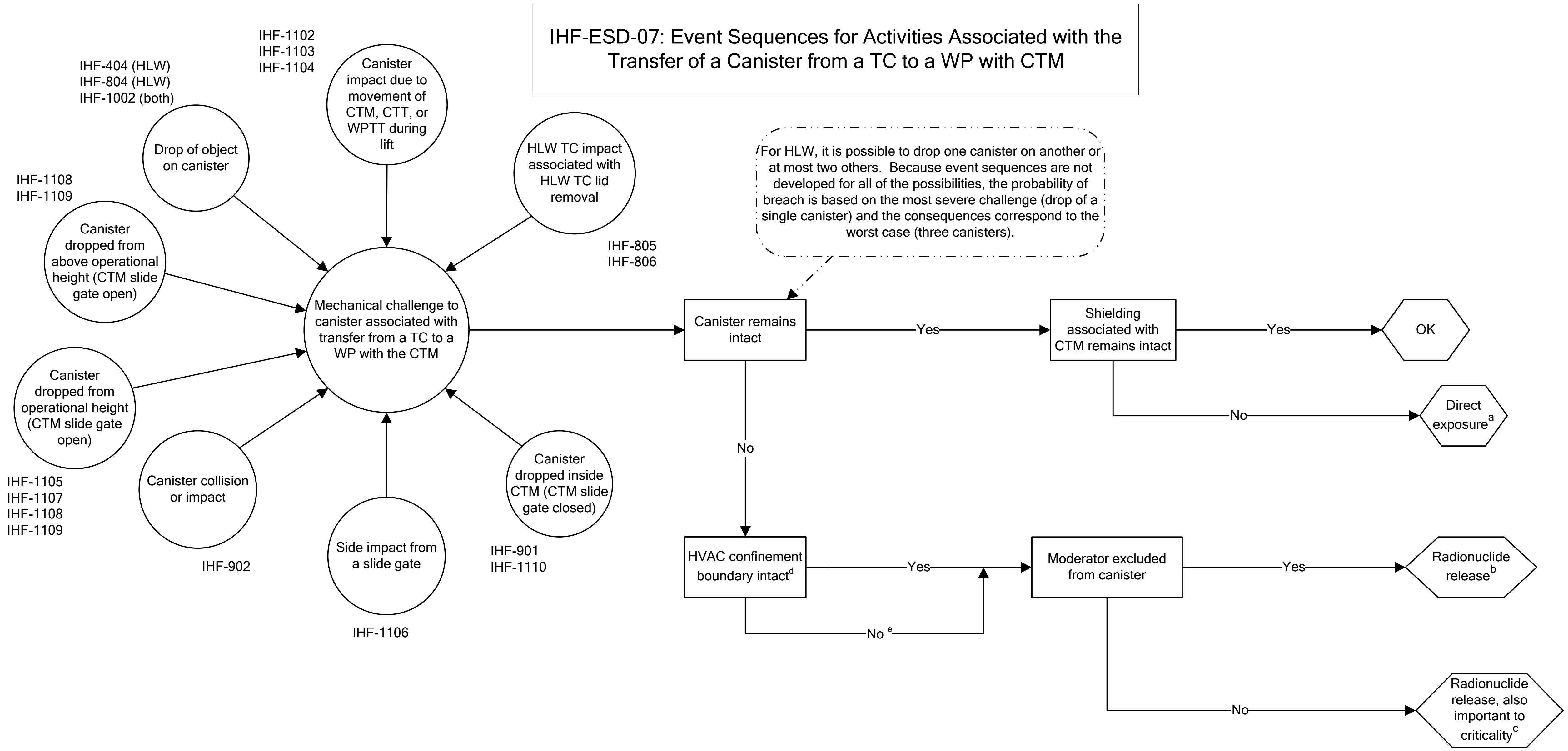
Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

[d] This ESD applies to naval and HLW waste forms.

[e] CTT = cask transfer trolley; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation and air conditioning; IHF = Initial Handling Facility; TC = transportation cask.

Source: Original

Figure F-6. IHF-ESD-06: Event Sequences for Activities Associated with Collision of CTT with Cask Unloading Room Shield Door




NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a radionuclide release.

Radionuclide release describes a condition where radioactive material has been released 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

b moderator is available to enter a breached container.

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

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.

d This ESD applies to naval and HLW waste forms. Where applicability of initiating events contributing to a small bubble is limited to one or the other waste form, the waste form applicability is

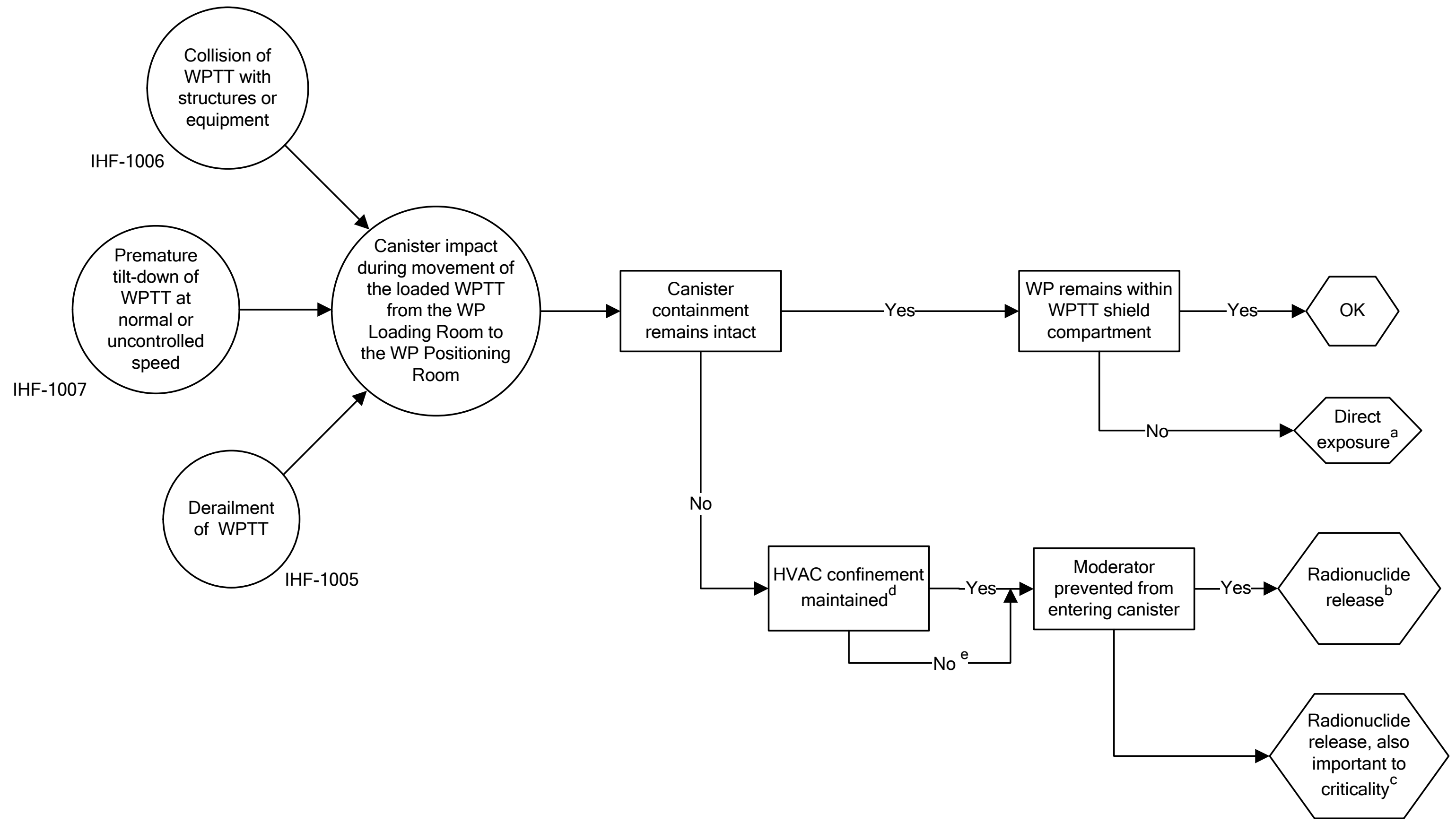
e indicated after the initiating event identifier as “(HLW)”, “(naval),” or “(both)”.

CTM = cask transfer machine; CTT = cask transfer trolley; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation and air conditioning; IHF = Initial Handling Facility; TC = transportation cask; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure F-7. IHF-ESD-07: Event Sequences for Activities Associated with the Transfer of a Canister to or from a TC to a WP with CTM

IHF-ESD-08: Event Sequences for Activities Associated with WP Transfer from WP Loading Room to Closing Position in WP Positioning Room below WP Closure Room




NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a radionuclide release.

Radionuclide release describes a condition where radioactive material has been released 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

[b] moderator is available to enter a breached container.

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

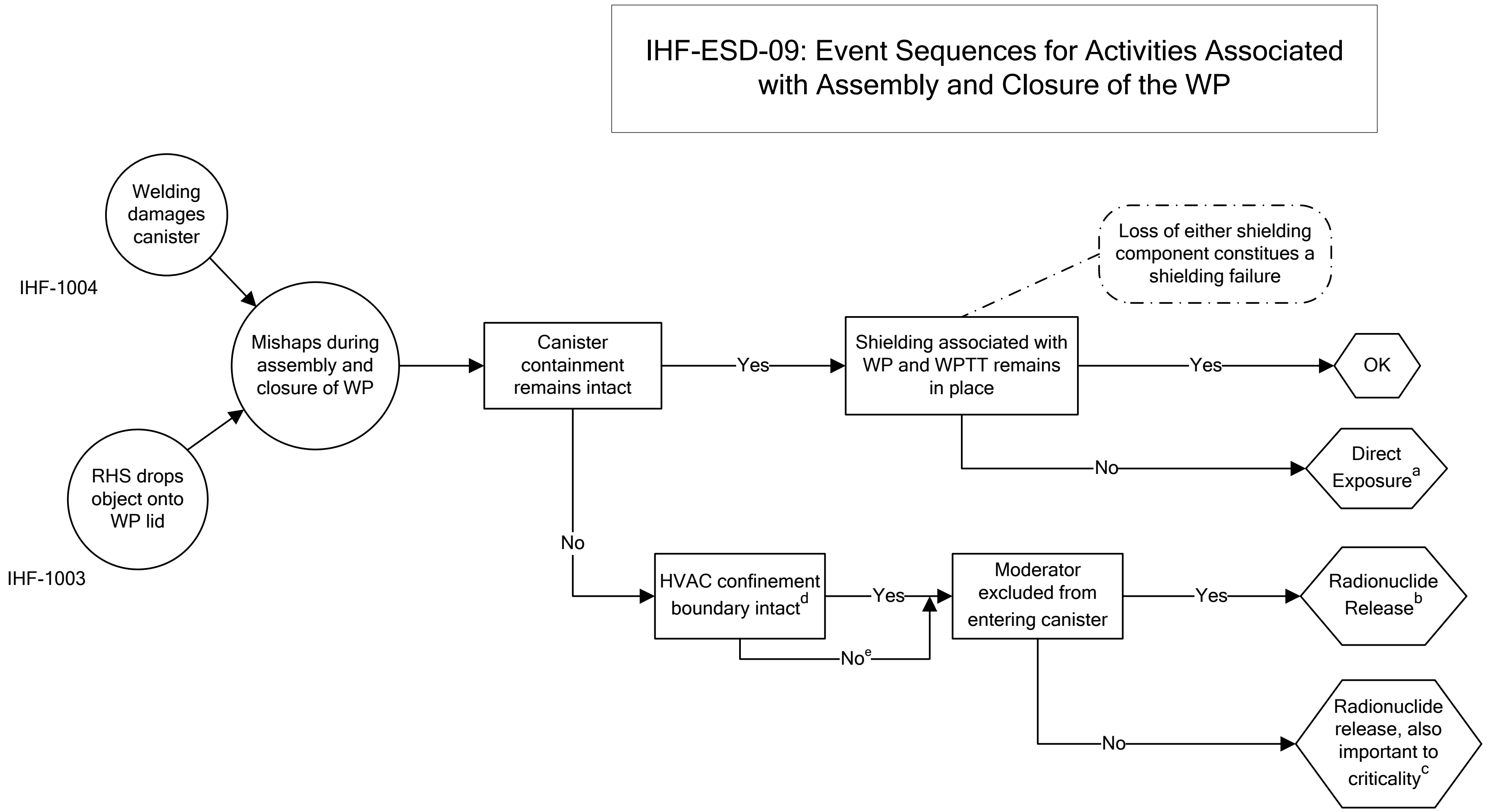
Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

[d] This ESD applies to naval and HLW waste forms.

[e] ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation and air conditioning; IHF = Initial Handling Facility; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure F-8. IHF-ESD-08: Event Sequences for Activities Associated with WP Transfer from WP Loading Room to Closing Position in WP Positioning Room below WP Closure Room




NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a radionuclide release. For this event sequence, the potential for direct exposure is limited because personnel would not normally be present during closure operations.

Radionuclide release describes a condition where radioactive material has been released 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

[b] moderator is available to enter a breached container.

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

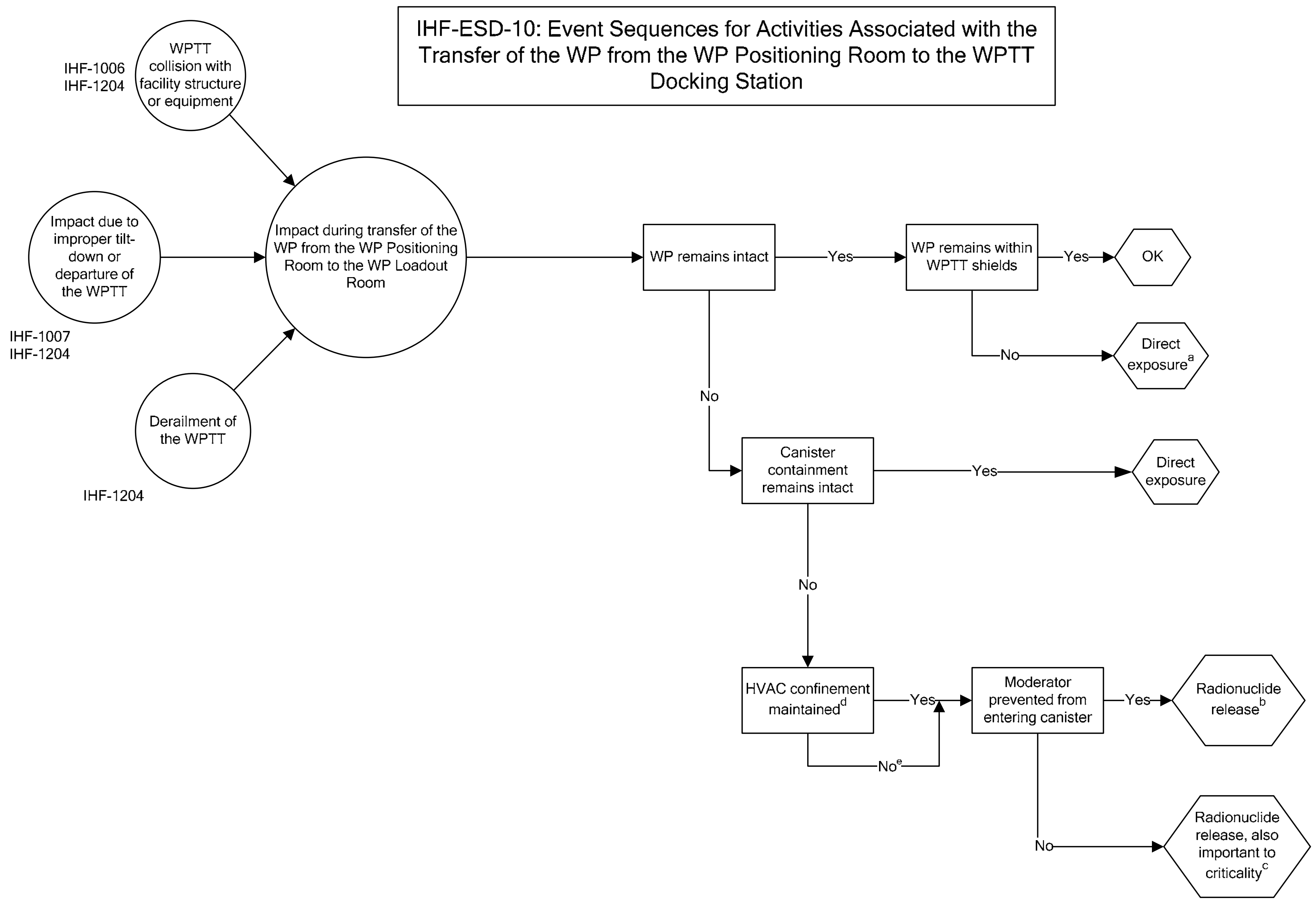
Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

[d] This ESD applies to naval and HLW waste forms.

[e] ESD = event sequence diagram; HVAC = heating, ventilation and air conditioning; IHF = Initial Handling Facility; RHS = remote handling system; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure F-9. IHF-ESD-09: Event Sequences for Activities Associated with Assembly and Closure of the WP




NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a radionuclide release.

Radionuclide release describes a condition where radioactive material has been released 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

[b] moderator is available to enter a breached container.

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

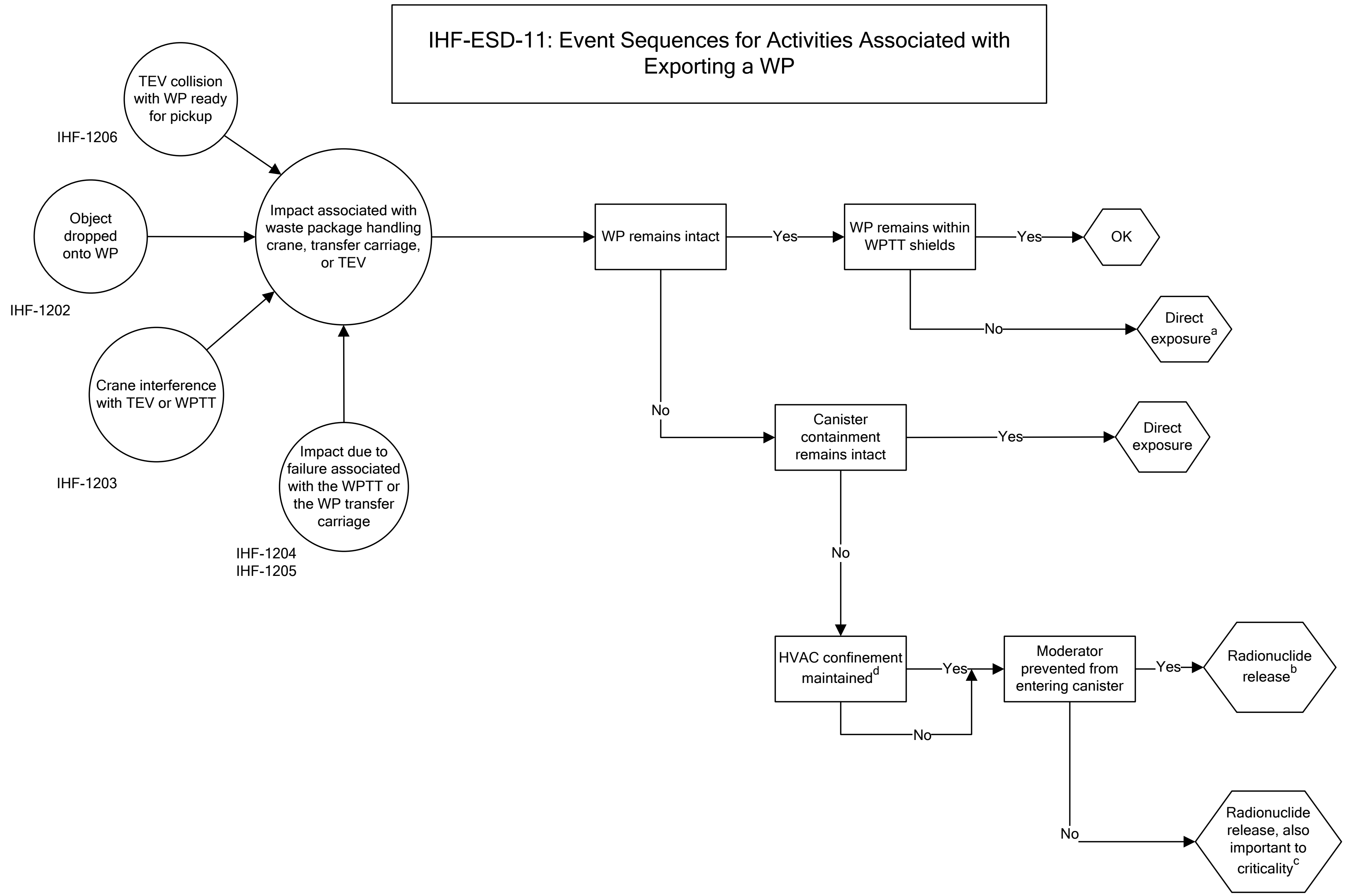
Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

[d] This ESD applies to naval and HLW waste forms.

[e] ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation and air conditioning; IHF = Initial Handling Facility; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure F-10. IHF-ESD-10: Event Sequences for Activities Associated with the Transfer of the WP from the WP Positioning Room to the WPTT Docking Station




NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a radionuclide release.

[b] Radionuclide release describes a condition where radioactive material has been released 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.

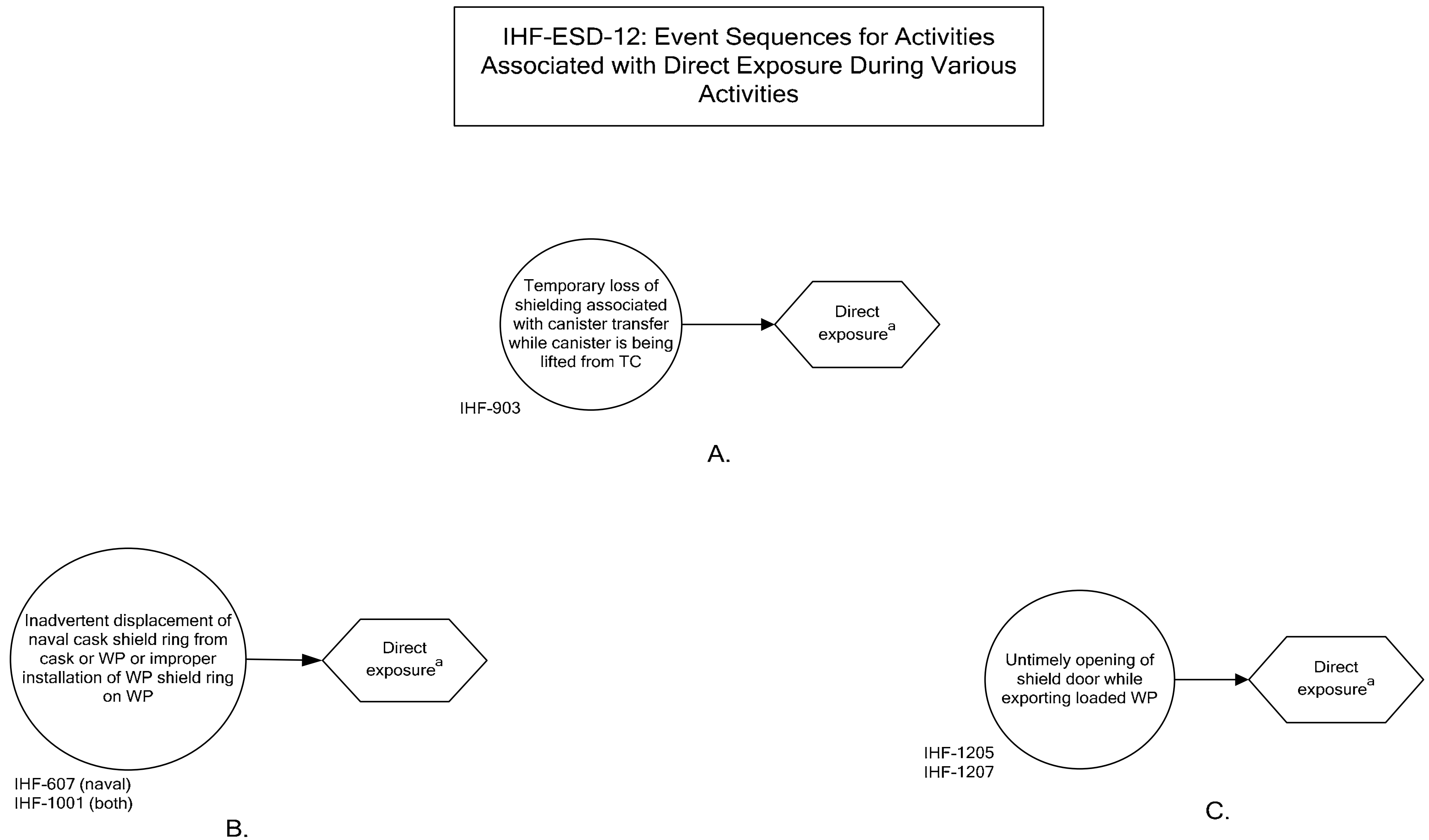
Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

This ESD applies to naval and HLW waste forms.

[e] ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation and air conditioning; IHF = Initial Handling Facility; TEV = transportation emplacement vehicle; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure F-11 IHF-ESD-11: Event Sequences for Activities Associated with Exporting a WP



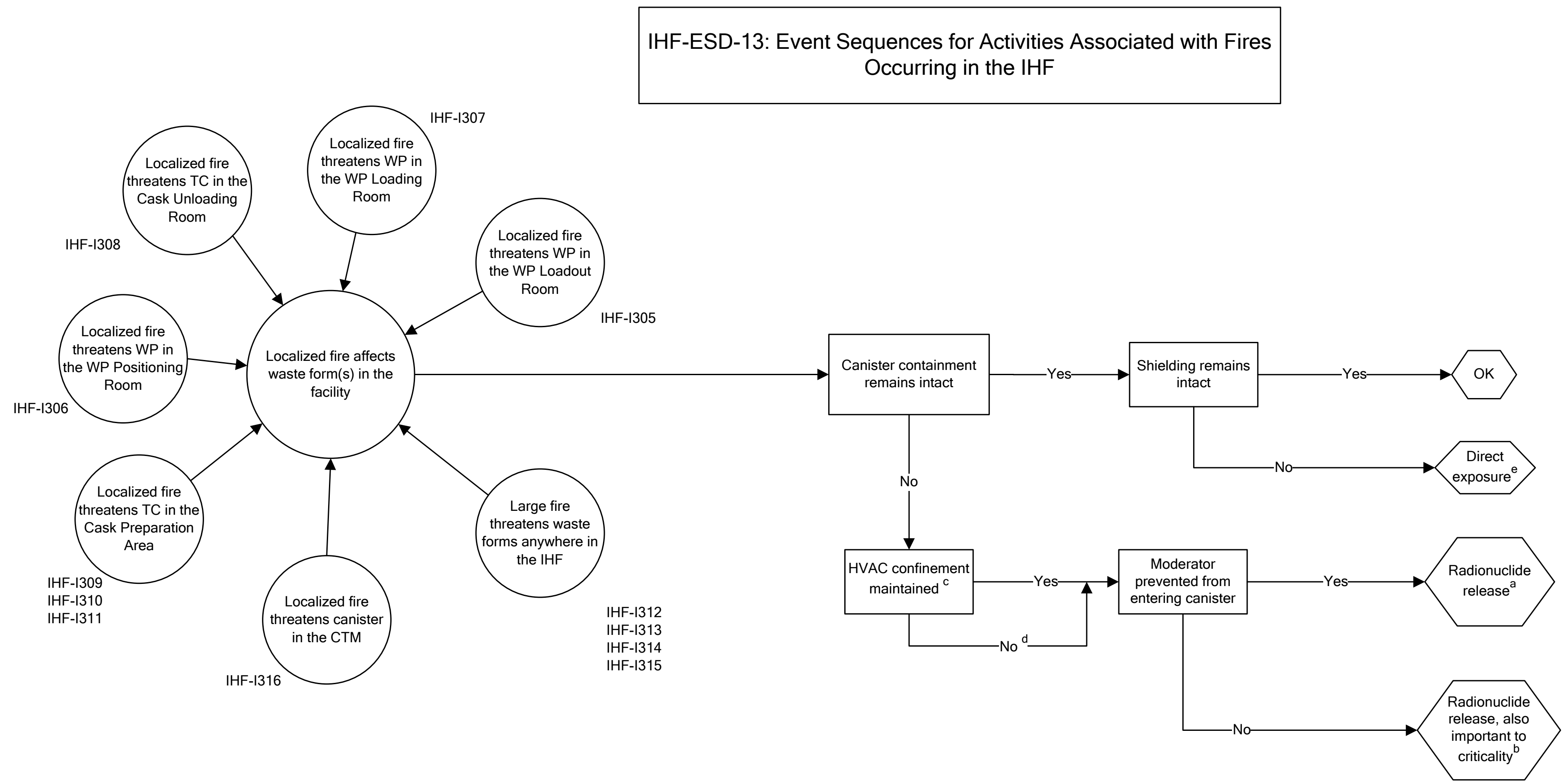

NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a radionuclide release.

This ESD applies to naval TCs and HLW TCs with impact limiters still in place. Where applicability of initiating events contributing to a small bubble is limited to one or the other waste form, the waste form applicability is indicated after the initiating event identifier as “(HLW)”, “(naval),” or “(both)”.

CTM = canister transfer machine; ESD = event sequence diagram; HLW = high-level radioactive waste; IHF = Initial Handling Facility; TC = transportation cask; WP = waste package.

Source: Original

Figure F-12. IHF-ESD-12: Event Sequences for Activities Associated with Direct Exposure during Various Activities




NOTE: [a] Radionuclide release describes a condition where radioactive material has been released 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.

Successful operation of the HVAC system would mitigate a radionuclide release. Filter degradation caused by fire could result in a failure to maintain HVAC confinement.

[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.

c Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a radionuclide release.

This ESD applies to naval and HLW waste forms.

CTM = canister transfer machine; ESD = event sequence diagram; IHF = Initial Handling Facility; HLW = high level radioactive waste;

e HVAC = heating, ventilation and air conditioning; TC = transportation cask; WP = waste package.

Source: Original

Figure F-13. IHF-ESD-13: Event Sequences Associated with Fires Occurring in the IHF

# ATTACHMENT G
# 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-38 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.

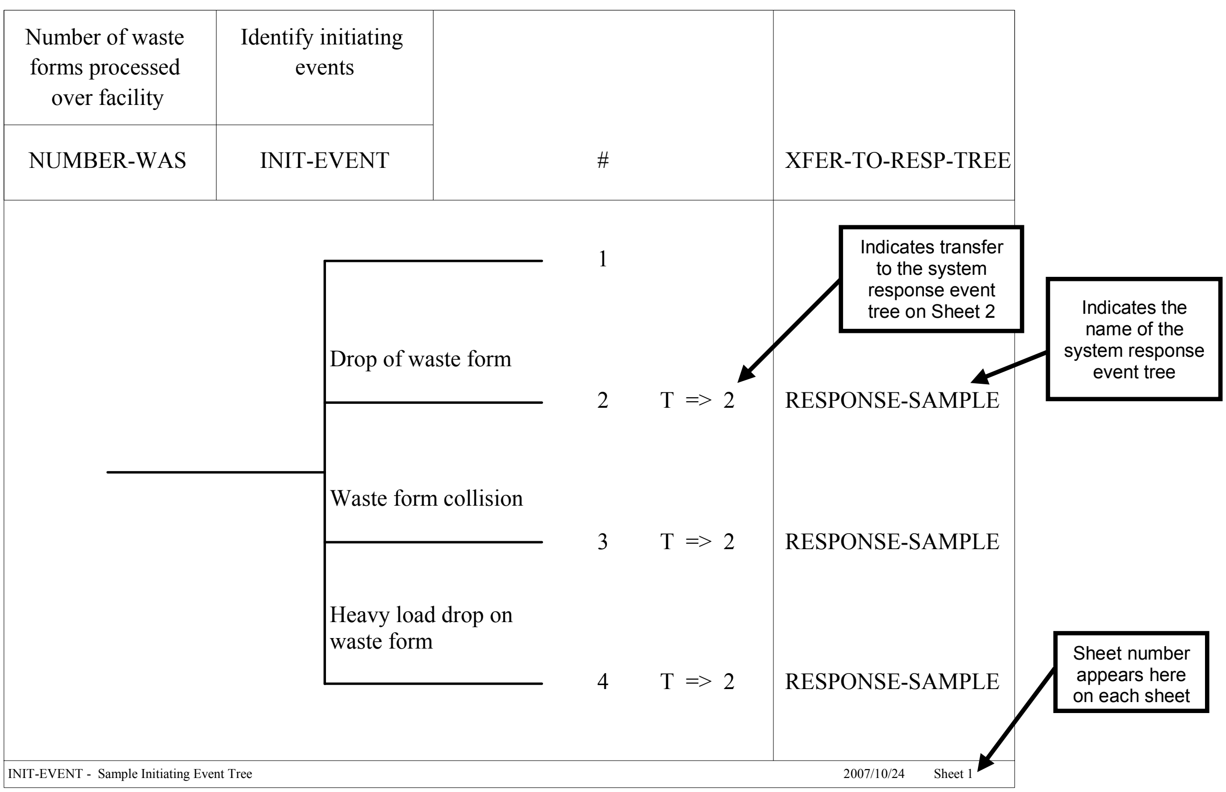



Figure G-1. Example Initiator Event Tree Showing Navigation Aids

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 |
|---|---|---|---|---|---|
| IHF-ESD-01 | Event Sequences for Activities Associated with Receipt of Naval or HLW TC on RC or TT in Cask Preparation Area and Upending and Transfer of Naval TC to CTT | ESD-01-HLW<br>ESD-01-NVL | Figure G-2<br>Figure G-4 | IHF-RESP-TC1<br>IHF-RESP-TC1 | Figure G-3<br>Figure G-3 |
| IHF-ESD-02 | Event Sequences for Activities Associated with Removal of Impact Limiters, Upending and Transfer of HLW Cask to CTT and Removal of Impact Limiters from Naval TC | ESD-02-HLW | Figure G-5 | IHF-RESP-TC1 | Figure G-3 |
| IHF-ESD-03 | Event Sequences for Activities Associated with Cask Preparation Activities Associated with Unbolting and Lid Adapter Installation for the HLW Cask | ESD-03-HLW | Figure G-6 | IHF-RESP-TC1 | Figure G-3 |
| IHF-ESD-04 | Event Sequences for Activities Associated with Removal of the Naval Cask Lid and Installing the Naval Canister Lifting Adapter | ESD-04-NVL | Figure G-7 | IHF-RESP-CAN1 | Figure G-8 |
| IHF-ESD-05 | Event Sequences for Activities Associated with Transfer of a Cask on CTT from Cask Preparation Area to Cask Unloading Room | ESD-05-HLW<br>ESD-05-NVL | Figure G-9<br>Figure G-11 | IHF-RESP-CAN2-HLW<br>IHF-RESP-CAN2-NVL | Figure G-10<br>Figure G-12 |
| IHF-ESD-06 | Event Sequences for Activities Associated with Collision of CTT with Cask Unloading Room Shield Door | ESD-06-HLW<br>ESD-06-NVL | Figure G-13<br>Figure G-14 | N/A<br>N/A | N/A<br>N/A |
| IHF-ESD-07 | Event Sequences for Activities Associated with the Transfer of a Canister to or from a TC to a WP with CTM | ESD-07-HLW<br>ESD-07-NVL | Figure G-15<br>Figure G-16 | IHF-RESP-CAN1<br>IHF-RESP-CAN1 | Figure G-8<br>Figure G-8 |
| IHF-ESD-08 | Event Sequences for Activities Associated with WP Transfer from WP Loading Room to Closing Position in WP Positioning Room below WP Closure Room | ESD-08-HLW<br>ESD-08-NVL | Figure G-17<br>Figure G-19 | IHF-RESP-WP1<br>IHF-RESP-WP1 | Figure G-18<br>Figure G-18 |
| IHF-ESD-09 | Event Sequences for Activities Associated with Assembly and Closure of the WP | ESD-09-HLW<br>ESD-09-NVL | Figure G-20<br>Figure G-22 | IHF-RESP-WP2<br>IHF-RESP-WP2 | Figure G-21<br>Figure G-21 |

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

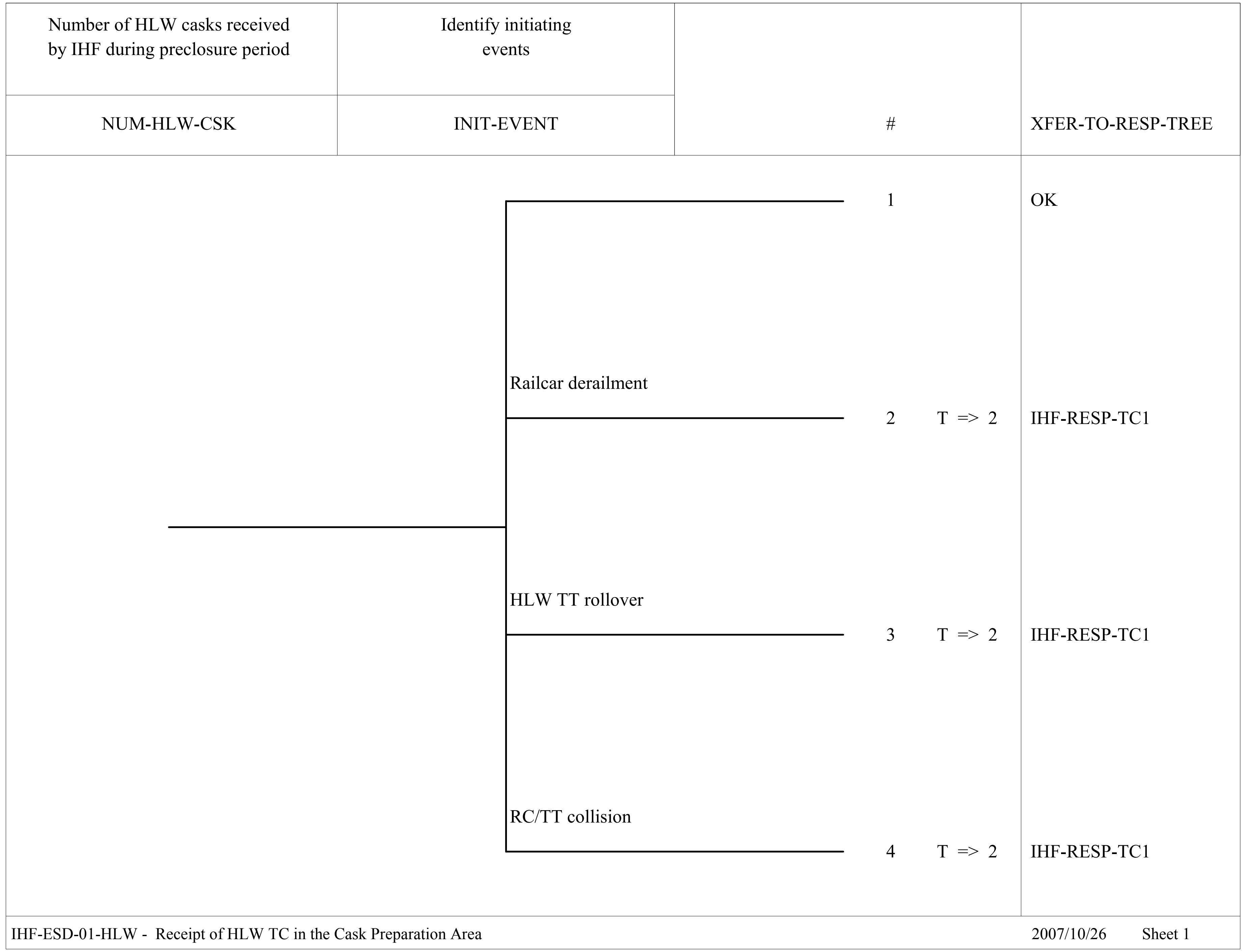
| ESD# | ESD Title | IE Event Tree Name | IE Event Tree Location | Response Tree Name | Response Tree Location |
|---|---|---|---|---|---|
| IHF-ESD-10 | Event Sequences for Activities Associated with the Transfer of the WP from the WP Positioning Room to the WPTT Docking Station | ESD-10-HLW<br>ESD-10-NVL | Figure G-23<br>Figure G-25 | IHF-RESP-WP3<br>IHF-RESP-WP3 | Figure G-24<br>Figure G-24 |
| IHF-ESD-11 | Event Sequences for Activities Associated with Exporting a WP | ESD-11-HLW<br>ESD-11-NVL | Figure G-26<br>Figure G-27 | IHF-RESP-WP3<br>IHF-RESP-WP3 | Figure G-24<br>Figure G-24 |
| IHF-ESD-12 | Event Sequences for Activities Associated with Direct Exposure During Various Activities | ESD-12A-HLW<br>ESD-12A-NVL<br>ESD-12B-HLW<br>ESD-12B-NVL<br>ESD-12C-HLW<br>ESD-12C-NVL | Figure G-28<br>Figure G-29<br>Figure G-30<br>Figure G-31<br>Figure G-32<br>Figure G-33 | N/A<br>N/A<br>N/A<br>N/A<br>N/A | N/A<br>N/A<br>N/A<br>N/A<br>N/A |
| IHF-ESD-13[a] | Event Sequences Associated with Fires Occurring in the IHF | ESD-13-HLW-CAN<br>ESD-13-HLW-CSK<br>ESD-13-HLW-WP<br>ESD-13-NVL | Figure G-34<br>Figure G-36<br>Figure G-37<br>Figure G-38 | IHF-RESP-FIRE | Figure G-35<br>Figure G-35<br>Figure G-35<br>Figure G-35 |

NOTE: [a] While only one event tree is used for the fire involving naval SNF, there are three event trees used for HLW. Naval SNF is delivered one canister to a TC and emplaced one canister to a waste package. Thus, the waste form count at each handling stage is the same. However, HLW is delivered either five to a TC (rail cask) or one to a TC (truck cask) and each canister is transferred individually. Finally, the canisters are emplaced five to a WP. Therefore, the number of TCs handled at the front end is not the same as the number of canisters handled by the CTM and may or may not be equal to the number of WPs at the back end (depending on whether any HLW truck casks are handled in the IHF). Because the initiating event frequencies are expressed as per individual unit over the preclosure period, and must be multiplied by the number of units handled, it works best within SAPHIRE to use a separate event tree for each different waste form count.

[b] A large fire can affect HLW in a number of different locations. Because of the unique nature of the HLW handling that results from five HLW canisters being in most TCs and five canisters being placed in each waste package, it is possible for HLW to be in multiple locations in differing amounts during HLW handling. This differs from naval SNF, which can only be in one location and configuration when a large fire occurs. To consider all of the possible permutations of HLW locations and configurations that could arise (e.g., 1 canister in the waste package and 4 in the TC; 1 in the waste package, 1 in the CTM, and 3 in the TC; 2 in the waste package and 3 in the TC, etc.) would greatly complicate the analysis. Therefore, a simplifying approach is called for. Because the waste package is a relatively thin vessel that is not intended to provide radiation shielding (except at the top), it provides less thermal protection for the canisters than the transportation cask and CTM shield bell do. Taking a conservative approach, the large fire frequencies affecting HLW are added together and all of the HLW present in the facility is considered to be in the WP. Thus, the large fire initiating event for HLW only appears on the fire event tree for the HLW waste package.

CAN = canister; CTM = canister transfer machine; CTT = cask transfer trolley; ESD = event sequence diagram; HLW = high-level radioactive waste; IHF = Initial Handling Facility; NVL = naval; RC = railcar; RESP = response; TC = transportation cask; TT = transfer trolley; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

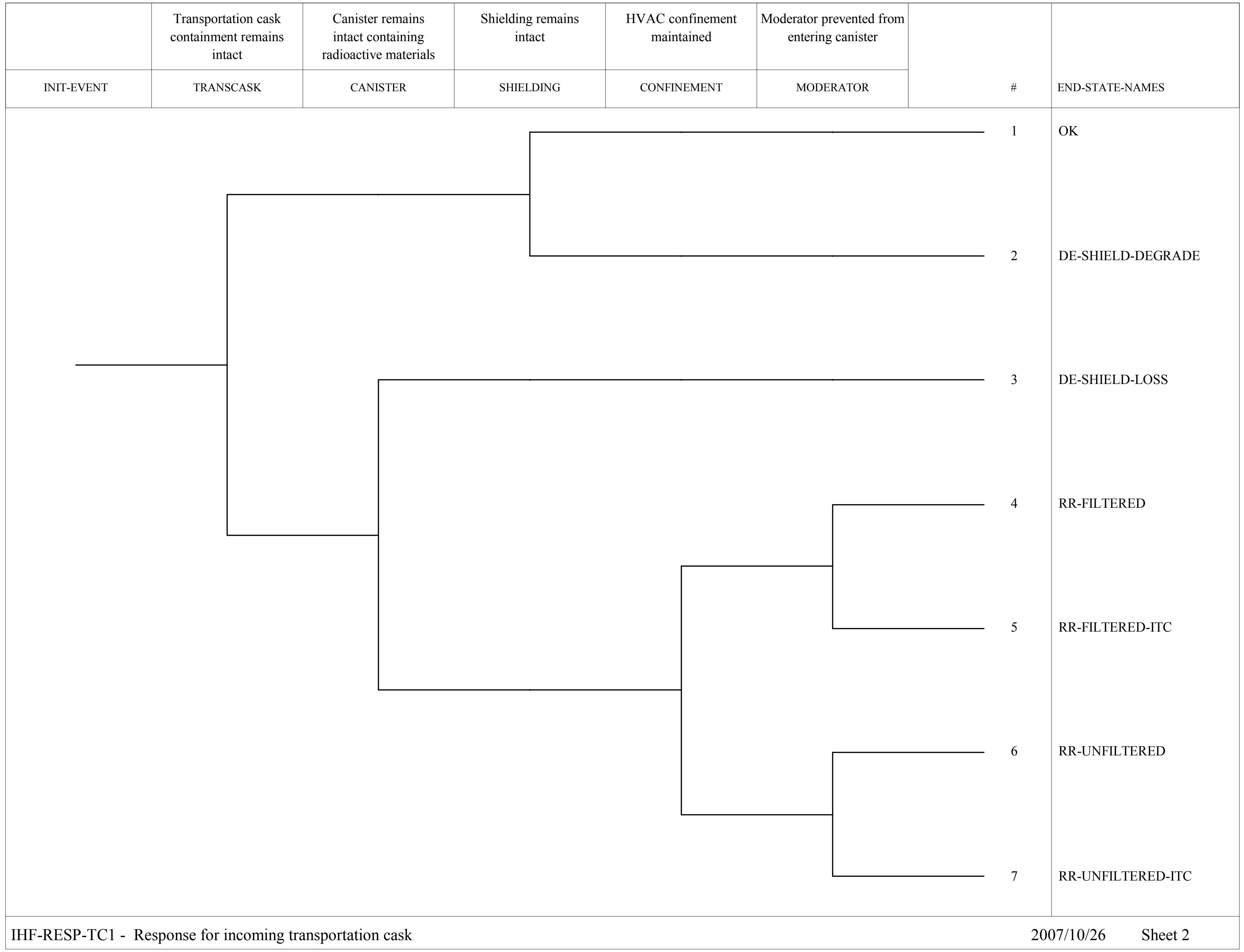



NOTE: The column of numbers under the "#" symbol is automatically provided by SAPHIRE and is not used elsewhere in this analysis.

CSK = cask; HLW = high-level (radioactive) waste; IHF = Initial Handling Facility; INIT = initiating; NUM = number; RC = railcar; RESP = response; T = transfer; TC = transportation cask; TT = truck trailer; XFER = transfer.

Source: Original

Figure G-2. Event Tree ESD-01-HLW – Receipt of HLW TC in the Cask Preparation Area




NOTE: DE = direct exposure; HVAC = heating, ventilation, and air conditioning; INIT = initiating; ITC = important to criticality; RR = radioactive release.

Source: Original

Figure G-3. Event Tree IHF-RESP-TC1 – Response for Incoming Transportation Cask

| Number of naval casks received by IHF over the preclosure period | Identify initiating events | # | | XFER-TO-RESP-TREE |
|---|---|---|---|---|
| NUM-NVL | INIT-EVENT | | | |
| | | 1 | | OK |
| | Crane drops object | 2 | T => 2 | IHF-RESP-TC1 |
| | Crane drops TC from operational height | 3 | T => 2 | IHF-RESP-TC1 |
| | Crane drops TC from above operational height | 4 | T => 2 | IHF-RESP-TC1 |
| | Railcar derailment | 5 | T => 2 | IHF-RESP-TC1 |
| | RC collision | 6 | T => 2 | IHF-RESP-TC1 |
| | Cask collision off railcar | 7 | T => 2 | IHF-RESP-TC1 |
| | Naval TC tipover | 8 | T => 2 | IHF-RESP-TC1 |

IHF-ESD-01-NVL - Receipt of naval TC in the Cask Preparation Area and transfer to CTT 2008/01/04 Sheet 3

NOTE: CTT = cask transfer trolley; IHF = Initial Handling Facility; INIT = initiating; NUM = number; NVL = naval; RC = railcar; RESP = response; T = transfer; TC = transportation cask; TT = truck trailer; XFER = transfer.

Source: Original

Figure G-4 Event Tree ESD-01-NVL – Receipt of Naval TC in the Cask Preparation Area and Transfer to CTT

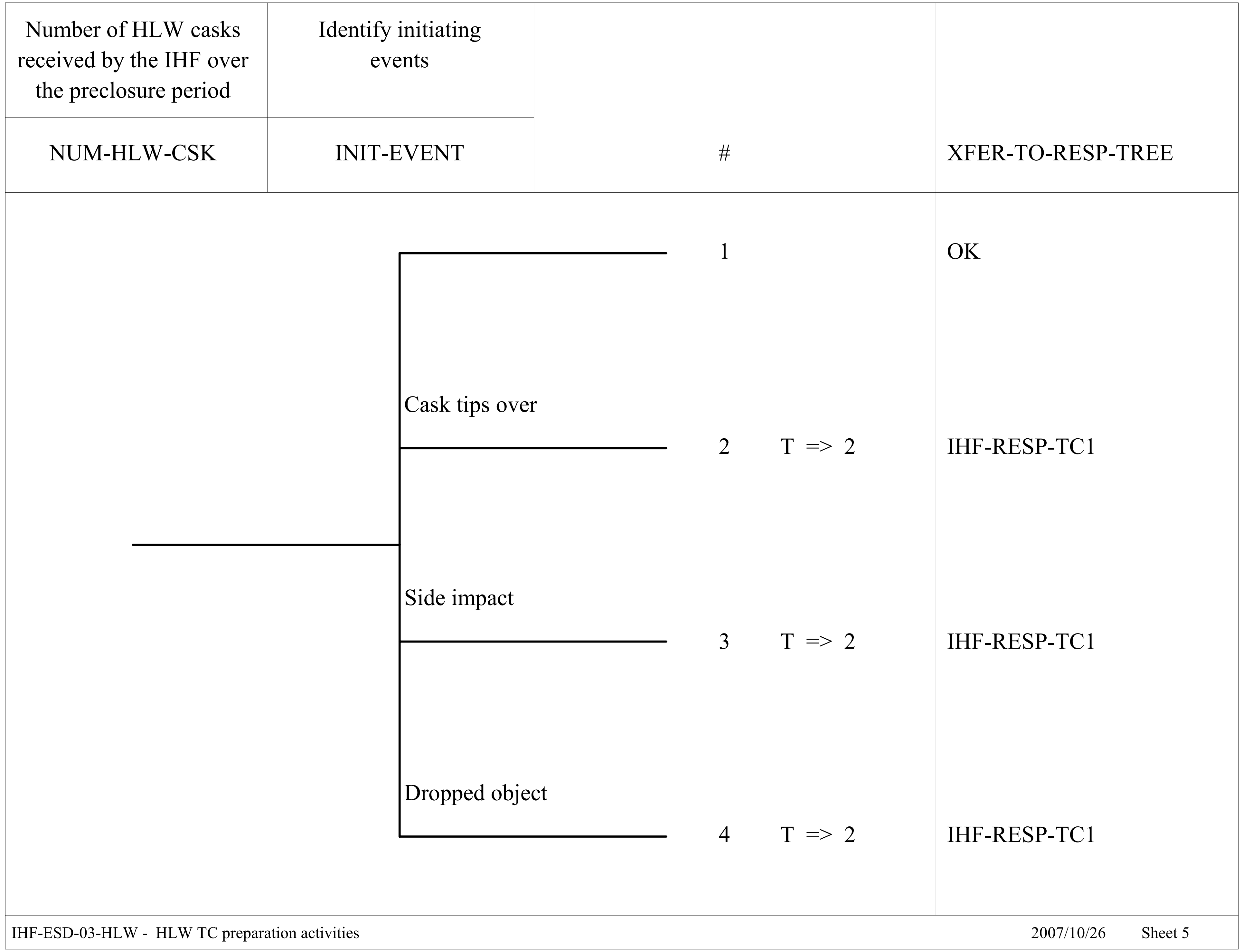
| Number of HLW casks received by IHF over the preclosure period | Identify initiating events | | |
|---|---|---|---|
| NUM-HLW-CSK | INIT-EVENT | # | XFER-TO-RESP-TREE |
| | | 1 | OK |
| | Cask drop from operational height | 2 T => 2 | IHF-RESP-TC1 |
| | Cask drop from above operational height | 3 T => 2 | IHF-RESP-TC1 |
| | Unplanned conveyance movement | 4 T => 2 | IHF-RESP-TC1 |
| | Collision with side impact | 5 T => 2 | IHF-RESP-TC1 |
| | Dropped object | 6 T => 2 | IHF-RESP-TC1 |
| | HLW TC tip over | 7 T => 2 | IHF-RESP-TC1 |

IHF-ESD-02-HLW - HLW TC upending and removal from conveyance 2007/10/26 Sheet 4

NOTE: CSK = cask; HLW = high-level (radioactive) waste; IHF = Initial Handling Facility; INIT = initiating; NUM = number; RESP = response; T = transfer; TC = transportation cask; XFER = transfer.

Source: Original

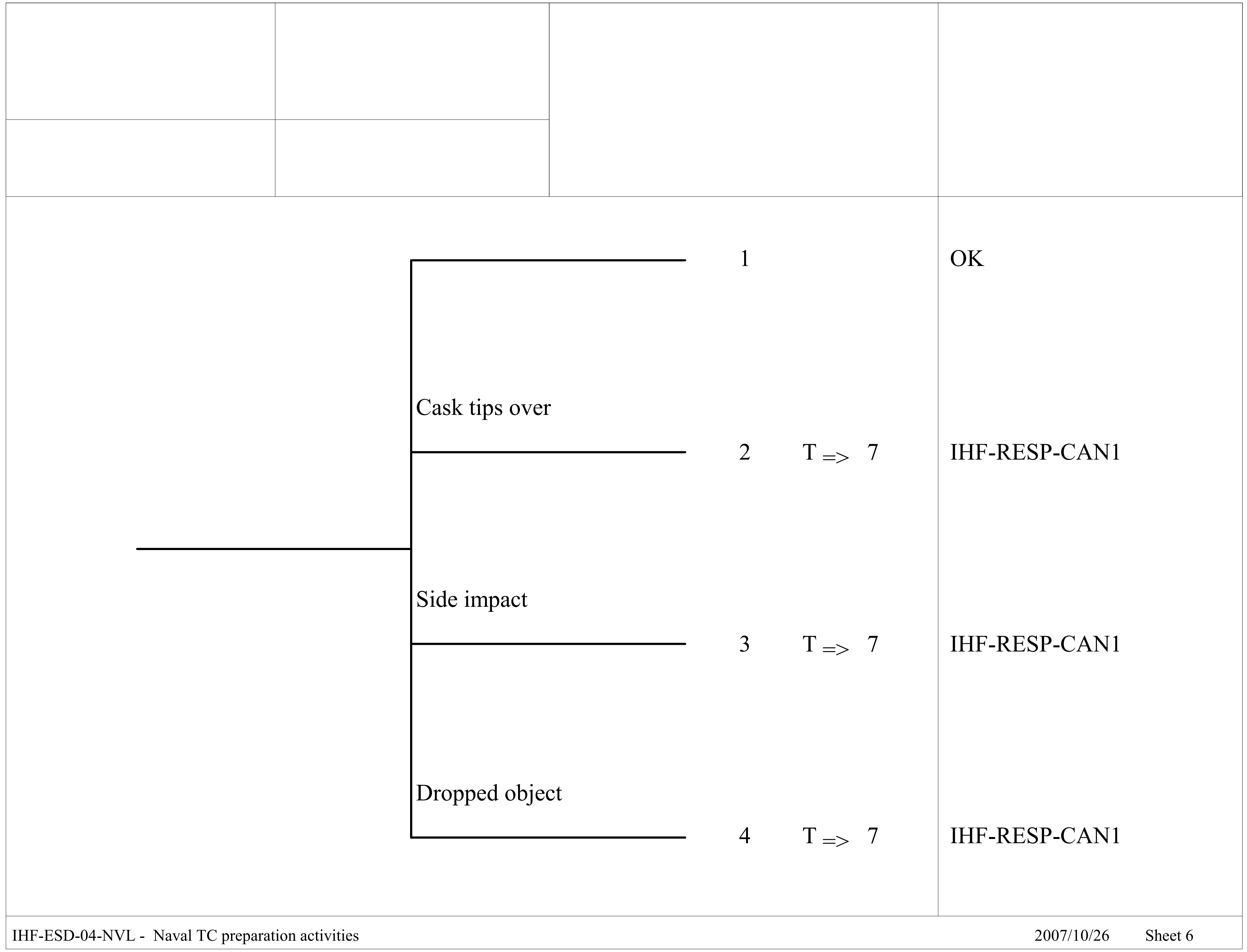
Figure G-5. Event Tree ESD-02-HLW – HLW TC Upending and Removal from Conveyance




NOTE: CSK = cask; HLW = high-level (radioactive) waste; IHF = Initial handling Facility; INIT = initiating; NUM = number; RESP = response; T = transfer; TC = transportation cask; XFER = transfer.

Source: Original

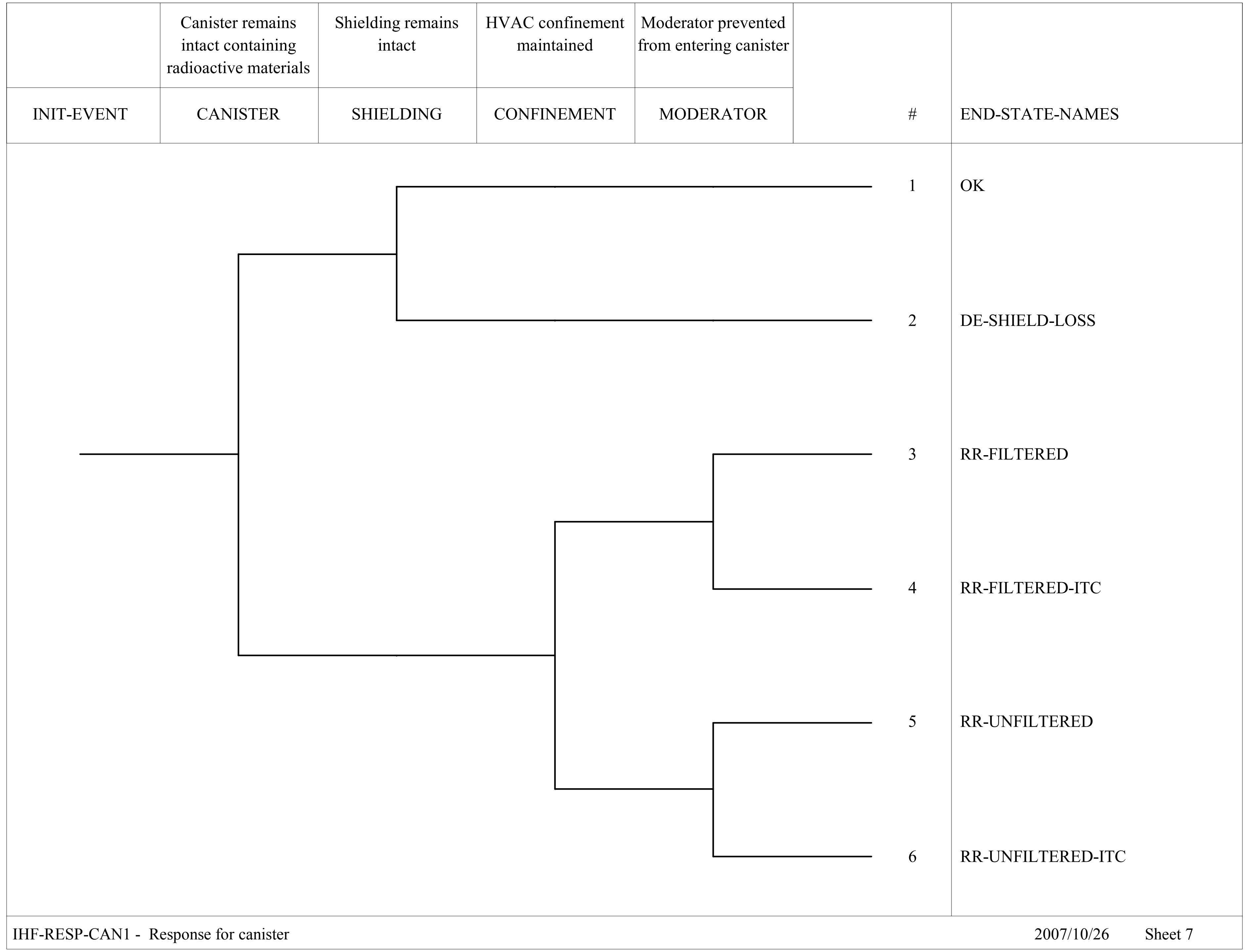
Figure G-6. Event Tree ESD-03-HLW – HLW TC Preparation Activities




NOTE: CAN = canister; IHF = Initial Handling Facility; INIT = initiating; NUM = number; NVL = naval; RESP = response; T = transfer; TC = transportation cask; XFER = transfer.

Source: Original

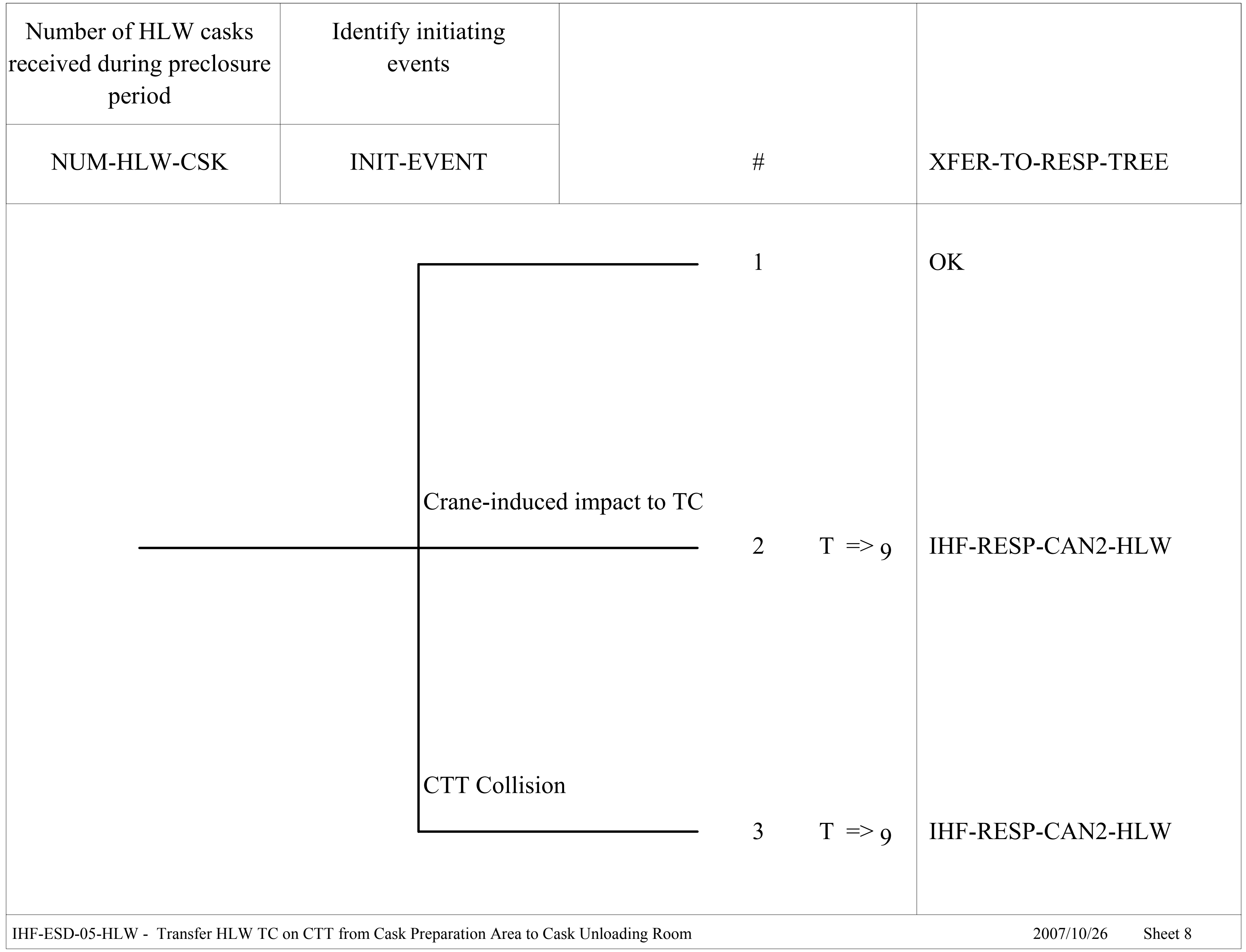
Figure G-7. Event Tree ESD-04-NVL – Naval TC Preparation Activities




NOTE: DE = direct exposure; HVAC = heating, ventilation, and air conditioning; INIT = initiating; ITC = important to criticality; RR = radioactive release.

Source: Original

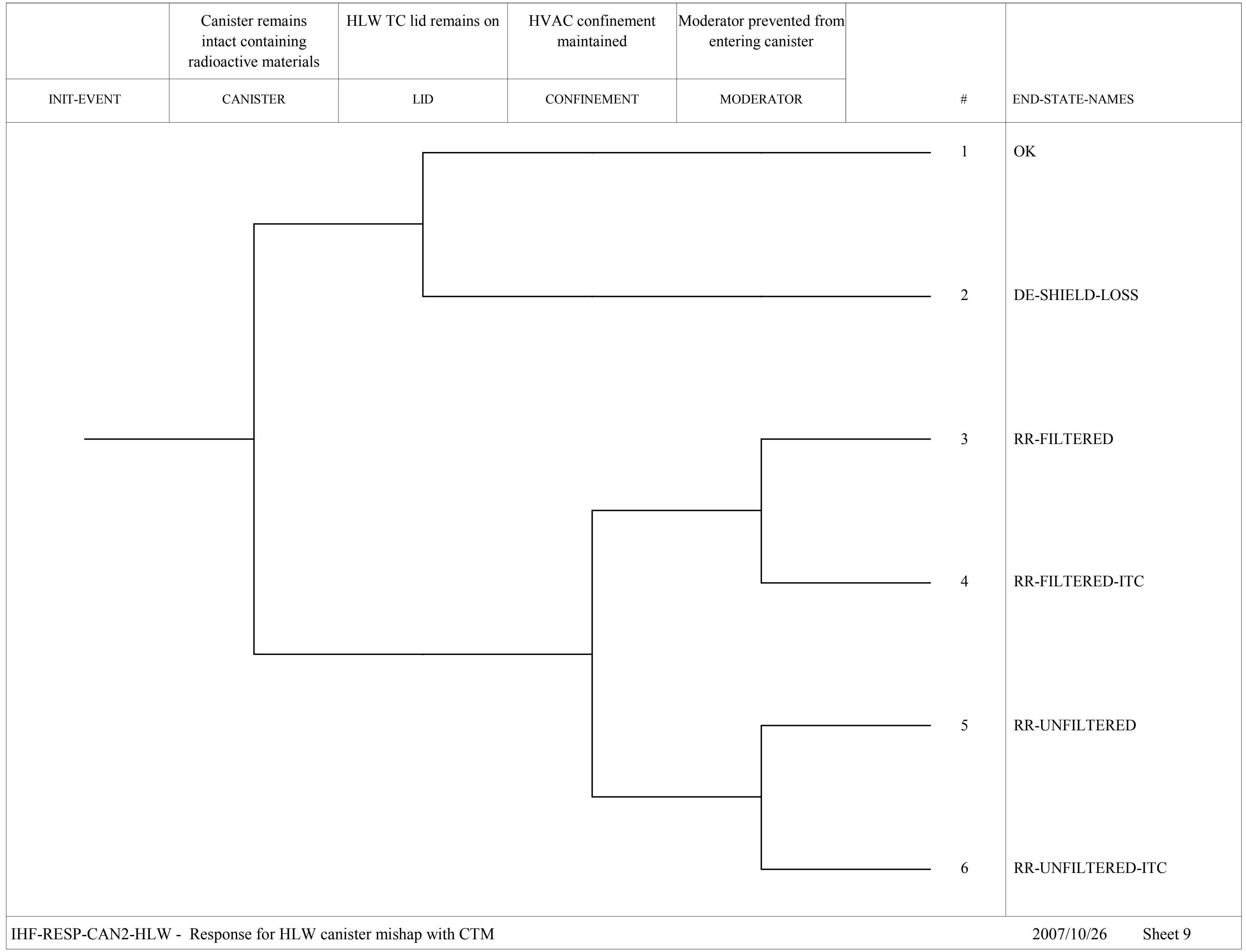
Figure G-8. Event Tree IHF-RESP-CAN1 – Response for Canister




NOTE: CAN = canister; CSK = cask; CTT = cask transfer trolley; HLW = high-level (radioactive) waste; IHF = Initial Handling Facility; INIT = initiating; NUM = number; NVL = naval; RESP = response; T = transfer; TC = transportation cask; XFER = transfer.

Source: Original

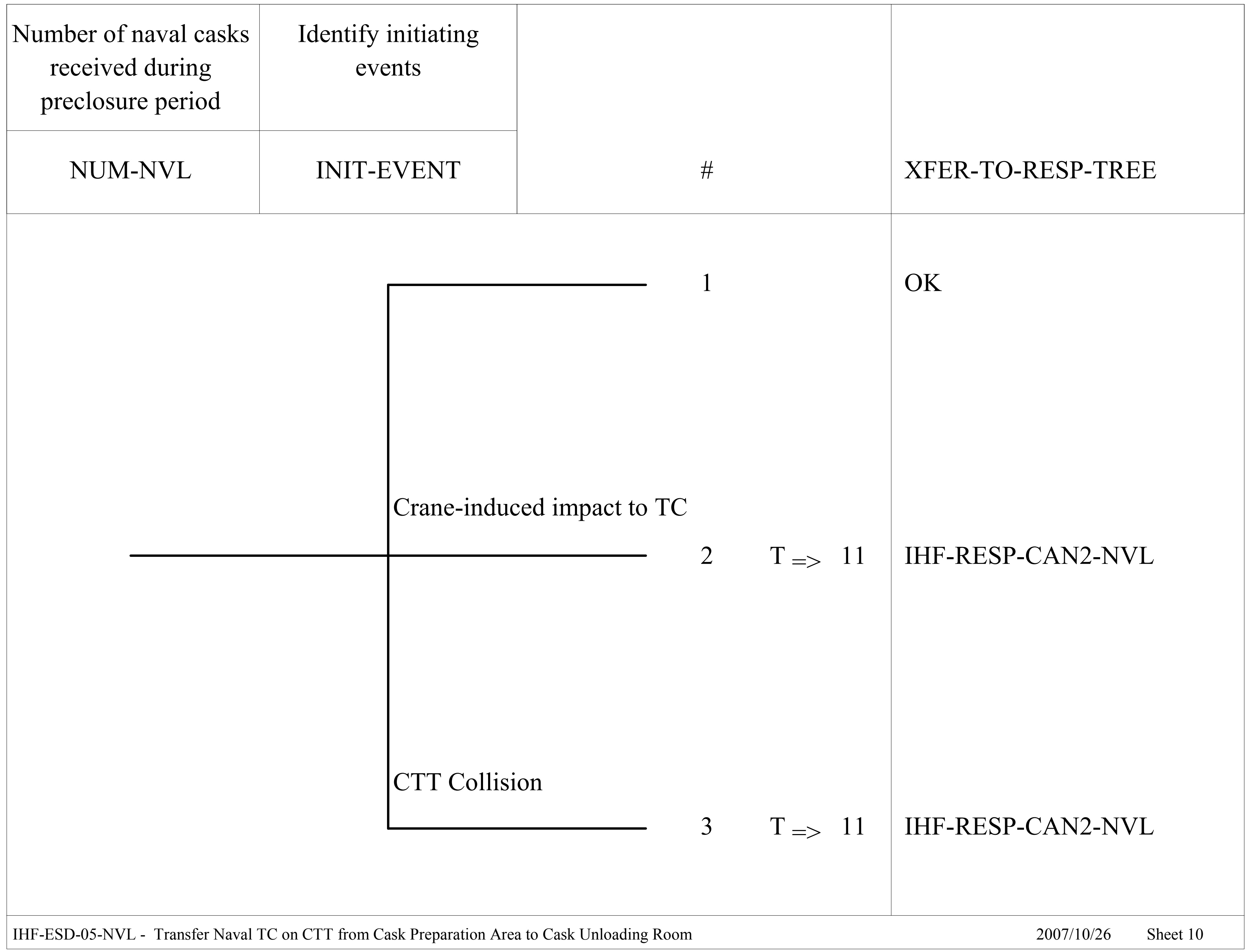
Figure G-9. Event Tree ESD-05-HLW – Transfer HLW TC on CTT from Cask Preparation Area to Cask Unloading Room




NOTE: CTM = canister transfer machine; DE = direct exposure; HLW = high-level (radioactive) waste; HVAC = heating, ventilation, and air conditioning; INIT = initiating; ITC = important to criticality; RR = radioactive release.

Source: Original

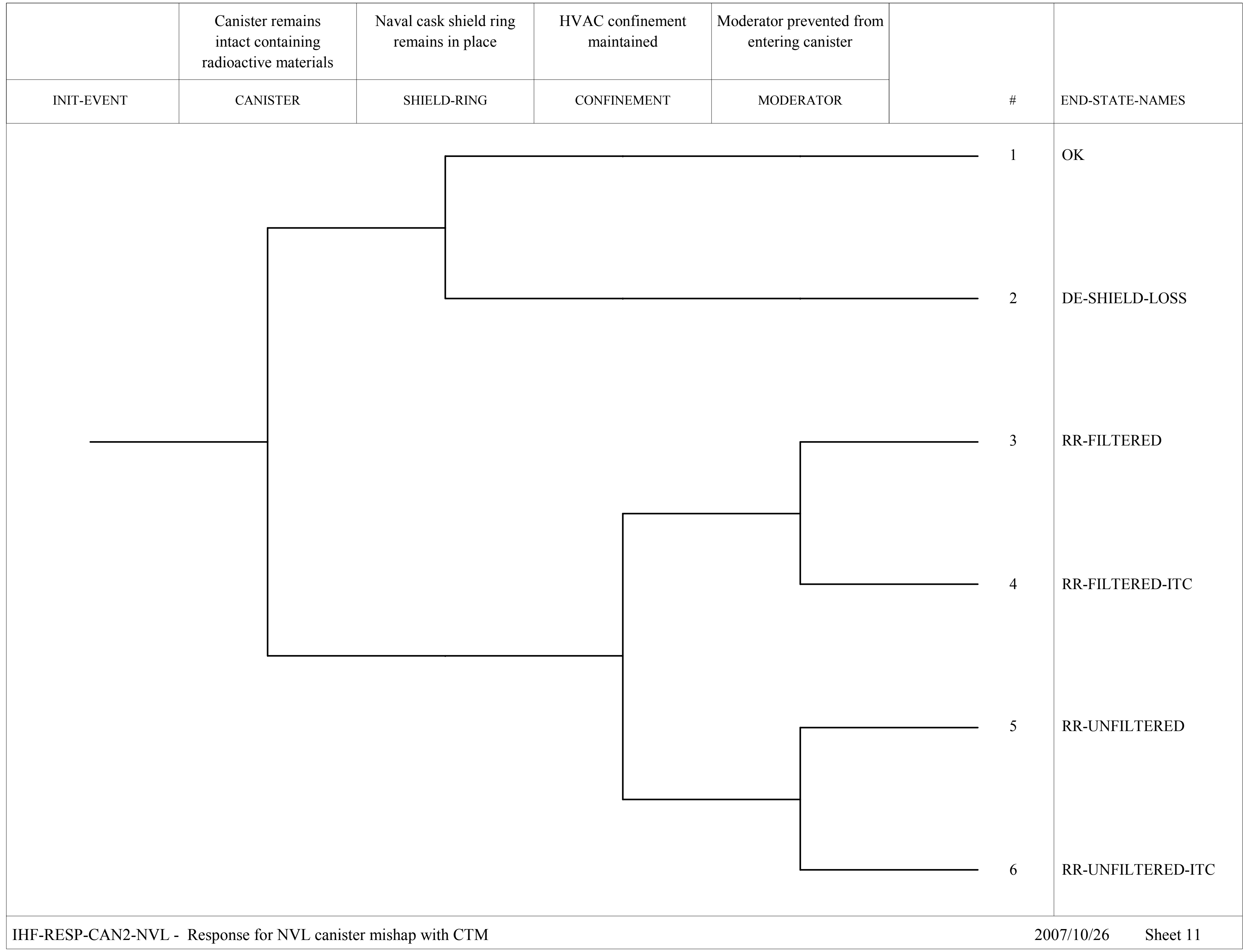
Figure G-10. Event Tree IHF-RESP-CAN2-HLW – Response for HLW Canister Mishap with CTM




NOTE: CAN = canister; CTT = cask transfer trolley; IHF = Initial Handling Facility; INIT = initiating; NUM = number; NVL = naval; RESP = response; T = transfer; TC = transportation cask; XFER = transfer.

Source: Original

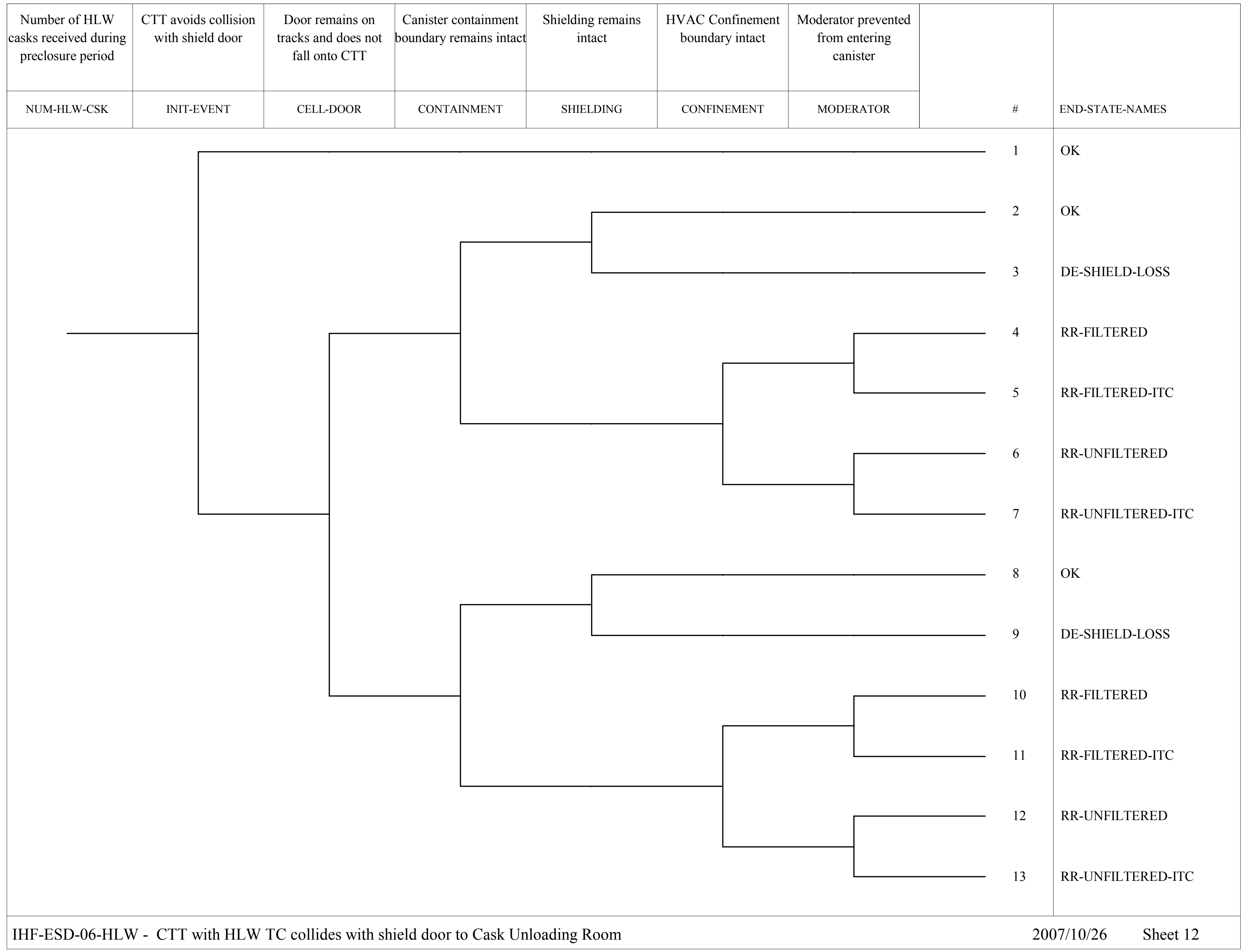
Figure G-11. Event Tree ESD-05-NVL – Transfer Naval TC on CTT from Cask Preparation Area to Cask Unloading Room




NOTE: DE = direct exposure; HVAC = heating, ventilation, and air conditioning; INIT = initiating; ITC = important to criticality; RR = radioactive release.

Source: Original

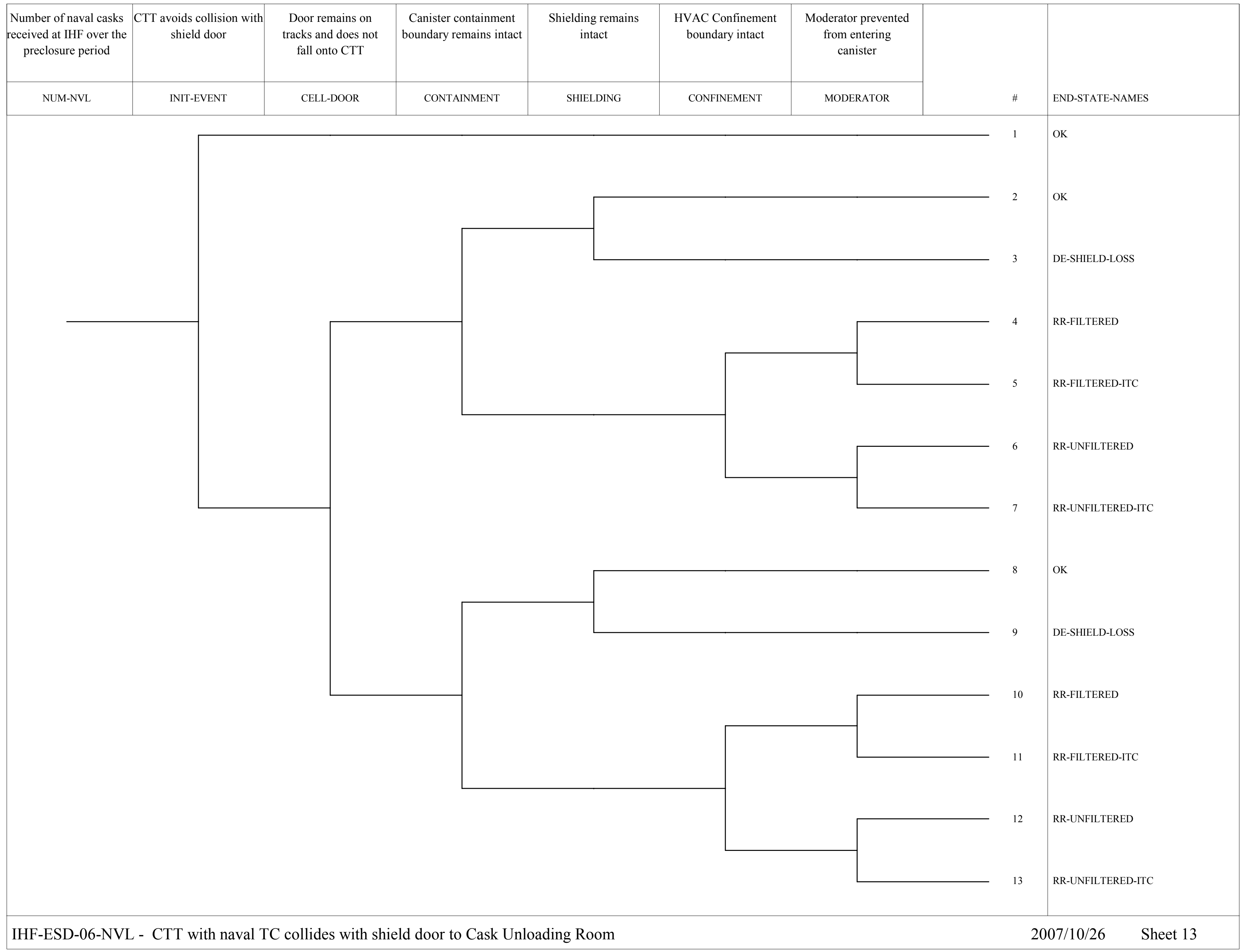
Figure G-12. Event Tree IHF-RESP-CAN2-NVL – Response for NVL Canister Mishap with CTM




NOTE: CSK = cask; CTT = cask transfer trolley; DE = direct exposure; HLW = high-level (radioactive) waste; HVAC = heating, ventilation, and air conditioning; INIT = initiating; ITC = important to criticality; NUM = number; RR = radioactive release; TC = transportation cask.

Source: Original

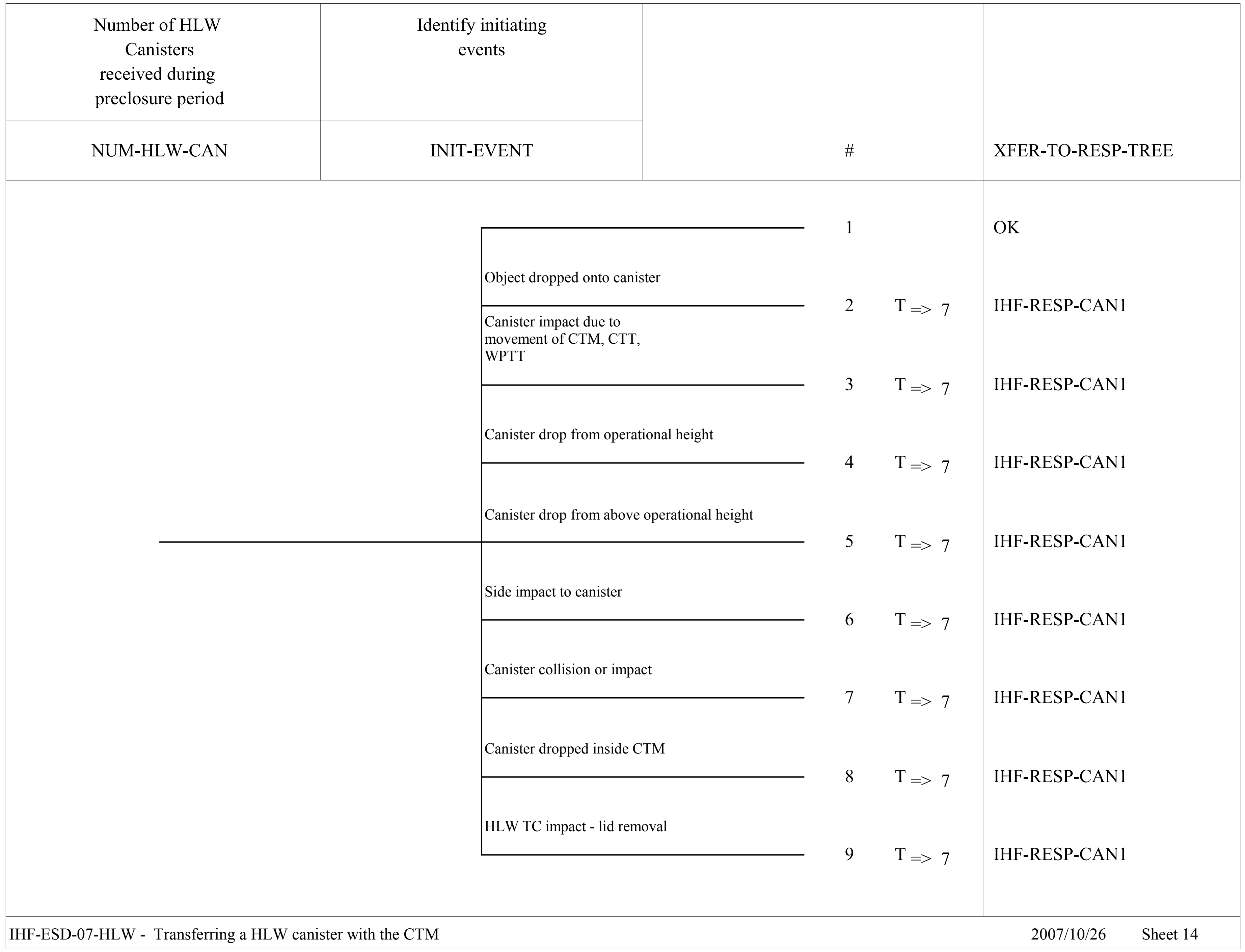
Figure G-13. Event Tree ESD-06-HLW – CTT with HLW TC Collides with Shield Door to Cask Unloading Room




NOTE: CTT = cask transfer trolley; DE = direct exposure; HVAC = heating, ventilation, and air conditioning; IHF = Initial Handling Facility; INIT = initiating; ITC = important to criticality; NUM = number; NVL = naval; RR = radioactive release; TC = transportation cask.

Source: Original

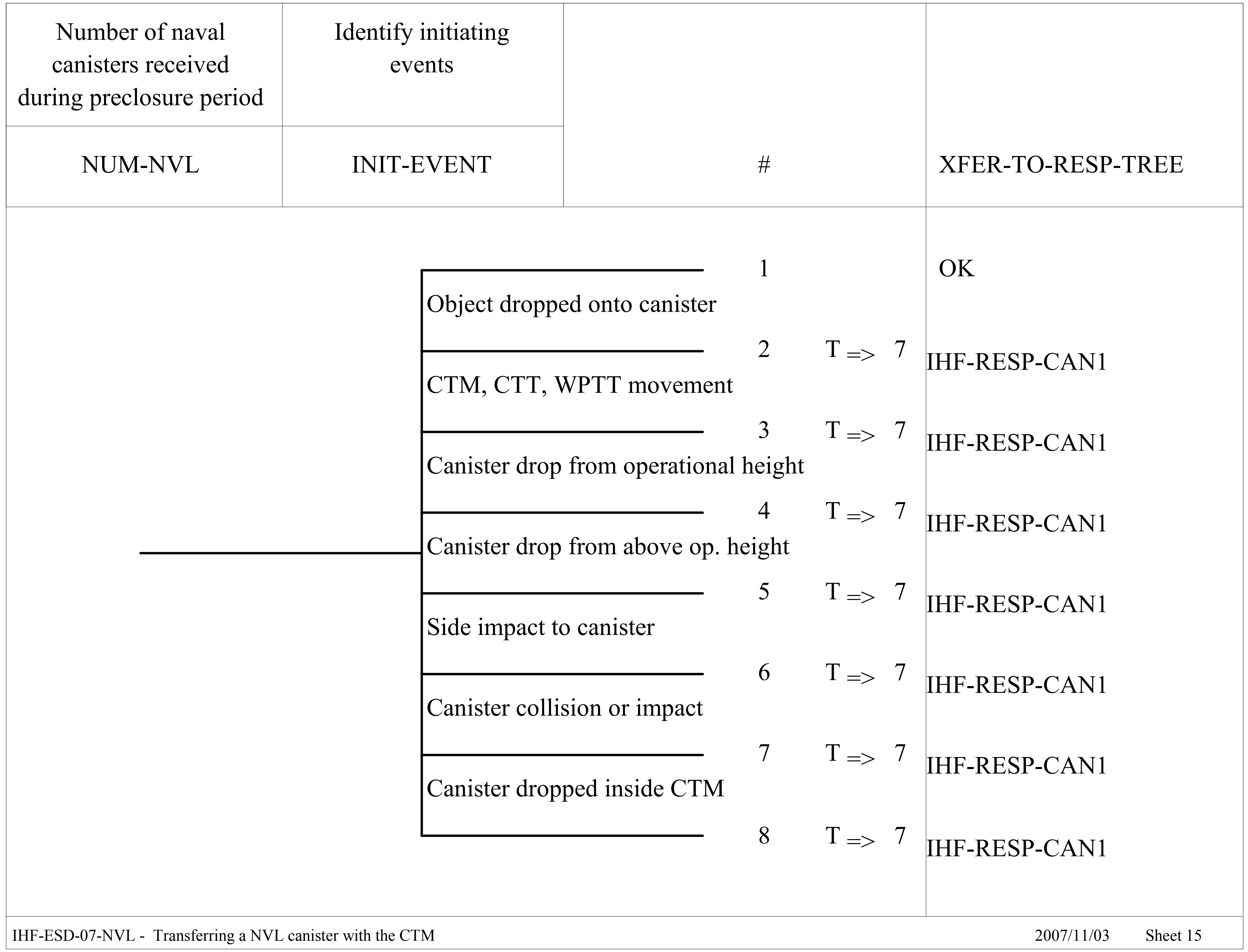
Figure G-14. Event Tree ESD-06-NVL – CTT with Naval TC Collides with Shield Door to Cask Unloading Room




NOTE: CAN = canister; CTM = canister transfer machine; CTT = cask transfer trolley; HLW = high-level (radioactive) waste; IHF = Initial Handling Facility; INIT = initiating; NUM = number; RESP = response; T = transfer; WPTT = waste package transfer trolley; XFER = transfer.

Source: Original

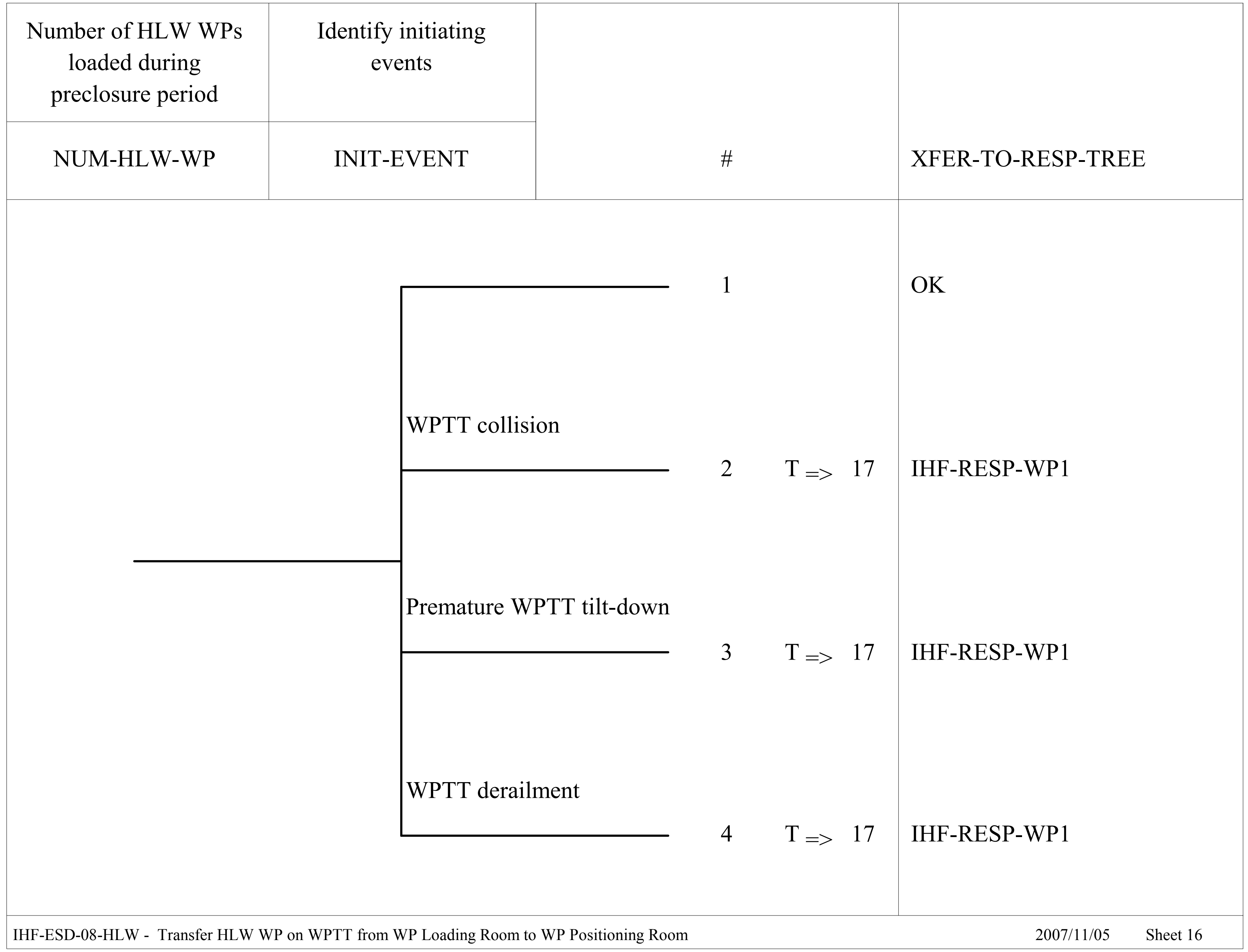
Figure G-15. Event Tree ESD-07-HLW – Transfer a HLW Canister with the CTM




NOTE: CAN = canister; CTM = canister transfer machine; CTT = cask transfer trolley; IHF = Initial Handling Facility; INIT = initiating; NUM = number; NVL = naval; RESP = response; T = transfer;' WPTT = waste package transfer trolley; XFER = transfer.

Source: Original

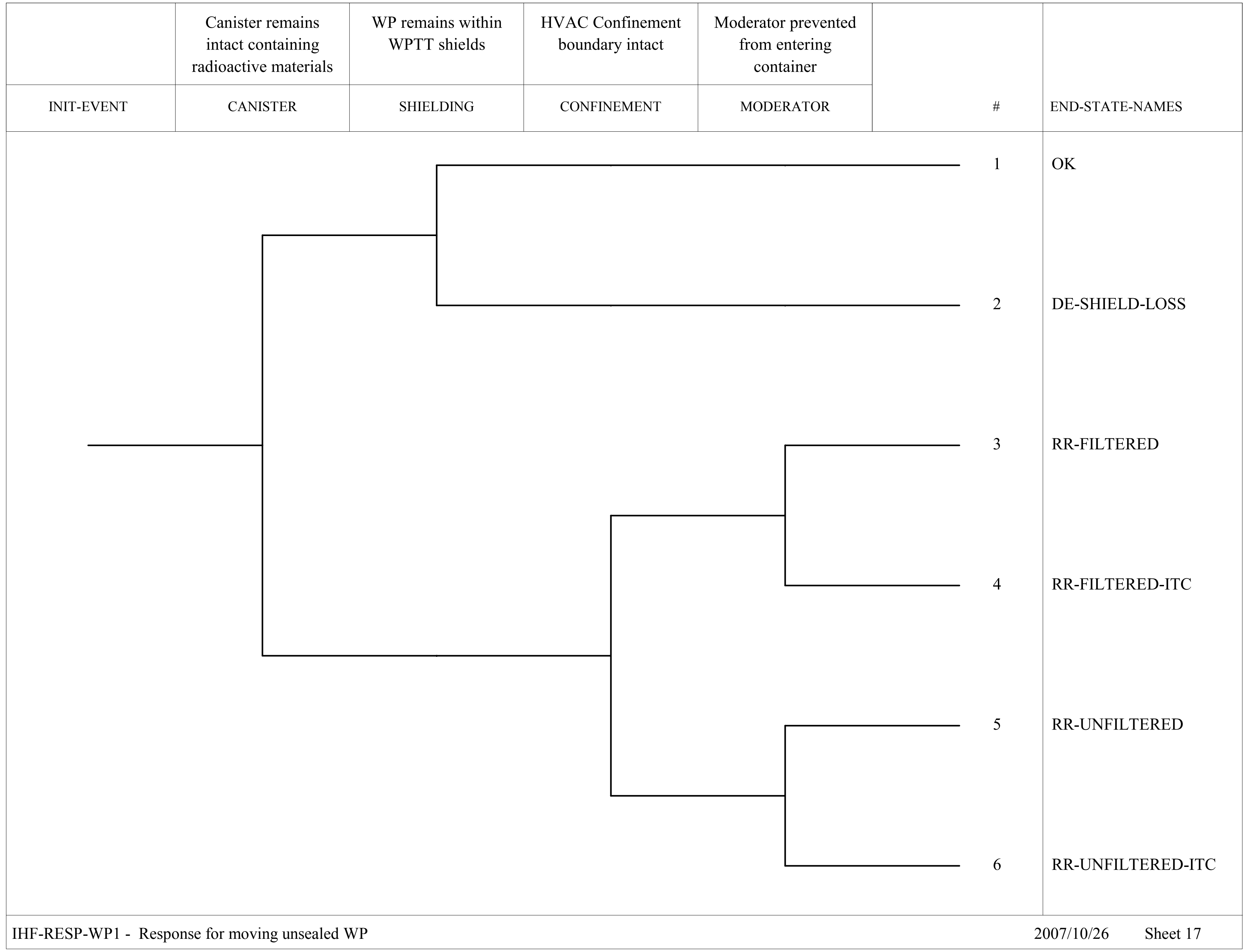
Figure G-16. Event Tree ESD-07-NVL – Transferring a NVL Canister with the CTM




NOTE: CSK = cask; HLW = high-level (radioactive) waste; IHF = Initial Handling Facility; INIT = initiating; NUM = number; RESP = response; T = transfer; WP = waste package; WPTT = waste package transfer trolley; XFER = transfer.

Source: Original

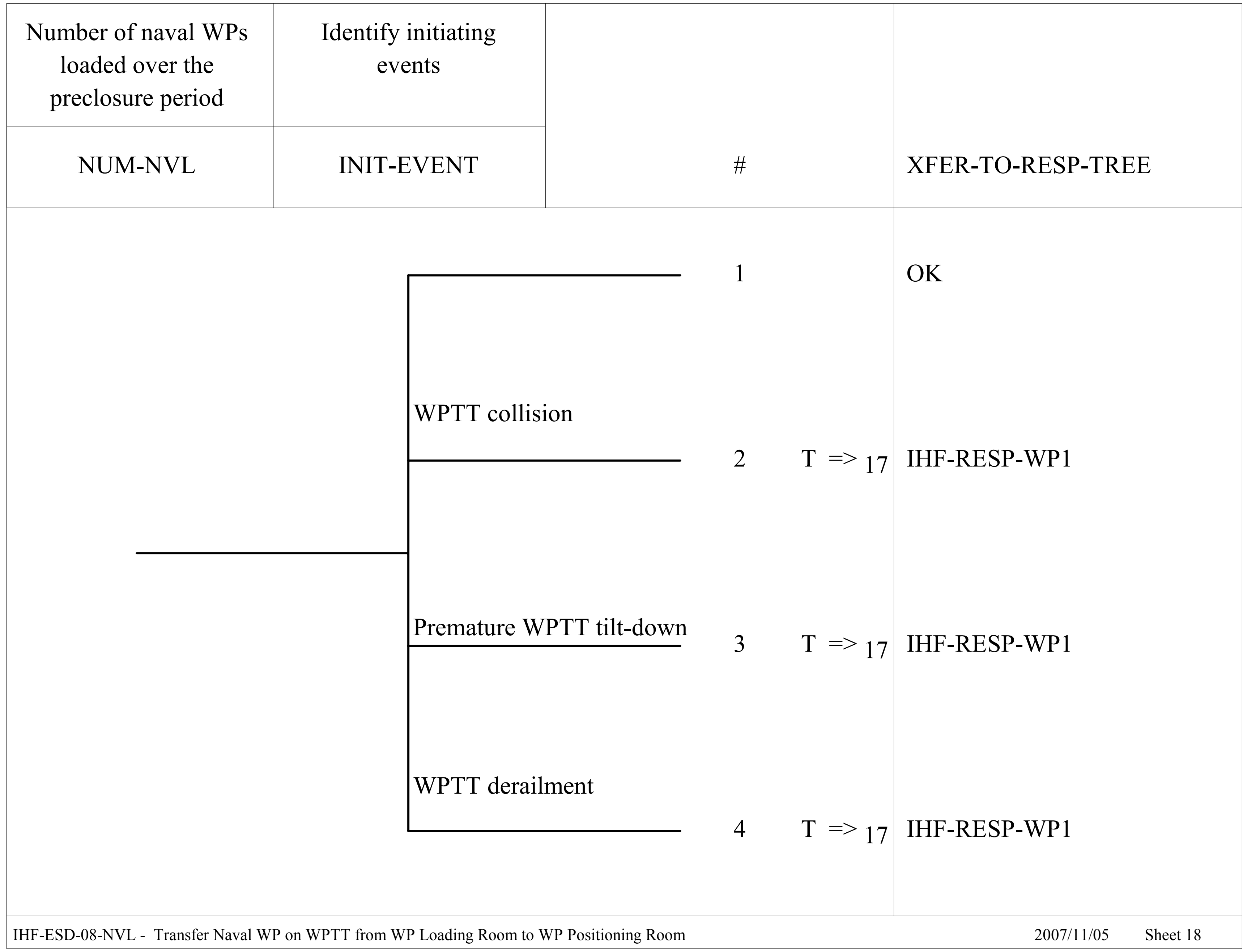
Figure G-17. Event Tree ESD-08-HLW – Transfer HLW WP on WPTT from WP Loading Room to WP Positioning Room




NOTE: DE = direct exposure; HVAC = heating, ventilation, and air conditioning; INIT = initiating; ITC = important to criticality; RR = radioactive release; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

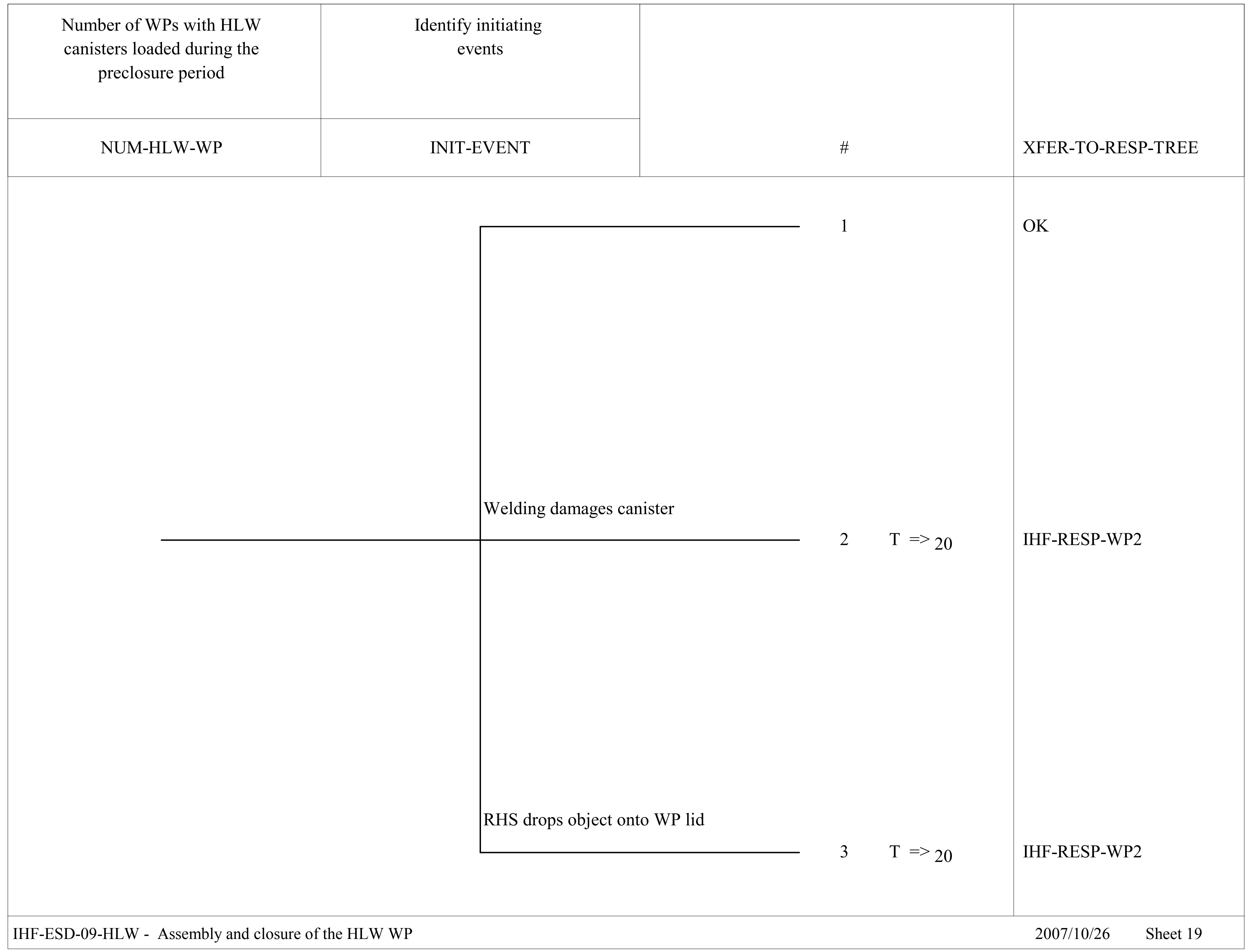
Figure G-18. Event Tree IHF-RESP-WP1 – Response for Moving Unsealed WP




NOTE: IHF = Initial Handling Facility; INIT = initiating; NUM = number; NVL = naval; RESP = response; T = transfer; WP = waste package; WPTT = waste package transfer trolley; XFER = transfer.

Source: Original

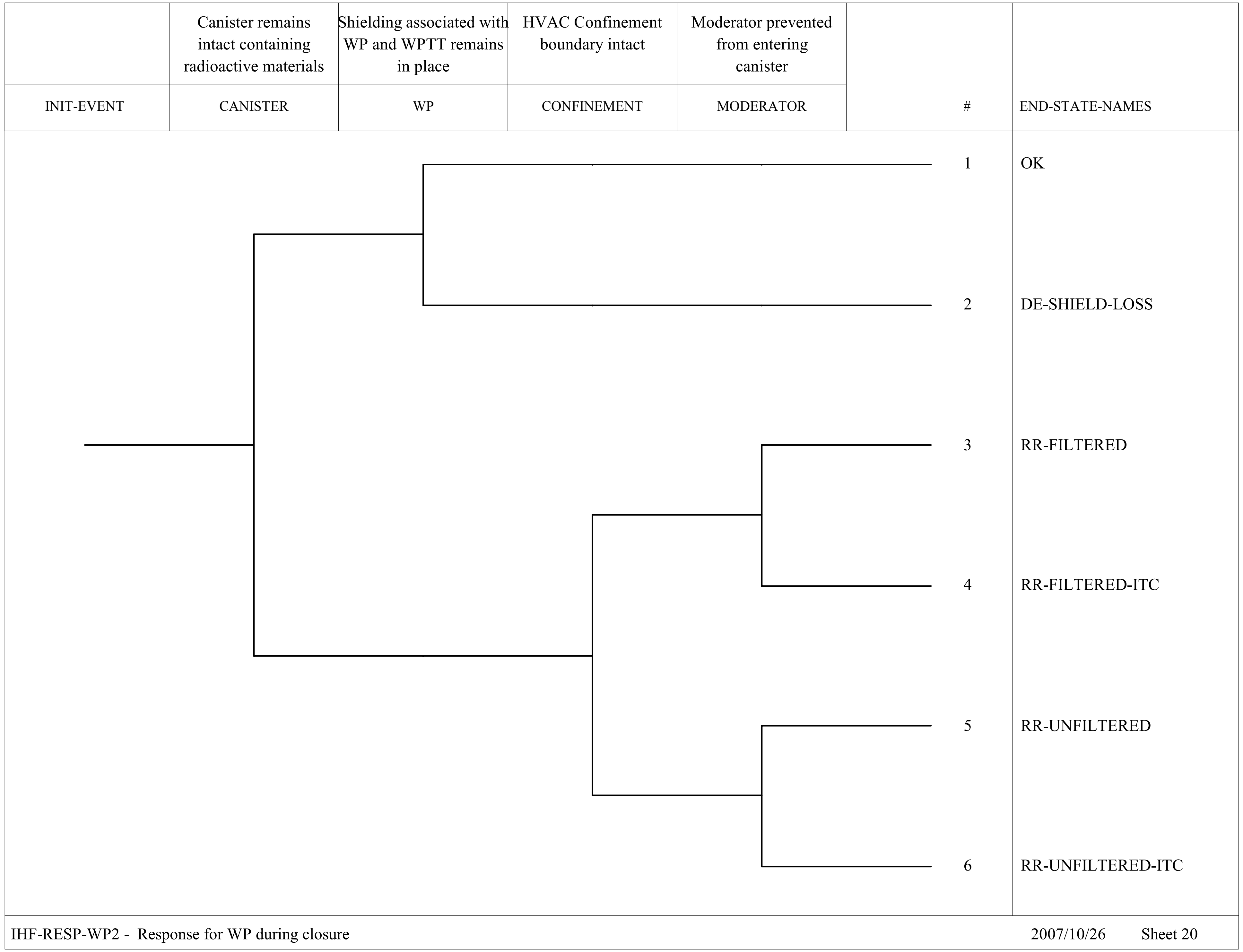
Figure G-19. Event Tree ESD-08-NVL – Transfer Naval WP on WPTT from WP Loading Room to WP Positioning Room




NOTE: CTM = canister transfer machine; HLW = high-level (radioactive) waste; IHF = Initial Handling Facility; INIT = initiating; NUM = number; RESP = response; RHS = remote handling system; T = transfer; WP = waste package; XFER = transfer.

Source: Original

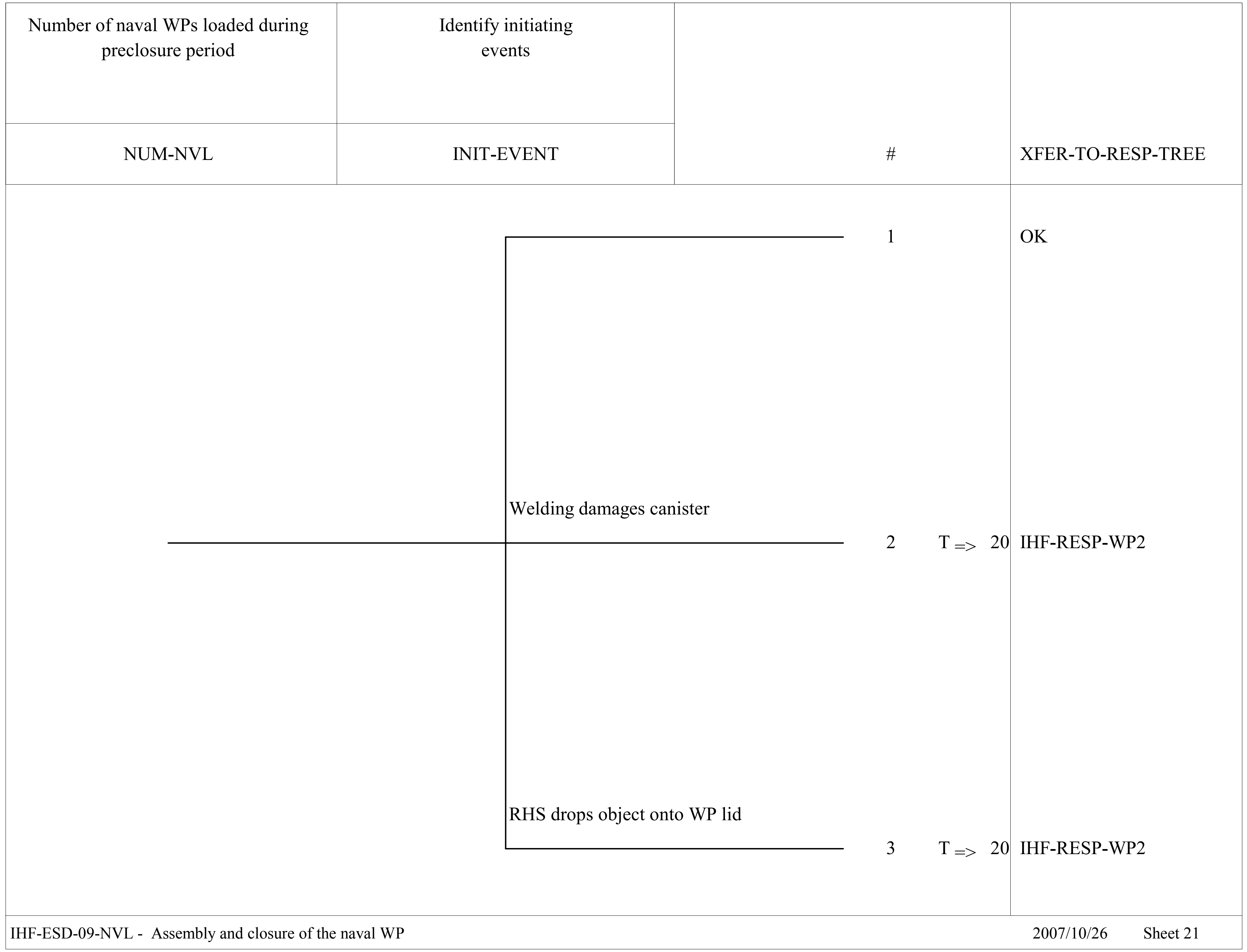
Figure G-20. Event Tree ESD-09-HLW – Assembly and Closure of the HLW WP




NOTE: DE = direct exposure; HVAC = heating, ventilation, and air conditioning; INIT = initiating; ITC = important to criticality; RR = radioactive release; WP = waste package.

Source: Original

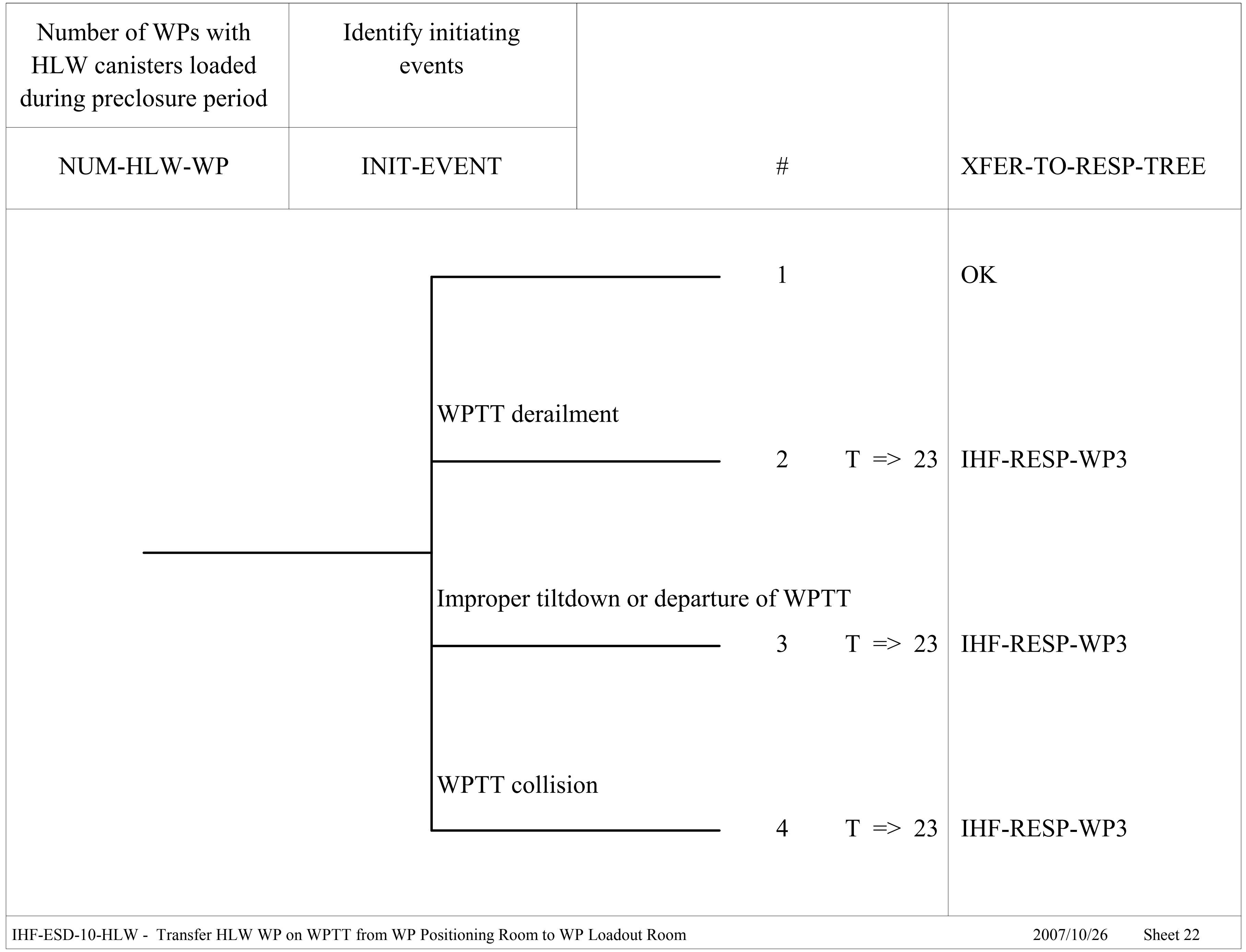
Figure G-21. Event Tree IHF-RESP-WP2 – Response for WP during Closure




NOTE: CTM = canister transfer machine; HLW = high-level (radioactive) waste; IHF = Initial Handling Facility; INIT = initiating; NUM = number; RESP = response; RHS = remote handling system; T = transfer; WP = waste package; XFER = transfer.

Source: Original

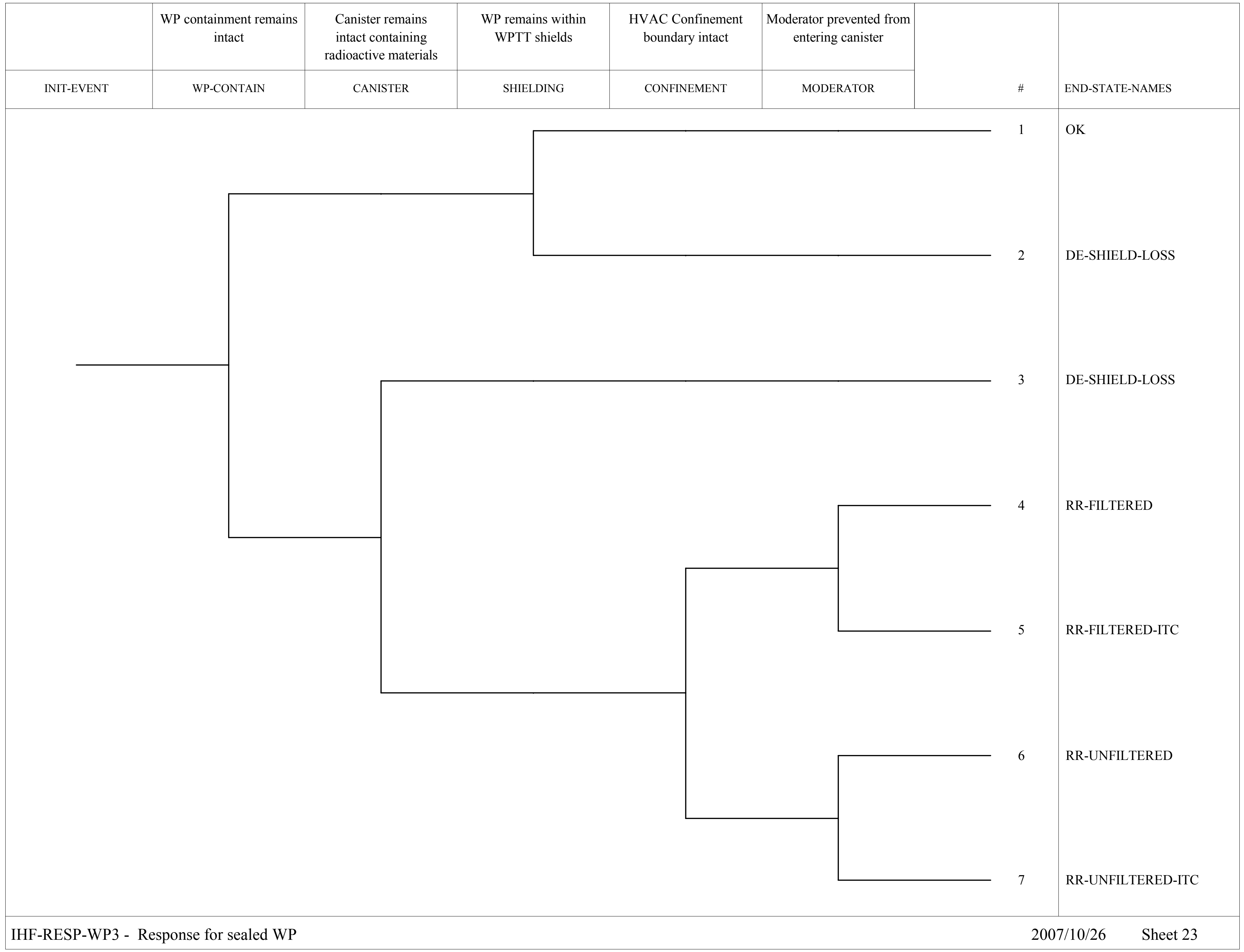
Figure G-22. Event Tree ESD-09-NVL – Assembly and Closure of the Naval WP




NOTE: HLW = high-level (radioactive) waste; IHF = Initial Handling Facility; INIT = initiating; NUM = number; RESP = response; T = transfer; WP = waste package; WPTT = waste package transfer trolley; XFER = transfer.

Source: Original

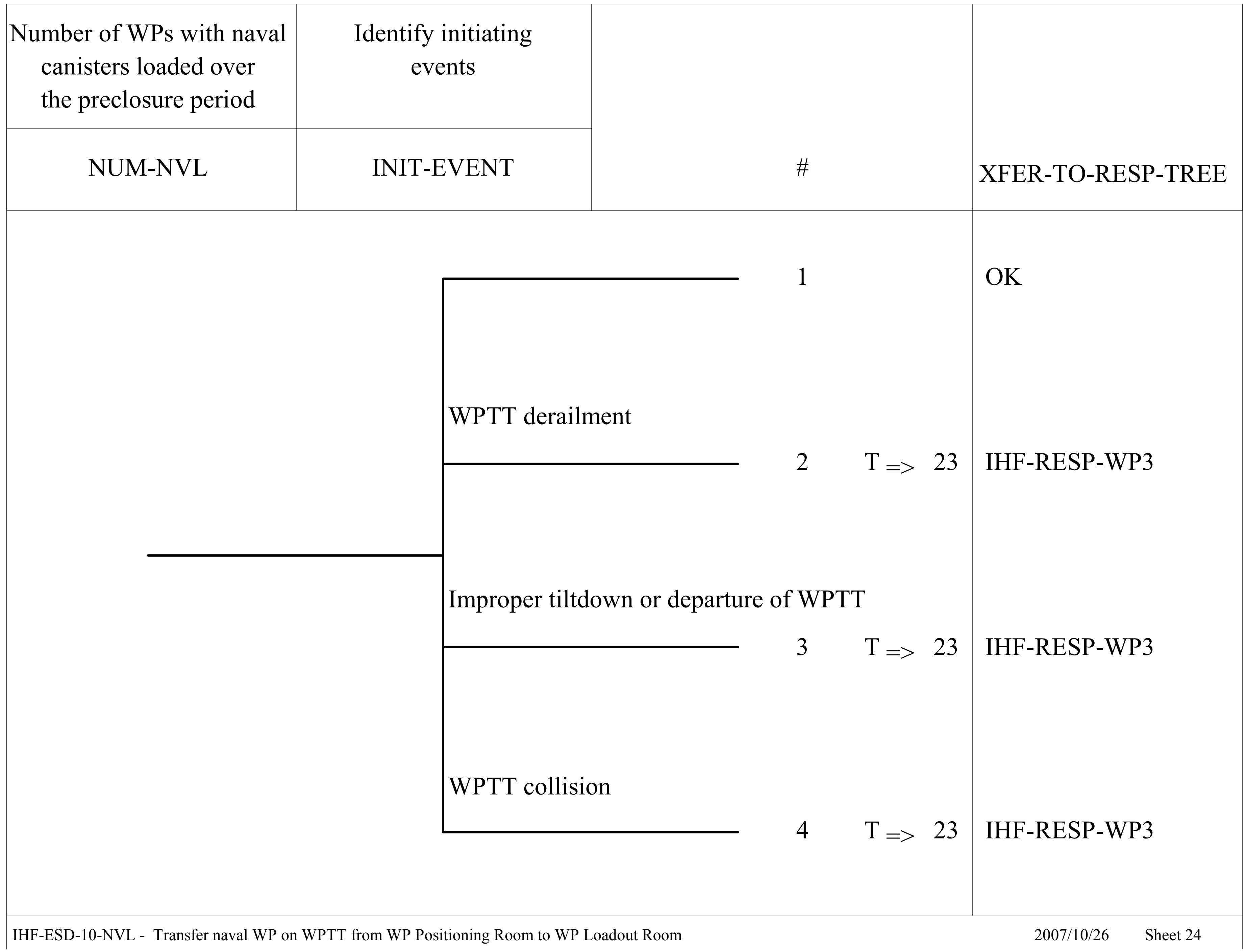
Figure G-23 Event Tree ESD-10-HLW – Transfer HLW WP on WPTT from WP Positioning Room to WP Loadout Room




NOTE: DE = direct exposure; HVAC = heating, ventilation, and air conditioning; INIT = initiating; ITC = important to criticality; RR = radioactive release; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

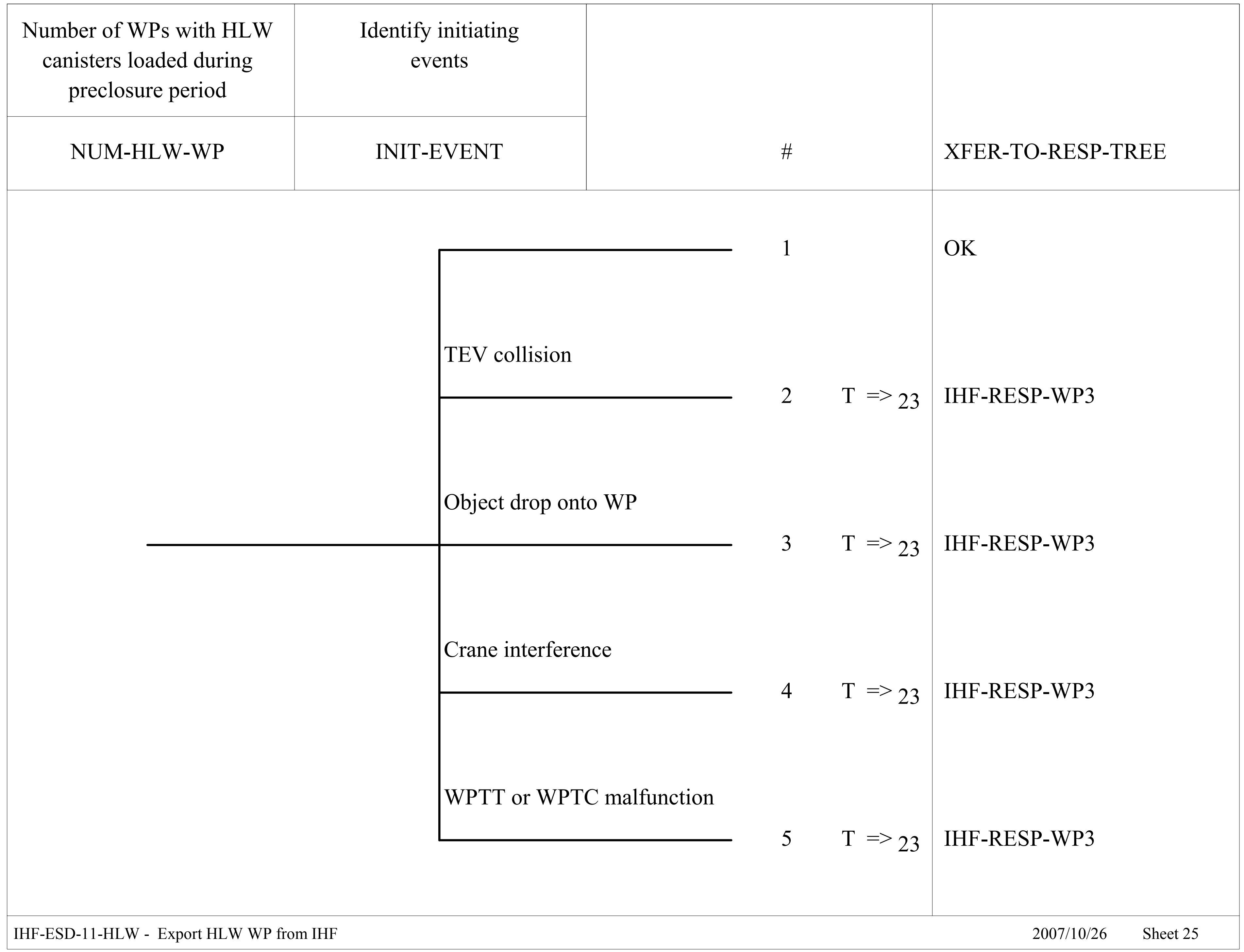
Figure G-24. Event Tree IHF-RESP-WP3 – Response for Sealed WP




NOTE: IHF = Initial Handling Facility; INIT = initiating; NUM = number; NVL = naval; RESP = response; T = transfer; WP = waste package; WPTT = waste package transfer trolley; XFER = transfer.

Source: Original

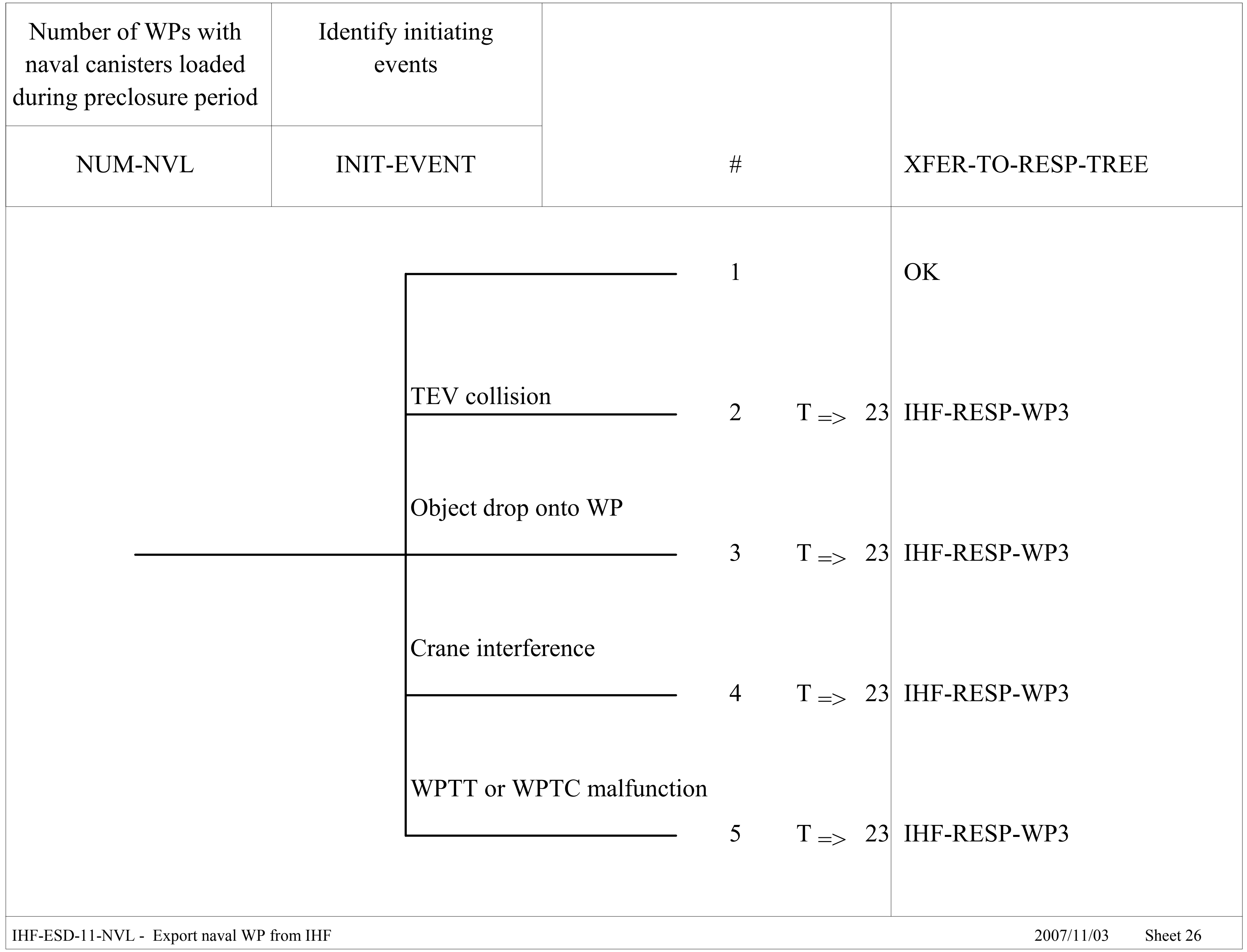
Figure G-25. Event Tree ESD-10-NVL – Transfer Naval WP on WPTT from WP Positioning Room to WP Loadout Room




NOTE: HLW = high-level (radioactive) waste; IHF = Initial Handling Facility; INIT = initiating; NUM = number; RESP = response; T = transfer; TEV = transport and emplacement vehicle; WP = waste package; WPTC = waste package transfer carriage; WPTT = waste package transfer trolley; XFER = transfer.

Source: Original

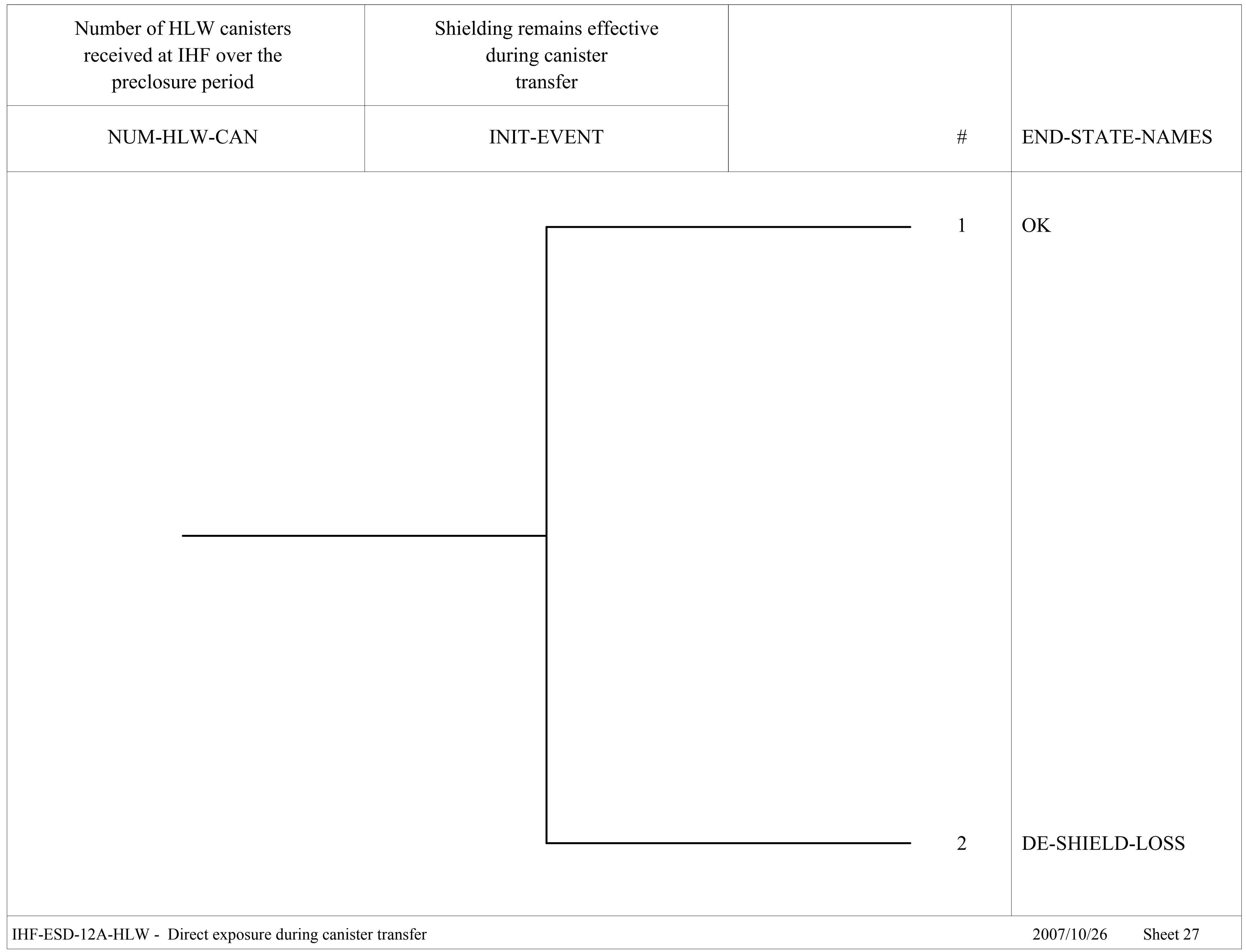
Figure G-26. Event Tree ESD-11-HLW – Export HLW WP from IHF




NOTE: IHF = Initial Handling Facility; INIT = initiating; NUM = number; NVL = naval; RESP = response; T = transfer; TEV = transport and emplacement vehicle; WP = waste package; WPTC = waste package transfer carriage; WPTT = waste package transfer trolley; XFER = transfer.

Source: Original

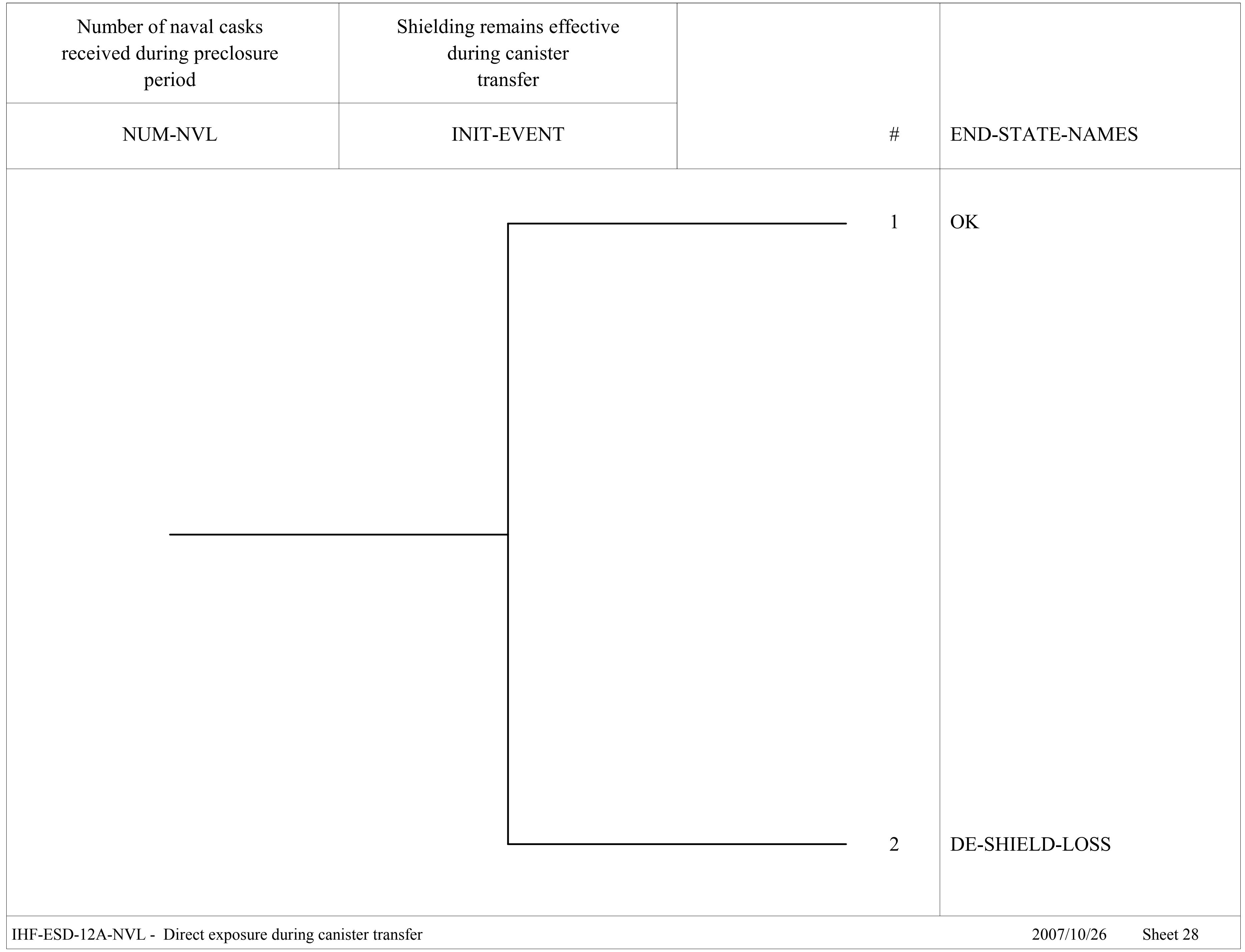
Figure G-27. Event Tree ESD-11-NVL – Export Naval WP from IHF




NOTE: CAN = canister; DE = direct exposure; HLW = high-level (radioactive) waste; IHF = Initial Handling Facility; INIT = initiating; NUM = number.

Source: Original

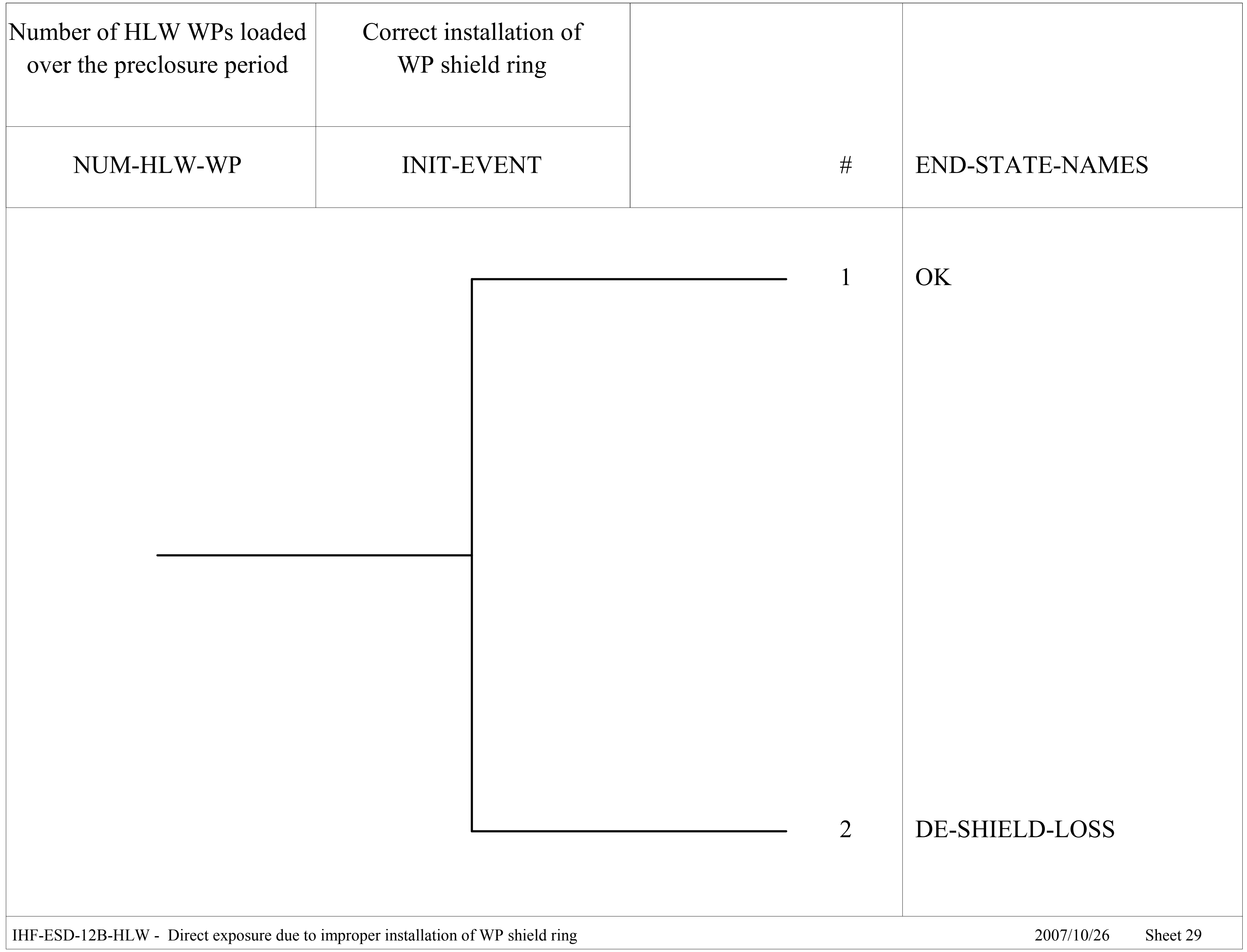
Figure G-28. Event Tree ESD-12A-HLW – Direct Exposure during Canister Transfer




NOTE: DE = direct exposure; INIT = initiating; NUM = number; NVL = naval.

Source: Original

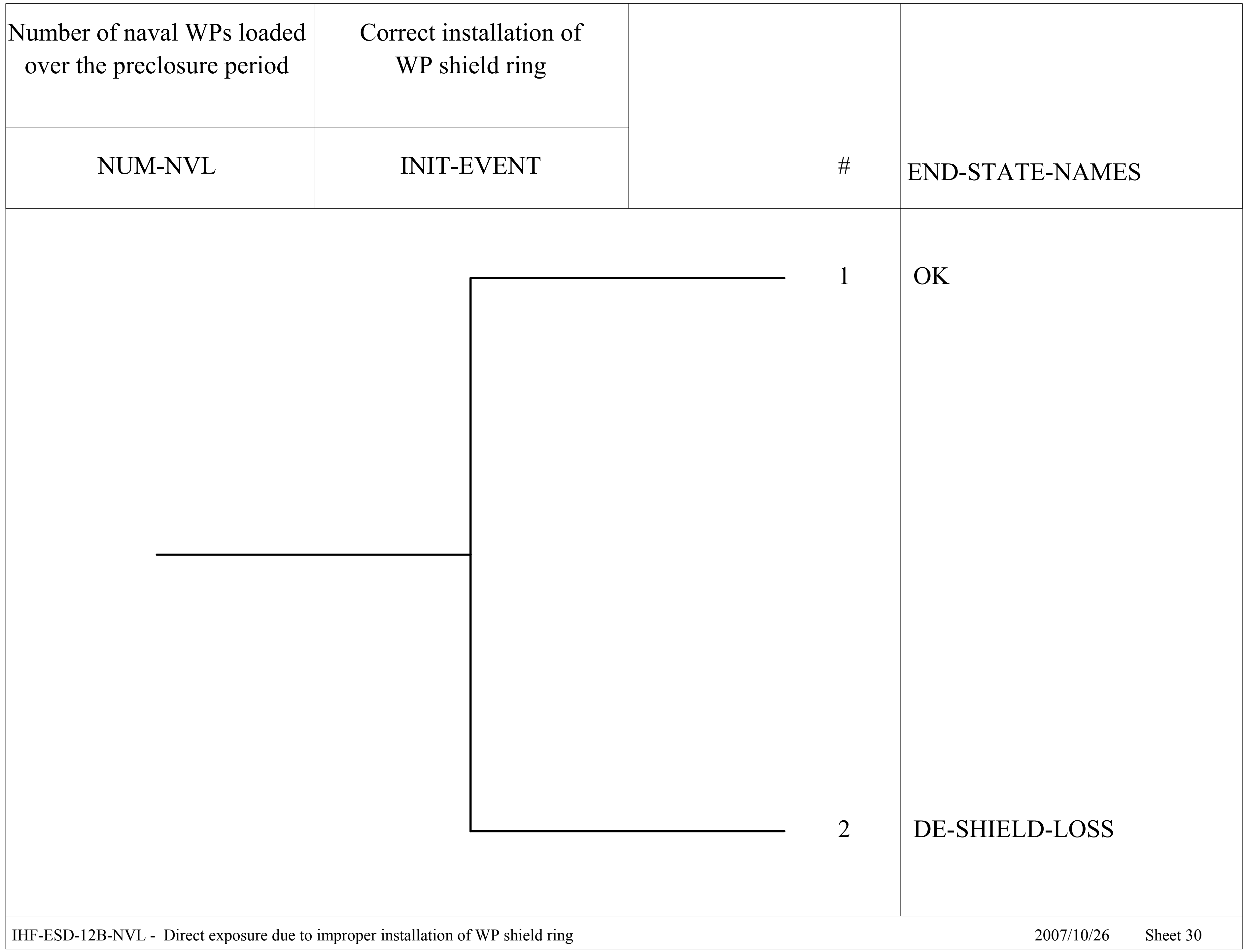
Figure G-29. Event Tree ESD-12A-NVL – Direct Exposure during Canister Transfer




NOTE: DE = direct exposure; HLW = high-level (radioactive) waste; IHF = Initial Handling Facility; INIT = initiating; NUM = number; WP = waste package.

Source: Original

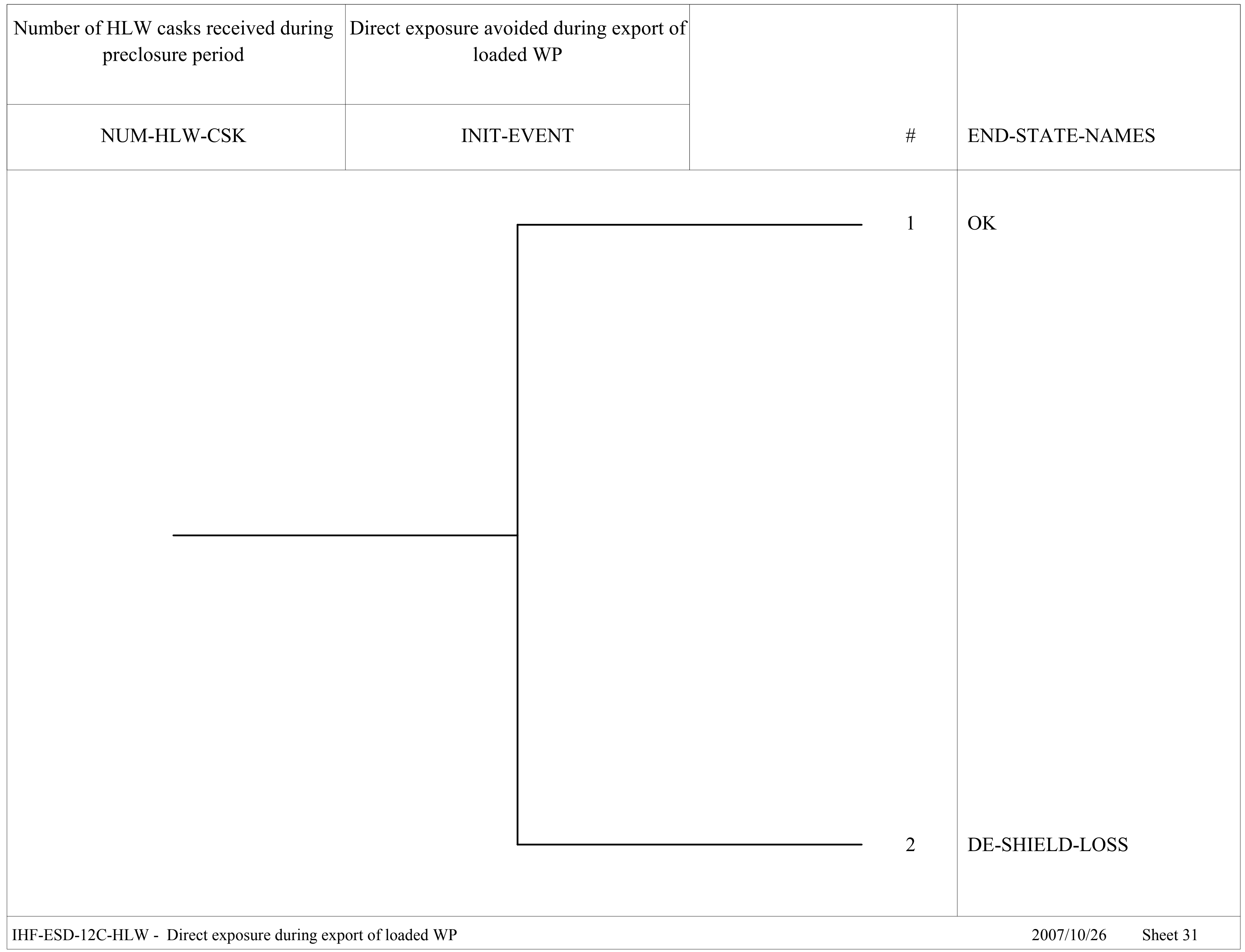
Figure G-30. Event Tree ESD-12B-HLW – Direct Exposure due to Improper Installation of Shield Ring




NOTE: DE = direct exposure; IHF = Initial Handling Facility; INIT = initiating; NUM = number; NVL = naval; WP = waste package.

Source: Original

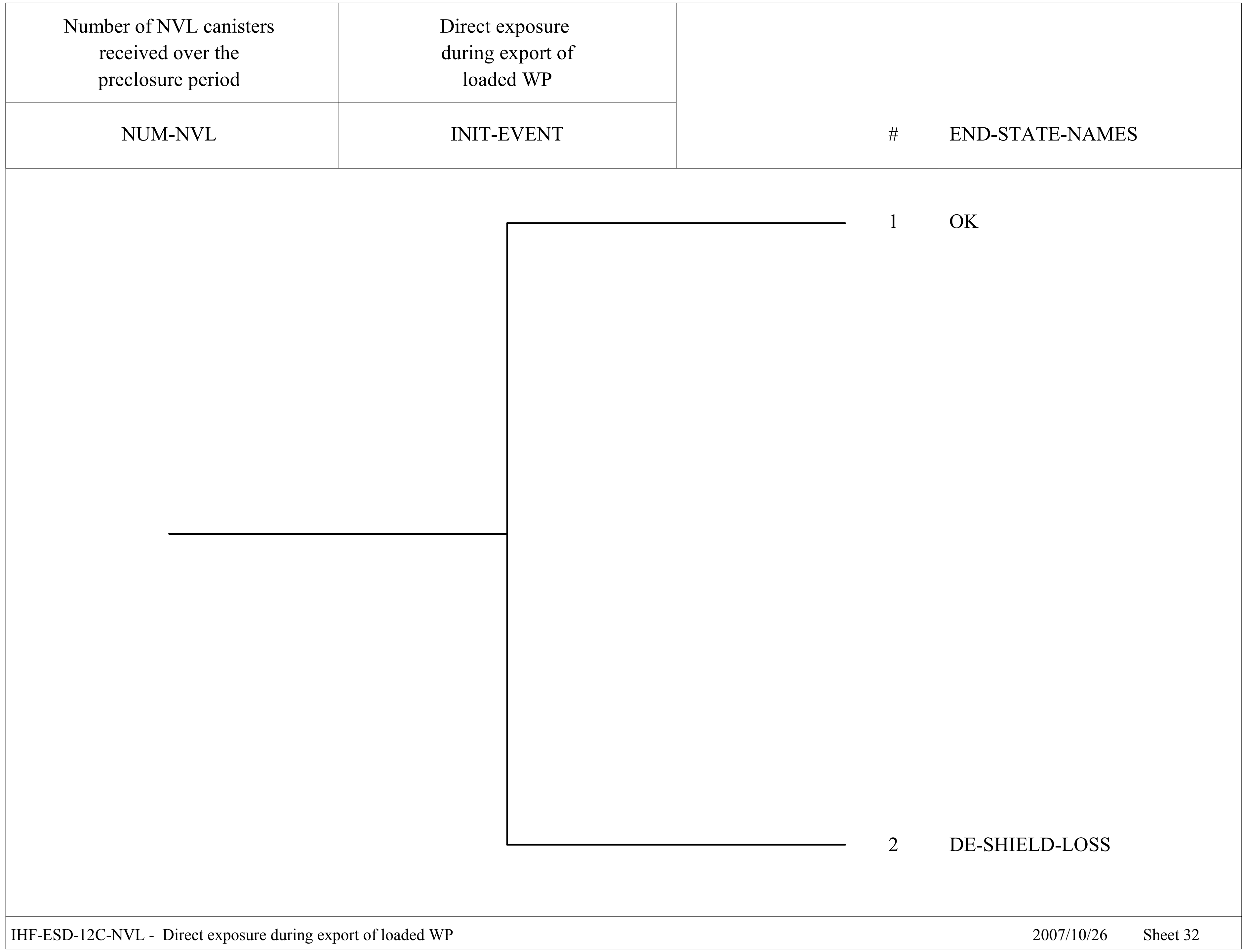
Figure G-31. Event Tree ESD-12B-NVL – Direct Exposure due to Improper Installation of Shield Ring




NOTE: DE = direct exposure; INIT = initiating; NUM = number; NVL = naval; WP = waste package.

Source: Original

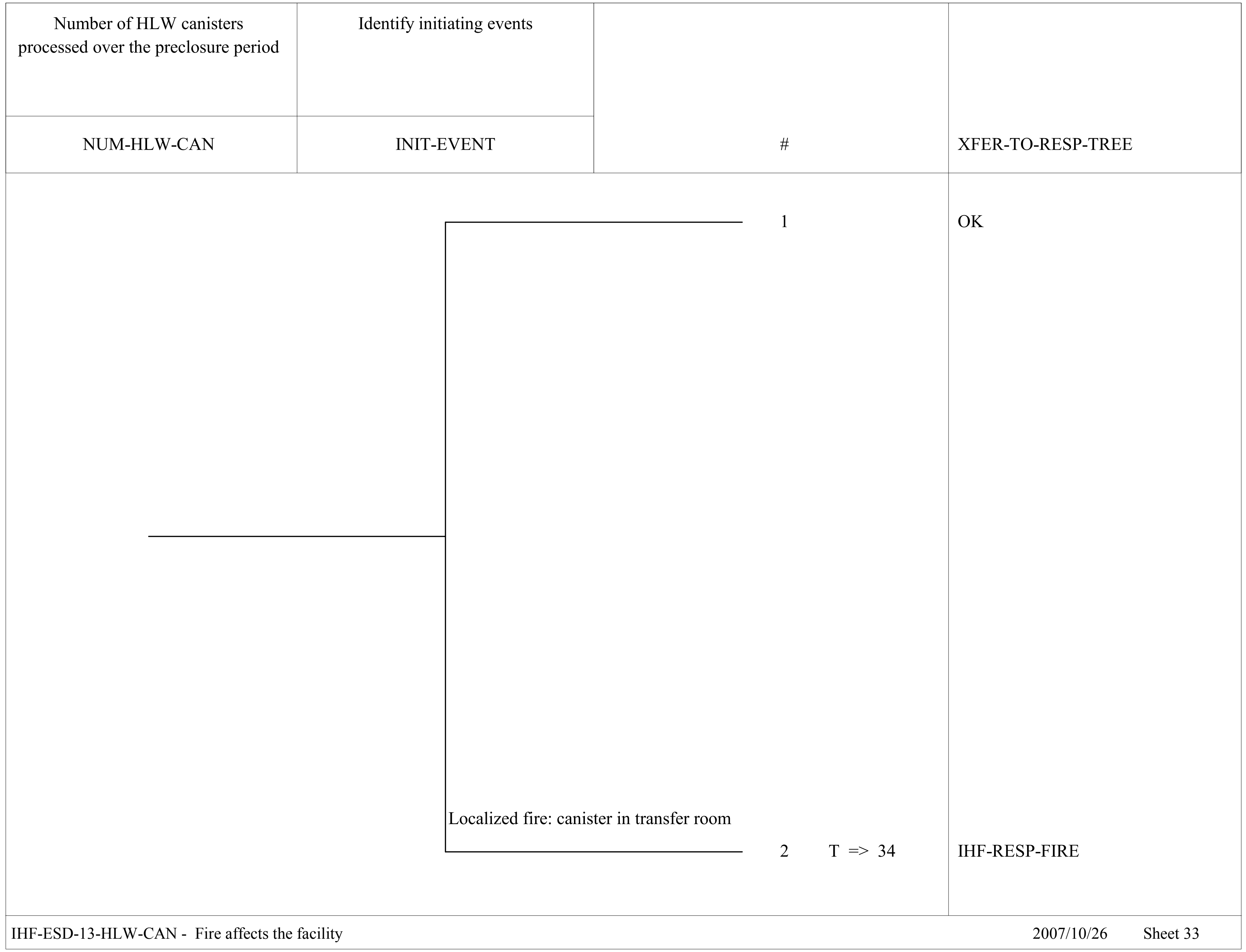
Figure G-32. Event Tree ESD-12C-HLW – Direct Exposure during Export of Loaded WP




NOTE: DE = direct exposure; IHF = Initial Handling Facility; INIT = initiating; NUM = number; NVL = naval; WP = waste package.

Source: Original

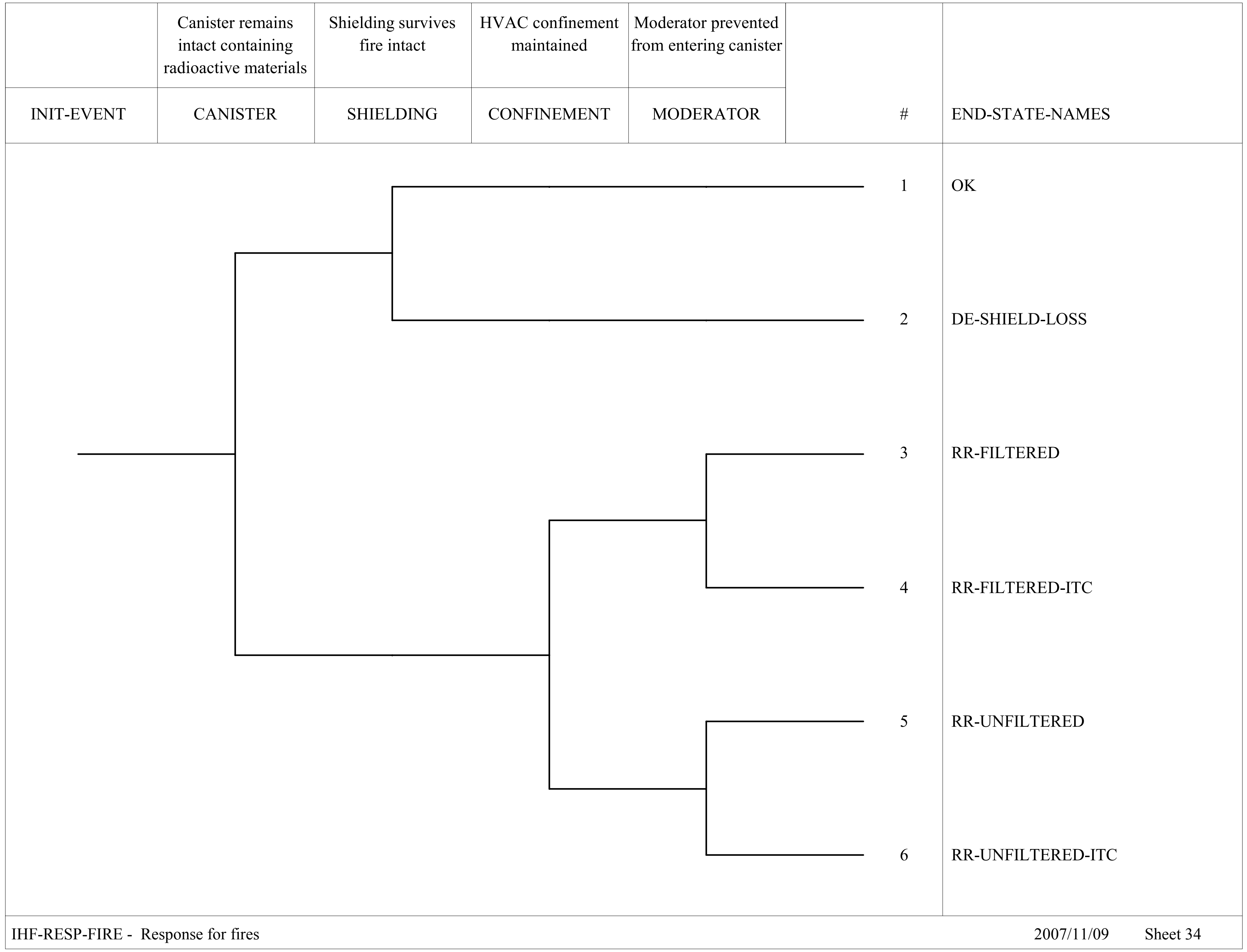
Figure G-33. Event Tree ESD-12C-NVL – Direct Exposure during Export of Loaded WP




NOTE: See the note on IHF-ESD-13 at the bottom of Table G-1 for a discussion of how the fire event trees were derived from the fire ESD.
CAN = canister; HLW = high-level (radioactive) waste; IHF = Initial Handling Facility; INIT = initiating; NUM = number; RESP = response; T = transfer; XFER = transfer

Source: Original

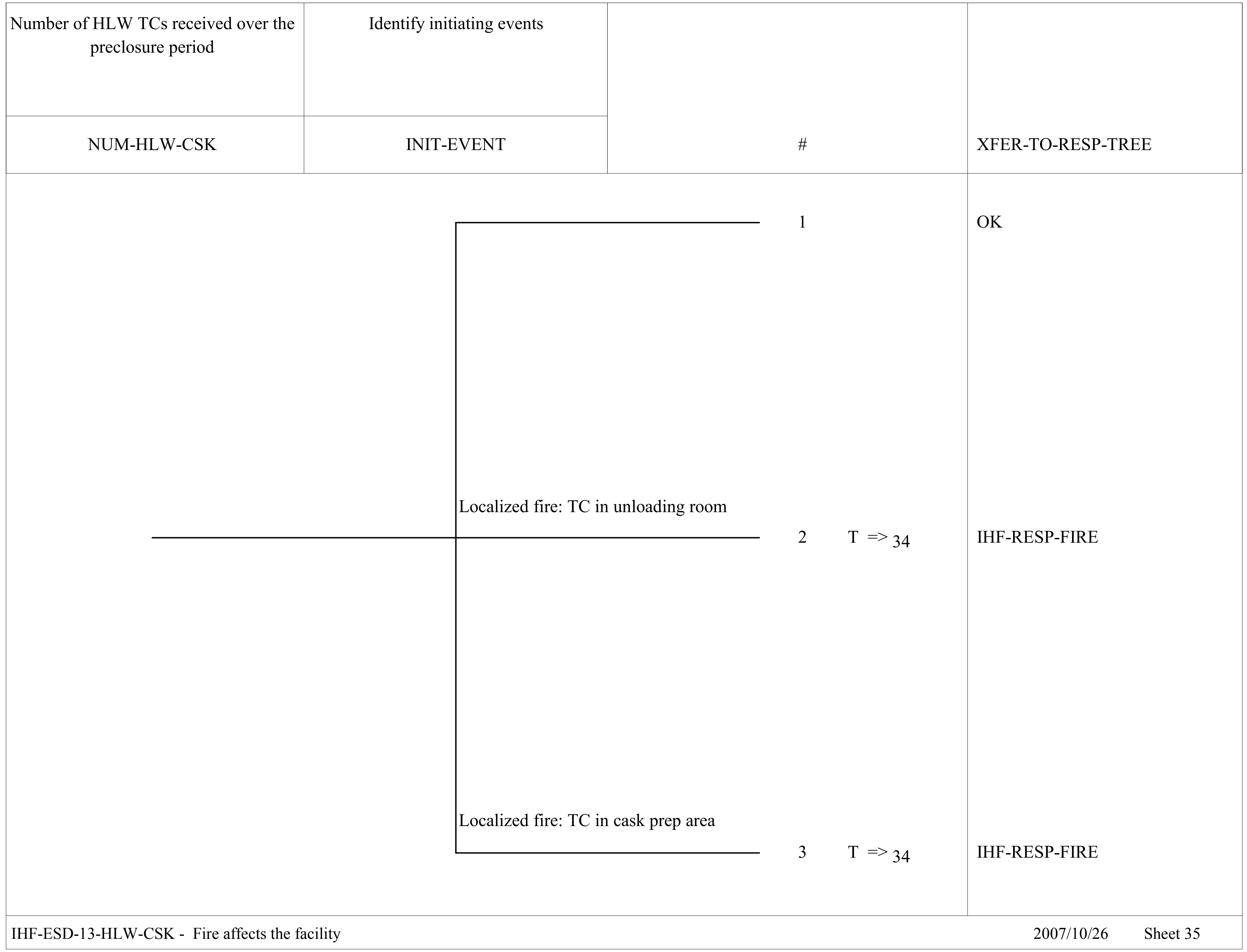
Figure G-34. Event Tree ESD-13-HLW-CAN – Fire Affects the Facility




NOTE: HVAC = heating, ventilation, and air conditioning; INIT = initiating; ITC = important to criticality; RR = radioactive release.

Source: Original

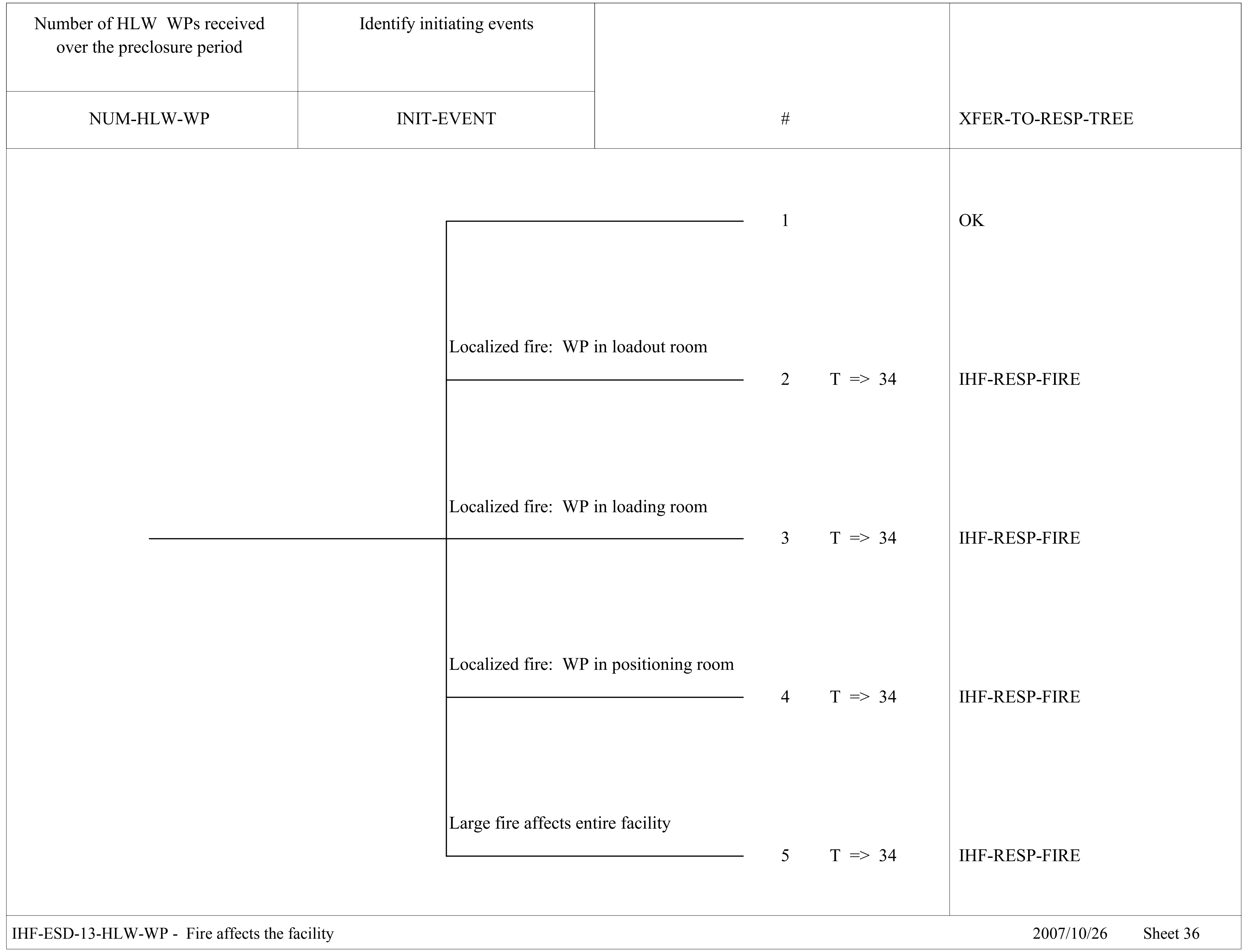
Figure G-35. Event Tree IHF-RESP-FIRE – Response for Fires




NOTE: See the note on IHF-ESD-13 at the bottom of Table G-1 for a discussion of how the fire event trees were derived from the fire ESD.
CSK = cask; CTT = cask transfer trolley; HLW = high-level (radioactive) waste; IHF = Initial Handling Facility; INIT = initiating; NUM = number; RC = railcar; RESP = response; T = transfer; TC = transportation cask; XFER = transfer.

Source: Original

Figure G-36. Event Tree ESD-13-HLW-CSK – Fire Affects the Facility




NOTE: See the note on IHF-ESD-13 at the bottom of Table G-1 for a discussion of how the fire event trees were derived from the fire ESD.
HLW = high-level (radioactive) waste; IHF = Initial Handling Facility; INIT = initiating; NUM = number; RESP = response; T = transfer; WP = waste package; XFER = transfer.

Source: Original

Figure G-37. Event Tree ESD-13-HLW-WP – Fire Affects the Facility

| Number of naval canisters received over the preclosure period | Identify initiating events | # | | XFER-TO-RESP-TREE |
|---|---|---|---|---|
| NUM-NVL | INIT-EVENT | | | |
| | | 1 | | OK |
| | Localized fire: WP in loadout room | 2 | T => 34 | IHF-RESP-FIRE |
| | Localized fire: WP in loading room | 3 | T => 34 | IHF-RESP-FIRE |
| | Localized fire: WP in unloading room | 4 | T => 34 | IHF-RESP-FIRE |
| | Localized fire: WP in positioning room | 5 | T => 34 | IHF-RESP-FIRE |
| | Localized fire: TC in cask prep area | 6 | T => 34 | IHF-RESP-FIRE |
| | Localized fire: canister in transfer room | 7 | T => 34 | IHF-RESP-FIRE |
| | Large fire affects entire facility | 8 | T => 34 | IHF-RESP-FIRE |

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NOTE: See the note on IHF-ESD-13 at the bottom of Table G-1 for a discussion of how the fire event trees were derived from the fire ESD.
IHF = Initial Handling Facility; INIT = initiating; NUM = number; NVL = naval; RESP = response; T = transfer; TC = transportation cask; WP = waste package; XFER = transfer.

Source: Original

Figure G-38. Event Tree ESD-13-NVL – Fire Affects the Facility