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Design Calculation or Analysis Cover Sheet

Complete only applicable items.

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8. Notes/Comments

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RECORD OF REVISIONS

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ACRONYMS AND ABBREVIATIONS

Acronyms

AIChE	American Institute of Chemical Engineers
BSC	Bechtel SAIC Company, LLC
BWR	boiling water reactor
CFR	code of federal regulations
CRCF	Canister Receipt and Closure Facility
CSNF	commercial spent nuclear fuel
CTM	canister transfer machine
CTT	cask transfer trolley
DOE	U.S. Department of Energy
DPC	dual-purpose canister
ESD	event sequence diagram
GROA	geologic repository operations area
HAZOP	hazard and operability
HEPA	high-efficiency particulate air (filter)
HLW	high-level radioactive waste
HTC	a transportation cask that is never upended
HVAC	heating, ventilation, and air conditioning
ITC	important to criticality
ITS	important to safety
LLW	low-level radioactive waste
LLWF	Low-Level Waste Handling Facility
MAP	mobile access platform
MLD	master logic diagram
NRC	U.S. Nuclear Regulatory Commission
P&ID	piping and instrumentation diagram
PCSA	preclosure safety analysis
PFD	process flow diagram
PRA	probabilistic risk assessment
PWR	pressurized water reactor
RHS	remote handling system

ACRONYMS AND ABBREVIATIONS (Continued)

SFTM	spent fuel transfer machine
SNF	spent nuclear fuel
SSC	structure, system, or component
SSCs	structures, systems, and components
SPM	site prime mover
STC	shielded transfer cask
TAD	transportation, aging, and disposal canister
TTC	a transportation cask that is upended using a tilt frame
TWF	typical waste-handling facility
WPTT	waste package transfer trolley
WHF	Wet Handling Facility

Abbreviations

ft	feet
hp	horse power
in.	inch

1. PURPOSE

This document, along with its companion document entitled *Wet 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. 2.3.2).

The PCSA uses probabilistic risk assessment (PRA) technology derived from both nuclear power plant and aerospace methods and applications in order to perform analyses to comply with the risk informed aspects of 10 CFR 63.111 and 10 CFR 63.112 (Ref. 2.3.2), and to be responsive to the acceptance criteria articulated in the *Yucca Mountain Review Plan, Final Report* (Ref. 2.2.102). The PCSA, however, limits the use of PRA technology to identification and development of event sequences that might lead to direct exposure of workers or on-site members of the public, radiological releases that may affect the public or workers (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 particular air (HEPA) filters when applicable. After completion of the event sequence development in the present analysis and its companion document, each Category 1 and Category 2 event sequence is conservatively matched with one of the categories of dose estimates.

"Event sequence" is defined in 10 CFR 63.2: *Energy: Disposal of High-Level Radioactive Waste in Geologic Repository at Yucca Mountain, Nevada* (Ref. 2.3.2) as follows:

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

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

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

10 CFR 63.112, Paragraph (e) and Subparagraph (e)(6) (Ref. 2.3.2) requires analyses to identify the controls that are relied upon to limit or prevent potential event sequences or mitigate their consequences. Subparagraph (e)(6) specifically notes that the analyses should include consideration of "means to prevent and control criticality." The PCSA criticality analyses employ specialized deterministic methods that are beyond the scope of the present analysis. However, the event sequence analyses serve as an input to the PCSA criticality analyses by identifying the event sequences and end states where conditions leading to criticality are in Category 1 or 2. Some event sequence end states include the phrase "important to criticality." This indicates that the event sequence has a potential for a reactivity increase that are analyzed to determine if reactivity can exceed the upper subcriticality limit.

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

The initiating events considered in the PCSA are limited to those that constitute a hazard to a waste form while it is present in the GROA. That is, an internal event due to a waste processing operation conducted in the GROA or an external event that imposes a potential hazard to a waste form, or waste processing systems, or personnel, (e.g., seismic or wind energy, flood waters) define initiating events that could occur within the site boundary. Such initiating events are included when developing event sequences for the PCSA. However, initiating events that are associated with conditions introduced in structures, systems, 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, 71 and 72) and associated quality assurance (QA) programs. As a result of compliance to such regulations, the SSCs are deemed to pose no undue risk to health and safety. Although the analyses do not address quantitative probabilities, it is clear that very conservative design criteria and QA result in very unlikely exposures to radiation.

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

Other boundary conditions used in the PCSA include:

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

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

- Component failure modes. The failure mode of 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 receipt of casks/canisters in two areas–either the Cask Preparation Area or the Site Transporter Vestibule of the WHF. There are two types of canisters handled in the WHF: dual-purpose canisters (DPCs) and transportation, aging, and disposal (TAD) canisters. DPCs in a transportation cask on a railcar or commercial spent nuclear fuel (CSNF) in a transportation cask on a truck trailer are received in the Cask Preparation Area. DPCs in aging overpacks on a site transporter are received in the Site Transporter Vestibule. Transportation casks with CSNF is sampled and cooled and sent directly to the pool for processing. DPCs are transferred from either transportation casks or aging overpacks to shielded transfer casks (STCs) using the canister transfer machine (CTM). The STC/DPCs are moved to the DPC cutting station where DPCs are sampled, cooled and then DPC lids are removed. Once the DPC lid is cut, the STC lid is replaced and fastened before the STC/DPC is transferred to the pool for processing. Pool processing includes transfer of spent fuel from either a transportation cask or DPC into a TAD canister. The TAD canister is placed in a STC, the STC lid is fastened under water and then the STC/TAD canister is removed from the pool and transferred to the TAD canister closure station where the TAD canister lids are welded. The STC/TAD canisters are then moved to the CTM where the TAD canister is transferred from the STC to an aging overpack. The aging overpack/TAD canister is shipped on a site transporter from the Site Transporter Vestibule to either the CRCF or an Aging Pad.

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 WHF) as well as external events (i.e., events that are initiated from outside the WHF). 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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2.2.62 BSC 2007. *Wet Handling Facility Mechanical Handling System Block Flow Diagram–Level 3 Sheet 12.* 050-MH0-H000-00212-000 REV 00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071126.0012.

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2.2.68 BSC 2007. *Wet Handling Facility Pool Water Cooling System Piping and Instrument. Diagram.* 050-M60-PW00-00105-000 REV 00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071205.0010.

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2.2.70 BSC 2007. *Wet Handling Facility Pool Water Treatment System Train A Piping and Instrument. Diagram.* 050-M60-PW00-00102-000 REV 00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071205.0007.

2.2.71 BSC 2007. *Wet Handling Facility Pool Water Treatment System Train B Piping and Instrument. Diagram.* 050-M60-PW00-00103-000 REV 00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071205.0008.

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2.2.73 BSC 2007. *Wet Handling Facility SNF Staging Racks Mechanical Equipment Envelope Sheet 1 of 3.* 050-M90-HTF0-00201-000 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071027.0020.

2.2.74 BSC 2007. *Wet Handling Facility SNF Staging Racks Mechanical Equipment Envelope Sheet 2 of 3.* 050-M90-HTF0-00202-000 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071027.0021.

2.2.75 BSC 2007. *Wet Handling Facility SNF Staging Racks Mechanical Equipment Envelope Sheet 3.* 050-M90-HTF0-00203-000 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071027.0022.

2.2.76 BSC 2007. *Wet Handling Facility Spent Fuel Transfer Machine Process and Instrumentation Diagram Sheet 1 of 2.* 050-M60-HTF0-00101-000 REV 00C. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071025.0004; ENG.20071203.0044.

2.2.77 BSC 2007. *Wet Handling Facility Spent Resin Handling System Piping & Instrument. Diagram.* 050-M60-PW00-00106-000 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071205.0011; ENG.20080208.0008.

2.2.78 BSC 2007. *Wet Handling Facility TAD Canister Welding Machine Mechanical Equipment Envelope.* 050-MJ0-HC00-00101-000 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070312.0006.

2.2.79 BSC 2007. *Wet Handling Facility TAD/RC/TC Transfer Stations Plan & Elevation Mechanical Equipment Envelope Sh 1 of 2.* 050-MJ0-H000-00301-000 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070312.0010.

2.2.80 BSC 2007. *Wet Handling Facility TAD/RC/TC Transfer Stations Pool Layout Mechanical Equipment Envelope Sheet 2.* 050-MJ0-H000-00302-000 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070312.0011.

2.2.81 BSC 2007. *Wet Handling Facility TAD/STC Drying and TAD Inerting Piping & Instrument. Diagram.* 050-M60-MR00-00101-000 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070330.0017; ENG.20080208.0007.

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2.3 DESIGN CONSTRAINTS

2.3.1 10 CFR Part 50. 2007. Energy: Domestic Licensing of Production and Utilization Facilities. Internet Accessible. (DIRS 181964)

2.3.2 10 CFR Part 63. 2007. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. U.S. Nuclear Regulatory Commission. [DIRS 180319]

2.3.3 10 CFR Part 71. 2007. *Energy: Packaging and Transportation of Radioactive Material*. ACC: MOL.20070829.0114. (DIRS 181967)

2.3.4 10 CFR Part 72. 2007. Energy: Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste. Internet Accessible. (DIRS 181968)

2.4 DESIGN OUTPUT

This calculation is used as input to the following analysis:

2.4.1 BSC 2008. *Wet Handling Facility Reliability and Event Sequence Categorization Analysis*. 050-PSA-WH00-00200-000-00A. Las Vegas, Nevada.

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. 2.2.29)

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, RF, and WHF Mobile Access Platform Mechanical Equipment Envelope Sheet 1 of 2.* (Ref. 2.2.11)
- *CRCF, RF, and WHF Mobile Access Platform Mechanical Equipment Envelope Sheet 2.* (Ref. 2.2.12)
- *CRCF, RF, WHF, and IHF CTM Maintenance Crane Process and Instrumentation Diagram*. (Ref. 2.2.22)
- *CRCF, RF, WHF & IHF Impact Limiter Lifting Device Mechanical Equipment Envelope.* (Ref. 2.2.13)
- *CRCF, RF, WHF & IHF Personnel Barrier Lifting Device Mechanical Equipment Envelope.* (Ref. 2.2.14)
- *Geologic Repository Operations Area North Portal Site Plan*. (Ref. 2.2.88)
- *Geologic Repository Operations Area Overall Site Plan*. (Ref. 2.2.89)
- *Nuclear Facilities Grapple Stand Mechanical Equipment Envelope.* (Ref. 2.2.26)
- *Pool Water Treatment and Cooling System*. (Ref. 2.2.28)

- *Wet Handling Facility Boric Acid Makeup System Piping and Instrument. Diagram*. (Ref. 2.2.32)
- *Wet Handling Facility CTM Maintenance Crane Mechanical Equipment Envelope*. (Ref. 2.2.34)
- *Wet Handling Facility DPC Cutting Machine Mechanical Equipment Envelope Sheet 1 of 2*. (Ref. 2.2.35)
- *Wet Handling Facility DPC Cutting Machine Mechanical Equipment Envelope Sheet 2*. (Ref. 2.2.36)
- *Wet Handling Facility Entrance Vestibule Crane Mechanical Equipment Envelope*. (Ref. 2.2.37)
- *Wet Handling Facility Pool Water Cooling System Piping and Instrument. Diagram*. (Ref. 2.2.68)
- *Wet Handling Facility Pool Water Treatment and Cooling System Piping and Instrument. Diagram*. (Ref. 2.2.69)
- *Wet Handling Facility Pool Water Treatment System Train A Piping and Instrument. Diagram*. (Ref. 2.2.70)
- *Wet Handling Facility Pool Water Treatment System Train B Piping and Instrument. Diagram*. (Ref. 2.2.71)
- *Wet Handling Facility Pool Water Treatment System Train C Piping and Instrument. Diagram* . (Ref. 2.2.72)
- *Wet Handling Facility Spent Resin Handling System Piping & Instrument. Diagram.* (Ref. 2.2.77)
- *Wet Handling Facility TAD Canister Welding Machine Mechanical Equipment Envelope*. (Ref. 2.2.78)
- *Wet Handling Facility TAD/RC/TC Transfer Stations Plan & Elevation Mechanical Equipment Envelope Sh 1 of 2*. (Ref. 2.2.79)
- *Wet Handling Facility TAD/RC/TC Transfer Stations Pool Layout Mechanical Equipment Envelope Sheet 2*. (Ref. 2.2.80)
- *Wet Handling Facility TAD/STC Drying and TAD Inerting Piping & Instrument. Diagram*. (Ref. 2.2.81)

- *Wet Handling Facility Transportation Cask/DPC/STC Cavity Gas Sampling System Piping & Instrument. Diagram*. (Ref. 2.2.82)

- *WHF Pool Equipment Crane Process and Instrumentation Diagram*. (Ref. 2.2.87)

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. 2.2.92) and *Component Design Description: Welding and Inspection System* (Ref. 2.2.105). 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:

- *A Survey of Crane Operating Experience at U.S. Nuclear Power Plants from 1968 through 2002*. (Ref. 2.2.97)

- *Canister Storage Building Design Basis Accident Analysis Documentation*. (Ref. 2.2.93)

- *Control of Heavy Loads at Nuclear Power Plants*. (Ref. 2.2.100).

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

- *Master Logic Diagram*. (Ref. 2.2.106)

- *Nonelectronic Parts Reliability Data 1995*. (Ref. 2.2.94)

- *Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR): Data Manual, Part 4: Summary Aggregations*. (Ref. 2.2.95)

- *PRA Procedures Guide, A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plant*. (Ref. 2.2.101)

- *Probabilistic Risk Assessment (PRA) of Bolted Storage Casks, Updated Quantification and Analysis Report* (Ref. 2.2.90).

- *Safety Analysis Report, Idaho Spent Fuel Facility*. (Ref. 2.2.96)

- *Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants*. (Ref. 2.2.91)

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. 2.2.103 and Ref. 2.2.104), 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:

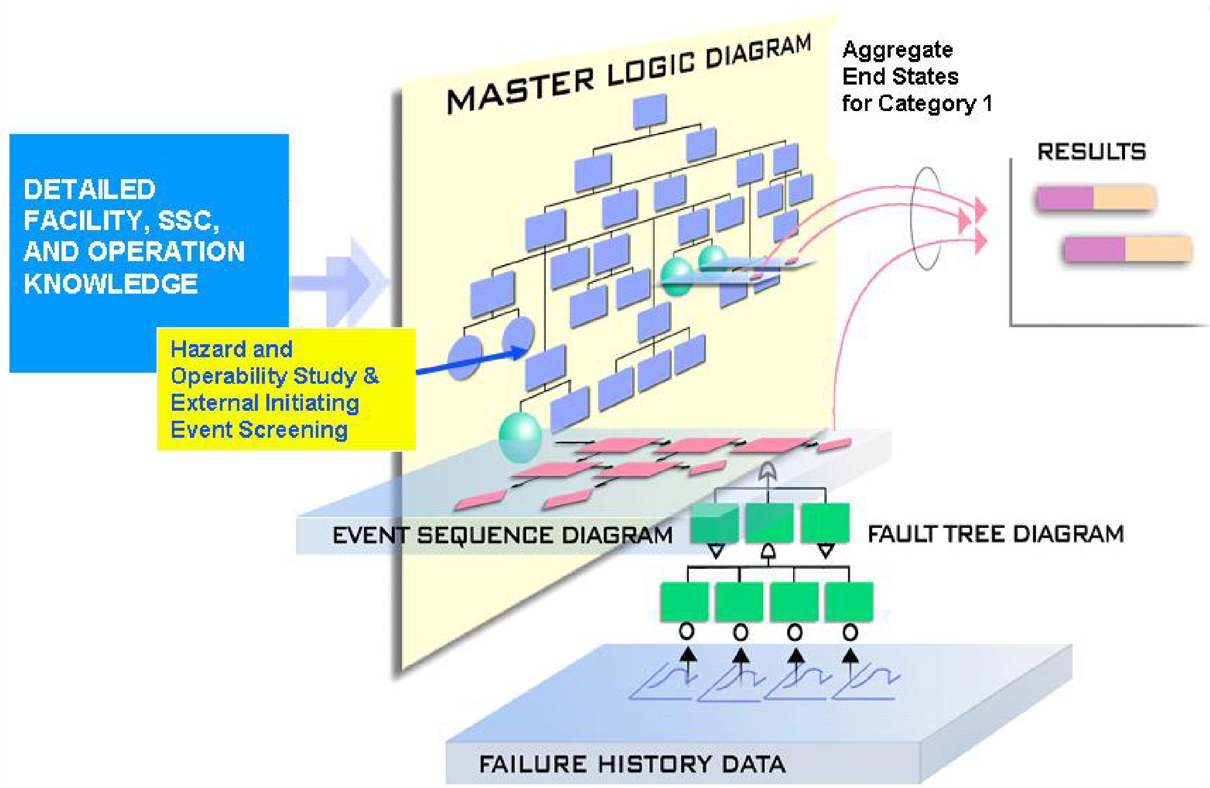
- Microsoft Windows 2000 Professional
- Windows XP
- Windows XP running inside a VMware virtual machine with VMware Player.

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 WHF. Specific features of the WHF and its operations are not discussed until Section 6, where the methods described here are applied to WHF. The PCSA uses the technology of probabilistic risk assessment (PRA) as described in references such as American Society of Mechanical Engineers *Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications* (Ref. 2.2.4). The PRA answers three questions:

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

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



Source: Modified from Probabilistic Risk Assessment: Master Logic Diagram (Ref. 2.2.106)

Figure 1. Event Sequence Analysis Process

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

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 1995* (Ref. 2.2.94) and *Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR), Volume 5: Data Manual, Part 4: Summary Aggregations* (Ref. 2.2.95)), 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. 2.2.5) is 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 level of detail of initiating events is such that they often are at a level of equipment assembly for which industry-wide reliability information does not exist. Fault trees are used to disaggregate or decompose the equipment (such as a crane) to SSCs for which reliability information is available. The PCSA, therefore, relies on ESDs and fault trees to represent the facility, equipment, and personnel responses to an initiating event.

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

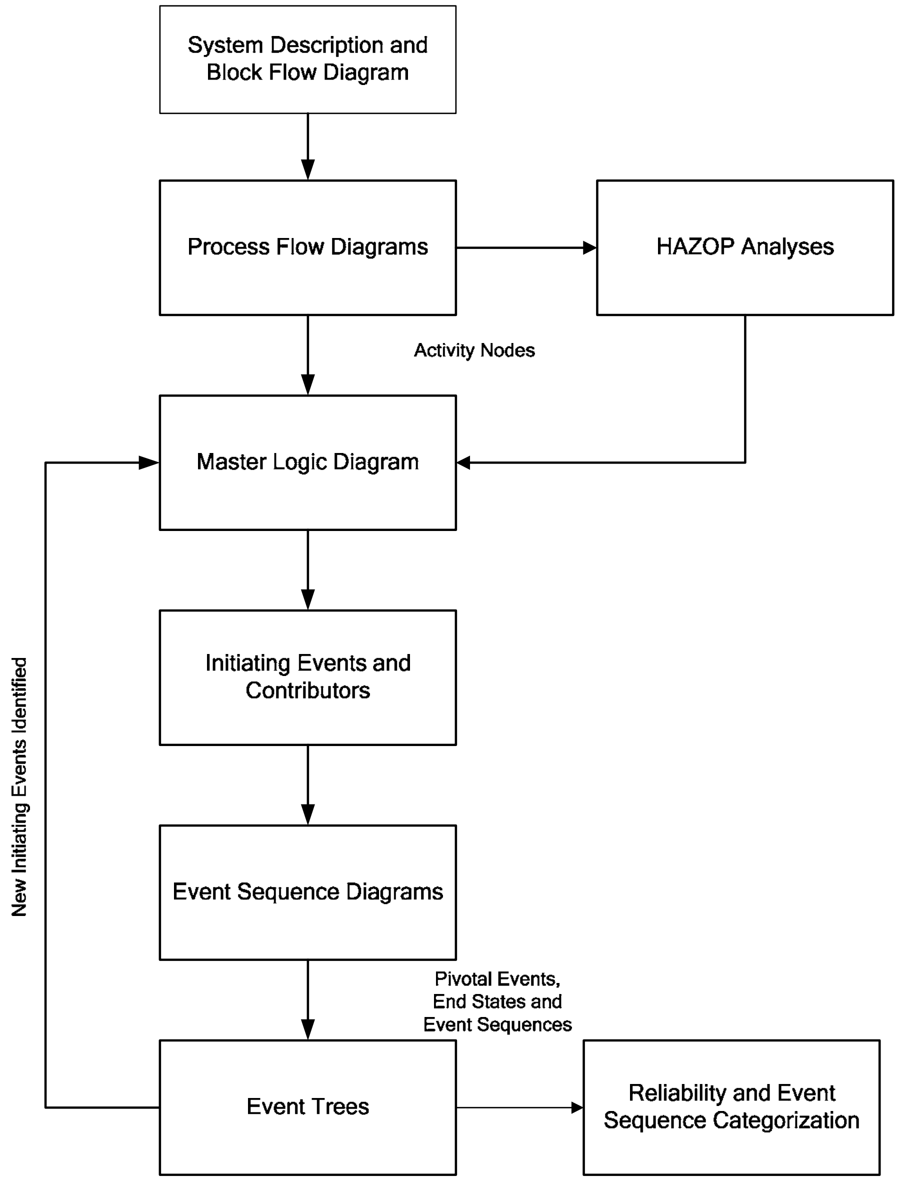
As required by the performance objectives for the geologic repository operations area through permanent closure in 10 CFR 63.111 (Ref. 2.3.2), each event sequence is categorized based on its frequency. Therefore, the focus of this analysis is to:

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

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

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

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



Source: Original

Figure 2. Preclosure Safety Analysis Process

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 Categorization, therefore, is based on each event sequence that emanates from the larger circle, for each waste form.

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

4.3.1 Initiating Event Development

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

[1]This is not to be confused with the aggregation of doses for normal operations and Category 1 event sequences described in 10 CFR 63.111a (Ref. 2.3.2).

is described in the *PRA Procedures Guide, A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants* (Ref. 2.2.101), 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 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. 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:

- *A Survey of Crane Operating Experience at U.S. Nuclear Power Plants from 1968 through 2002.* (Ref. 2.2.97)
- *Canister Storage Building Design Basis Accident Analysis Documentation*. (Ref. 2.2.93)
- *Control of Heavy Loads at Nuclear Power Plants.* (Ref. 2.2.100).
- *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. 2.2.90).
- *Safety Analysis Report, Idaho Spent Fuel Facility*. (Ref. 2.2.96)
- *Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants*. (Ref. 2.2.91)

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

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

Two key elements of the PCSA methodology are establishing and maintaining traceability among the PFD, MLD, and HAZOP. A PFD is broken down into nodes that group operational activities within a facility such as receipt, preparation, and transfer. Individual blocks within the nodes are used to *identify* specific processes and operations that are evaluated with both a MLD and HAZOP to identify potential initiators. Following this *identification* step, initiating events are then assigned a specific MLD index number (e.g., TWF-201) in the HAZOP table. This MLD index number correlates the initiator on the HAZOP to a corresponding initiator on the MLD. Any unique initiator index number can be traced back to the specific "node of origin" in its associated PFD in order to pinpoint the basis for a given event. This index number is then carried forward in developing the ESD, providing the traceability that ties MLD and HAZOP initiators to the initiators on the ESD. Figure 3, and Table 10 in Section 6, illustrate the above methodology.

4.3.1.1 Process Flow Diagram

A PFD is a simplified representation of a facility's processes and operations. It graphically represents information derived from the facility mechanical handling system block flow diagram and indicates how the mechanical equipment is to be operated. It is simplified because only information relevant to event sequences (potentially leading to dose or criticality) is depicted. As the example in Figure 7 in Section 4.3.4.2 shows, the general flow and relationships of the major operations and related systems that comprise a specific process are aggregated into nodes. These nodes represent groups of sequential steps in a process. The boundaries of each node are subjectively chosen to enable the analyst to easily keep in mind the operations within the node while considering what could go wrong within the node.

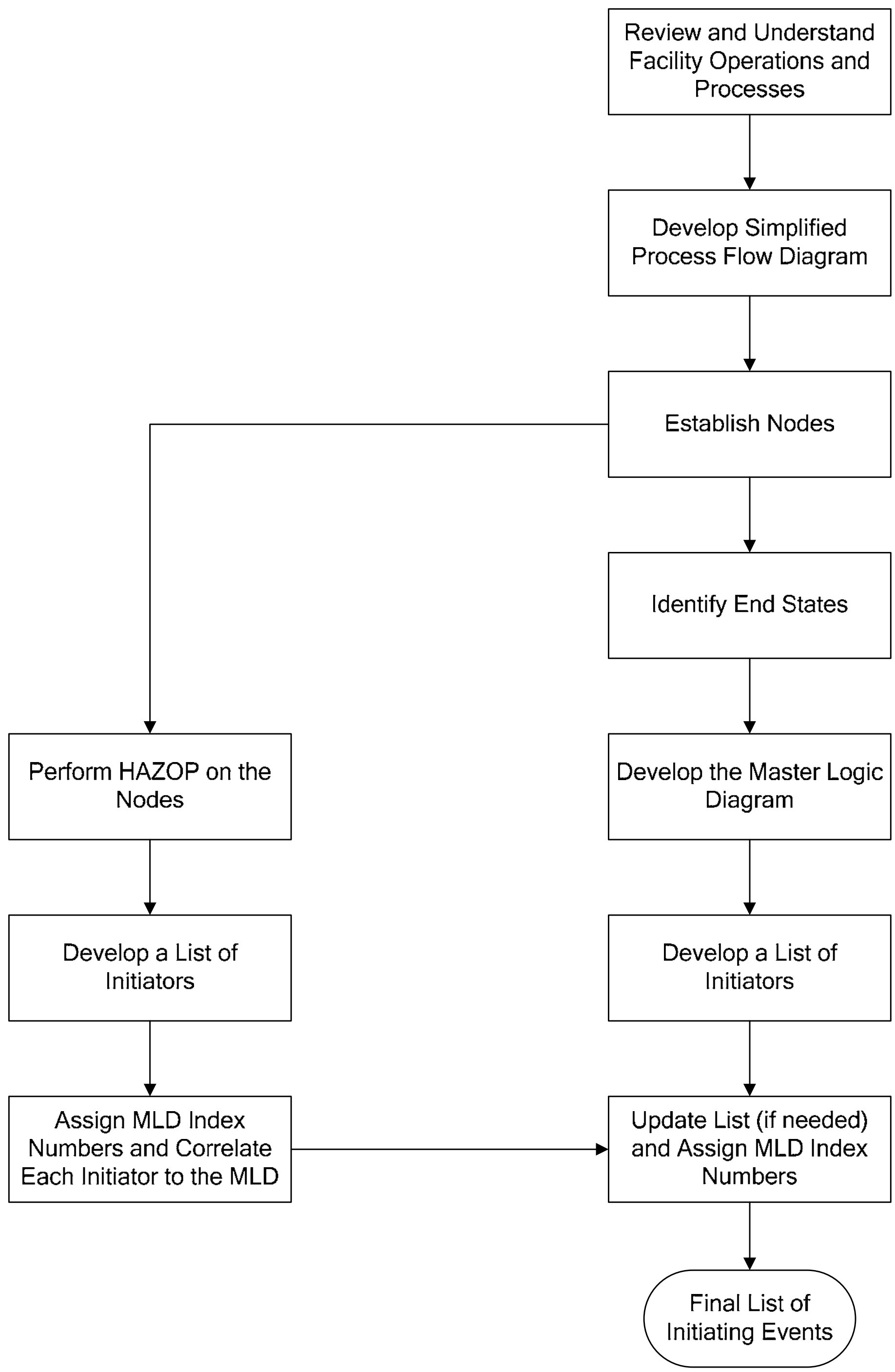


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Figure 3. Initiating Event Identification

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

4.3.1.2 Master Logic Diagram

The MLD technique is a structured, systematic process to develop a set of initiating events for a system and is described in *PRA Procedures Guide, A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants* (Ref. 2.2.101), Section 3.4.2.2. The method is adapted to the waste repository risk-informed PCSA. As a “top-down” analysis, the MLD starts with a top event, which represents a generalized undesired state. For this analysis, the top event includes direct exposure to radiation and exposure as result of a release of radioactive material. The basic question answered by the MLD is “How can the top event occur?” Each successively lower level in the MLD hierarchy divides the identified ways in which the top event can occur with the aim of eventually identifying specific initiating events that may cause the top event. In an MLD, the initiating events are shown at the next-to-lowest level. The lowest level provides contributors to the initiating event.

For example, initiating events may be defined at either a categorical level (e.g., “crane drops load”) that can be attributed to a specific crane (e.g., the 200-ton cask handling crane), down to a very specific level, such as a subsystem or component failure (e.g., “crane cable breaks”) or a human failure event (e.g., “operator opens cask grapple”).

A generalized logic structure for the PCSA MLD is presented below, and in Figure 4. In the development of a specific MLD (demonstrated per the example facility MLD shown in Section 4.3.4, Figure 6), this structure is generally followed for each branch until initiators are identified. Once initiators are identified, the process is terminated in that branch.

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

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

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

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

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

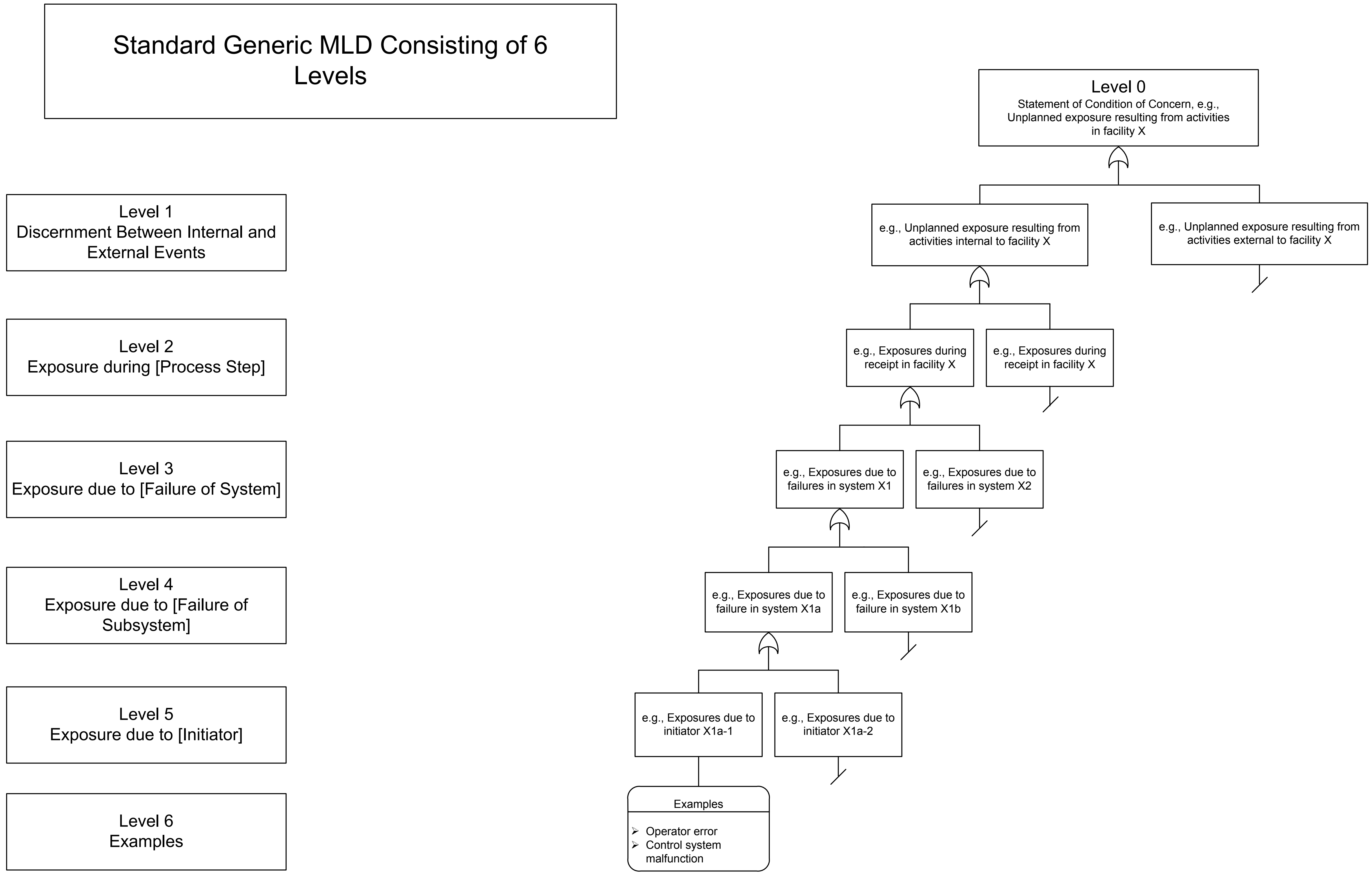

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Figure 4. Master Logic Diagram Framework

- Level 5: This level specifies the initiating event, usually in terms of equipment or component failure modes, that can result in the failure of subsystems or systems. In the MLD used herein to describe a typical waste-handling facility, each of the initiating event boxes is given an initiating-event identifier (e.g. TWF-201) which carries over to the corresponding ESD or ESDs. Level 5 is considered the appropriate grouping of initiating events for purposes of subsequent fault tree analysis.

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

4.3.1.3 Hazard and Operability Study

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

The HAZOP process focuses on identifying potential initiators that are depicted in the lower levels of the MLD. Initiating events are assigned a specific MLD index number (e.g., TWF-202) in the HAZOP table. The MLD index number correlates the initiator associated with the HAZOP with a corresponding initiator on the MLD. This correlation is reflected in Section 4.3.4.2, Figures 8 and 9.

As discussed in Section 4.3.1, the HAZOP is conducted to supplement the MLD results. The HAZOP is a "bottom-up" analysis used to supplement the "top-down" approach of the MLD (Ref. 2.2.2). It is a systematic study of the operations in each facility during the preclosure phase. The operations are divided into nodes, as shown in the PFD (Section 4.3.1.1). The purpose of defining nodes is to break down the overall facility operations into small pieces that can be examined in detail. The analysis of each node is completed before moving on to another node. The intended function of each node is first defined. The "intention" is a statement of what the node is supposed to accomplish as part of the overall operation. For example, Node 6 of the PFD for the example facility in Section 4.3.4.2, Figure 7 is entitled "Move CTT to Unloading Room."

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

Table 1. Standard Hazard and Operability Guidewords and Meanings

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

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

Each potential initiating event is first identified as a specific "deviation" from the well-defined, intended functions and behavior of each operational node. Deviations that have the potential for resulting in a radiological consequence are identified as a potential initiating event; (i.e., an initiating event that may result in an event sequence per the definition in 10 CFR 63.2 (Ref. 2.3.2)).

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

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

This PCSA follows the HAZOP guidance provided in the American Institute of Chemical Engineers *Guidelines for Hazard Evaluation Procedures* (Ref. 2.2.2). The *Yucca Mountain Review Plan, Final Report* (Ref. 2.2.102, Section 2.1.1.3.5), lists the American Institute of Chemical Engineers guidelines as a principal reference for performing a hazards evaluation. Consistent with the MLD, this HAZOP is focused on potential radiological hazards for the preclosure period that could lead to event sequences.

Table 2. Common Hazard and Operability Analysis Terminology

Term	Definition
STUDY NODES (or Process Sections)	Sections of equipment with definite boundaries (e.g., a line between two vessels) within which process parameters are investigated for deviations. The locations (on piping and instrumentation drawings, diagrams, and procedures) at which the process parameters are investigated for deviations.
OPERATING STEPS	Discrete actions in a batch process or a procedure analyzed by a HAZOP team. Steps may be manual, automatic, or software-implemented actions. The deviations applied to each process step are different than deviations that may be defined for a continuous process.
INTENTION	Defines how the plant or process node is expected to operate in the absence of deviations at the study nodes. This can take a number of forms and can either be descriptive or diagrammatic (e.g., flow sheets, line diagrams, piping and instrumentation diagrams).
GUIDEWORDS	Simple words that are used to qualify or quantify the intention in order to guide and stimulate the brainstorming process and so discover deviations. The guidewords shown in Table 1 are the ones most often used in a HAZOP. However, the list may be made more application-specific to guide the team more quickly to the areas where prior operations or experience have identified problems. Each guideword is applied to the process variables at the point in the plant (study node) which is being examined.
PROCESS PARAMETER	Physical or chemical property associated with the process. This includes general terms like mixing, concentration and specific items such as temperature, pressure, flow, and phase for processes, or general terms like lift, relocate, and specific terms like lift height and speed of movement for handling of containers.
DEVIATIONS	Departures from the intention that are discovered by systematically applying the guidewords to process parameters (e.g., "more pressure," “too high lift height”). This provides a list of potential deviations for the team to consider for each node. Teams may supplement the list of deviations with ad hoc items.
CAUSES	Reasons why deviations might occur. Once a deviation has been shown to have a credible cause, it can be treated as a meaningful deviation. These causes can be hardware failures, human failure events, an unanticipated process state (e.g., change of composition, or introduction of an over-weight or over-sized container into the handling facility), external disruptions (e.g., loss of power), etc.
CONSEQUENCES	Results of the deviations should they occur (e.g., release of radioactive or toxic materials, exposure to radiation). Normally, the team assumes that active protection systems or safeguards fail to work. Consequences that are unrelated to the study objective are not considered. Minor consequences, relative to the study objective, are dropped.
SAFEGUARDS	Engineering or administrative controls that are used to prevent the causes or mitigate the consequences of deviations (e.g., alarms, interlocks, procedures). Safeguards are not credited when defining consequences of a deviation, but are addressed in evaluating the need for actions or recommendations.
ACTIONS (or Recommendations, Comments)	Suggestions for design or procedural changes (i.e., to provide new or additional safeguards) or areas for further study (e.g., analyses of reliability of active or passive systems credited as safeguards, human reliability analysis, or radiological consequence analyses).

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

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

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

Table 3. Examples of Deviations for a Chemical Process

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

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

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

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

4.3.2 Internal Event Sequence Development

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

Event sequences are developed with the following objectives:

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

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

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

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

4.3.2.1 Event Sequence Diagrams

An ESD is a block flow diagram that displays the combinations of pivotal events that reflect the responses of SSCs and personnel after an initiating event or group of initiating events (Ref. 2.2.101), Section 3.4.3.2. To construct an ESD, the analyst, begins with the initiating events that were identified by the MLD and HAZOP and then, in effect, answers the question "What can happen next?" until an end state is reached. ESDs are designed to logically depict the progression of event sequences from the initiating event up to and including the end state. ESDs identify the key safety functions necessary to reach an end state after the initiating event, as well as the associated structure, system, or component responses. Although operator actions are not shown explicitly on the ESDs in this analysis, human failure events are implicit in some of the initiating events and pivotal events. An ESD is structured as a decision tree in which pivotal events are queried with two possible results: a yes/success (desired) outcome and a no/failure (undesired) outcome. The structure allows for a straightforward transposition of ESDs into event trees. In this PCSA, ESDs and the associated event trees consider human, mechanical, electrical, electronic, controller, structural, thermal and naturally occurring events. However, as noted in Section 1, event sequences for external events (including seismic events) are not developed in this analysis. External events and any associated event sequences are evaluated and documented separately.

Five end states are considered in the ESDs as follows:

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

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

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

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 a criticality investigation is indicated for Category 1 or 2 event sequences.

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

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

2. Direct Exposure, Degraded Shielding – Applies to event sequences where an SSC providing shielding is not breached, but 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 from containment and an indication of a reactivity increase.

3. Direct Exposure, Loss of Shielding – Applies to event sequences where an SSC providing shielding fails, leaving a direct path for radiation to stream. For example, this end state applies to a breached transportation cask, with the DPC or TAD canister inside maintaining its containment function. In another example, this end state applies to shield doors inadvertently opened. Excludes radionuclide release from containment and an indication of a reactivity increase.

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

5. Radionuclide Release, Unfiltered – Indicates a release of radioactive material from its containment, through the pool of the WHF or through an unfiltered path, to the environment. Excludes nuclear reactivity increases. Pool water provides particulate removal so that a particulate release to the WHF air does not occur. However, the pool water does not filter non-soluble gases such as noble gases. HVAC is also ineffective at filtering noble gases. The term “filtered” for this study means that HVAC is filtering particulates, so a pool-related release is not given the name “filtered release” with respect to the end state. Radionuclide release to the WHF pool will be referred to as a gaseous unfiltered release.

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

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

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

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

As has already been noted, the criticality parameter “moderation” is used as a basis for the development of event sequences important to criticality. The reason that the event sequence development includes moderation was explained in Section 1. The WHF contains a borated pool for handling of spent fuel assemblies. This end state applies to event sequences in the pool that might result in reactivity increases associated with reduction of boron concentration. 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 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. 2.2.101), 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.

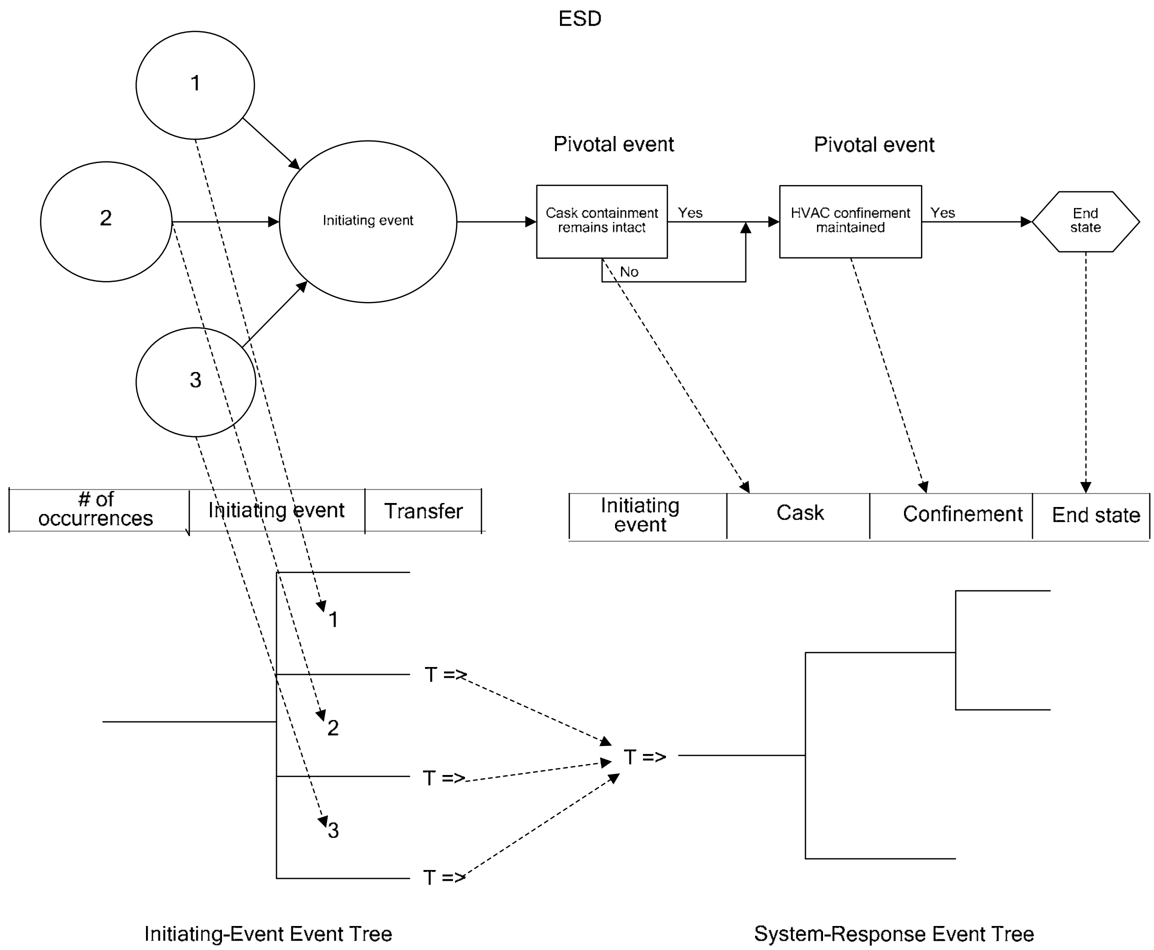

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Figure 5. Event Sequence Diagram–Event Tree Relationship

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

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

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

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

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

4.3.2.3 Internal Fire and Flooding Event Analysis

Fire initiating events identified in the MLDs are analyzed in the *Wet Handling Facility Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1). The MLD and HAZOP did not identify internal flooding event sequences for WHF that would threaten a waste form.

4.3.3 External Events

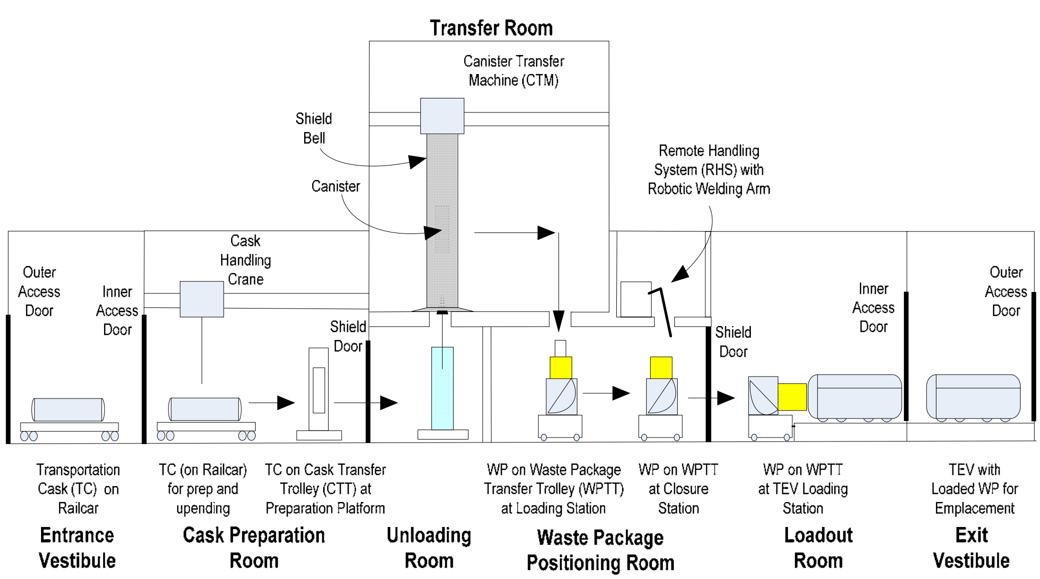
External initiating events are discussed further in the *External Events Hazards Screening Analysis* (Ref. 2.2.23).

4.3.4 Example Facility Analysis

This section illustrates the overall event sequence development approach using an example "typical waste-handling facility" (TWF). It is particularly useful for understanding the relationships among the PFD, MLD, HAZOP, ESDs and event trees. This example portrays a TWF in which the design and operations are generalized; as such, some of the specific features of the TWF are different from similar features in the WHF. WHF-specific features, initiating events, and event sequences are presented beginning in Section 6. This TWF receives, repackages, and exports waste forms for emplacement, employing equipment and processes that are representative of an actual facility. This example describes the facility, shows a generic PFD and a generalized MLD, provides a sample HAZOP, and describes development of an ESD and event tree for waste transfer activities of the facility using the 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 WHF and it has a fictitious mission, design features, and operations that differ from those of the WHF. 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 the facility personnel, move and open transportation casks, and remove and transfer the canisters to waste packages for emplacement. The mechanical handling equipment includes such major pieces of equipment as the overhead bridge cranes, cask transfer trolleys (CTT), CTM, waste package transfer trolley (WPTT), and associated lifting fixtures and devices.

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

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

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

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

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

4.3.4.1 Process Flow Diagram Development

The initial effort in identifying initiating events and developing ESDs and event trees involves gathering and reviewing facility design and operating information and documentation, which is then used to develop a PFD that summarizes the processes occurring within the facility. Relationships between operations and systems that characterize a specific process with defined boundaries are combined into distinct nodes on the PFD. A PFD for the example 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, ESD, and event tree.

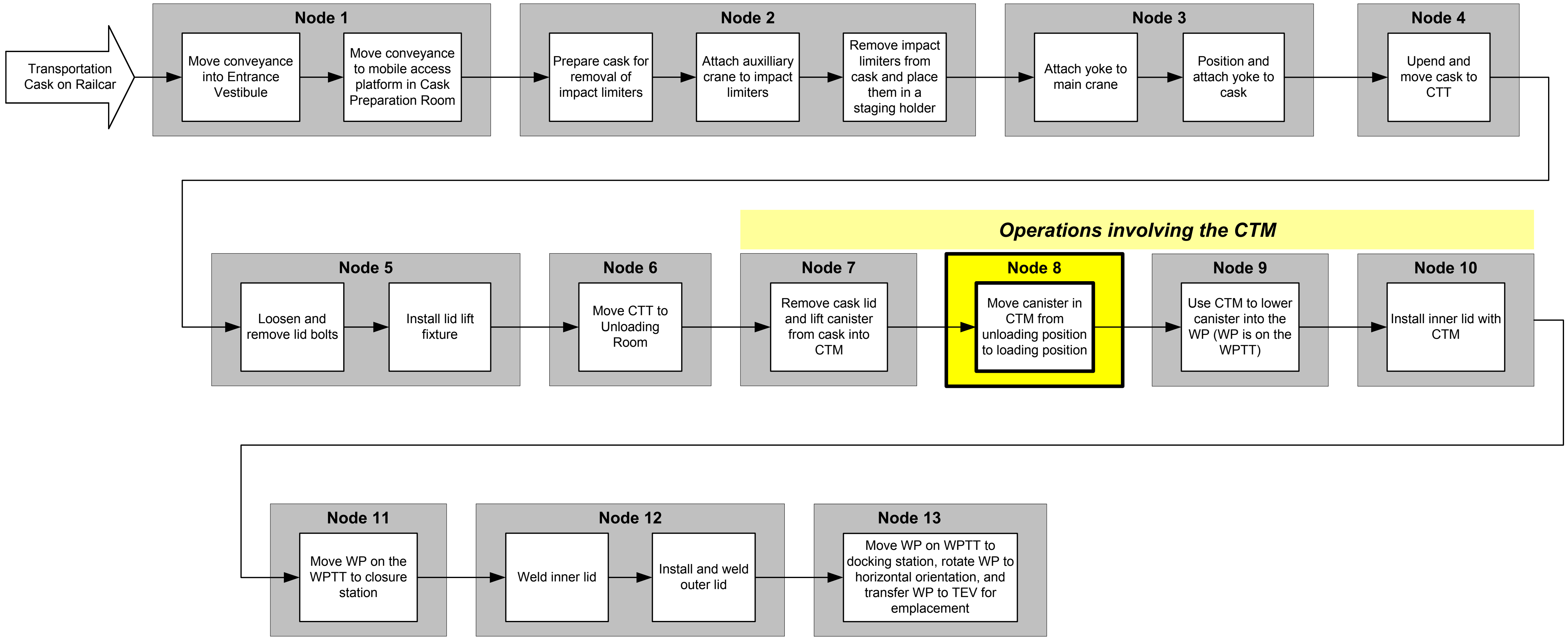
4.3.4.2 Master Logic Diagram Development

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

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

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

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



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

Source: Original

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

Table 4. Process Node Descriptions

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

Table 4. Process Node Descriptions (Continued)

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

Table 4. Process Node Descriptions (Continued)

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

Table 4. Process Node Descriptions (Continued)

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

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. The WPTT moves the loaded waste package from the loading station to the closure station, still in the Waste Package Positioning Room. The waste package is maneuvered to a position below the RHS for inner and outer waste package lid welding (refer to Node 12 description). Equipment involved in Node 11 operations: • WPTT • Waste Package Positioning Room shield door (closed). Additional equipment present during Node 11 operations: • RHS.
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. After the waste package is positioned under the portal, the robotic arms use the weld end effectors to weld the inner lid in place. The inner lid weld is inspected. After passing the inspection, The RHS is used to retrieve the outer lid and place it on the waste package. The robotic arms then use the end effectors to weld the outer lid into place. Another non-destructive examination inspection is performed to ensure this weld is also completed correctly. After this operation, the waste package can leave the facility for emplacement. Equipment involved in Node 12 operations: • RHS • Robotic arms • Weld end effectors • Inspection equipment. Additional equipment present during Node 12 operations: • WPTT • Waste Package Positioning Room shield door (closed).
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. After the lid welding operations are complete, the Exit Vestibule inner access door is closed and the Waste Package Positioning Room shield door is opened. The WPTT moves the waste package from the closure station to the Loadout Room TEV loading station. At the TEV loading station, the WPTT mechanically engages to the docking station. The waste package, waste package pallets, and transfer carriage are rotated by the trolley to a horizontal orientation. In the horizontal orientation, the waste package pallets are supporting the waste package on the transfer carriage. A TEV is at the docking station and set to receive the waste package. A worm drive (also referred to as a screw drive) engages the transfer carriage pulling it and the waste package riding on the waste package pallet into the TEV. (A worm drive is a gear that uses a spiral shaft to control speed and movement. It provides smooth movement and efficient speed control.) Inside the TEV, arms lift the waste package pallet supporting the waste package. The worm drive then reverses and returns the transfer carriage to the WPTT. The TEV door is closed. The waste package is now secured in the TEV, and the TEV exits the facility. With both the Waste Package Positioning Room shield door and the Exit Vestibule outer access door closed, the Exit Vestibule inner access door is opened. The loaded TEV transports the waste package out of the facility to the Exit Vestibule, which is the interface point between the facility and the outside. The Exit Vestibule inner access door is closed, completing the facility’s canister transfer operation. The Exit Vestibule outer access door is opened, and the TEV takes the waste package to the repository for emplacement.

Table 4. Process Node Descriptions (Continued)

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

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

Source: Original

Table 5. Equipment Descriptions

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

Table 5. Equipment Descriptions (Continued)

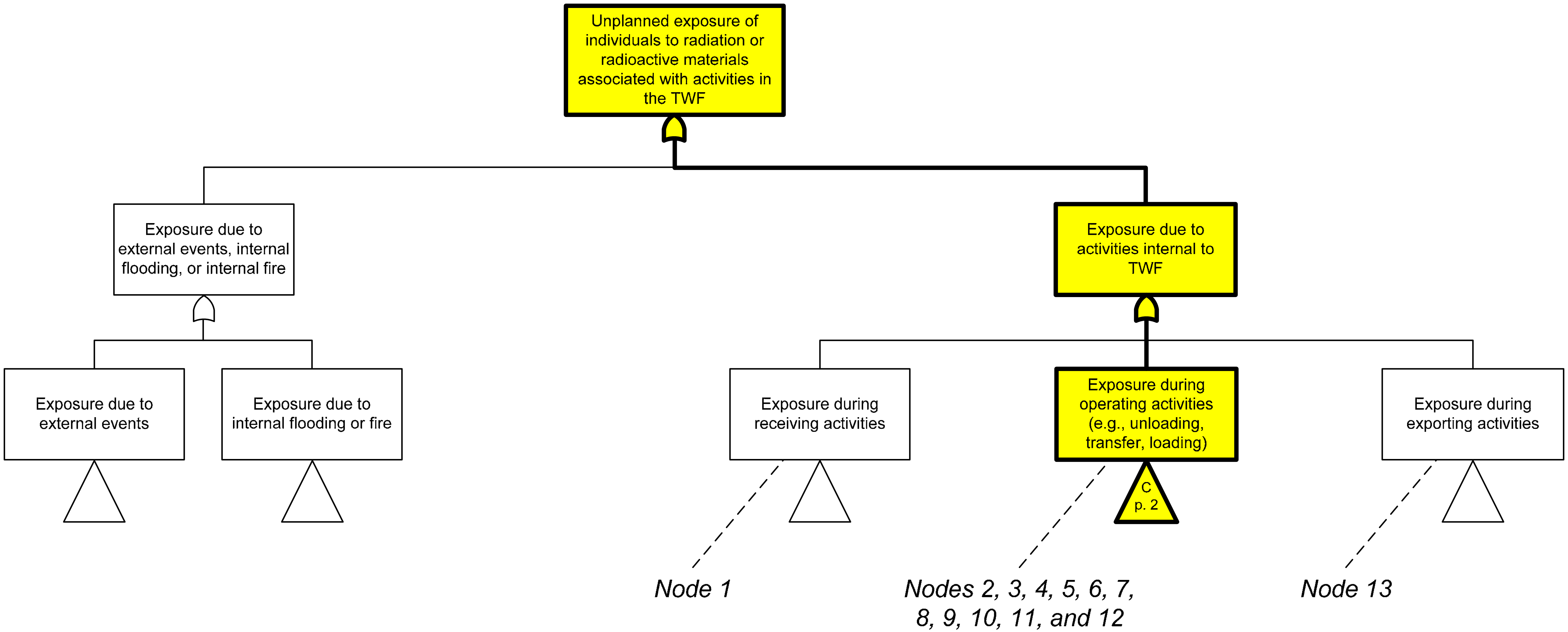
Equipment Type	Description
Cask Transfer Trolley	The CTT is used to transfer transportation casks between the Cask Preparation Room and the Unloading Room. The CTT is a metal frame platform that, when in operation, floats on a thin film of air above the floor surface. The frame and restraining brackets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

Table 5. Equipment Descriptions (Continued)

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

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

Source: Original



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

Source: Original

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

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

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

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

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

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

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

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

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

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

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

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

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

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

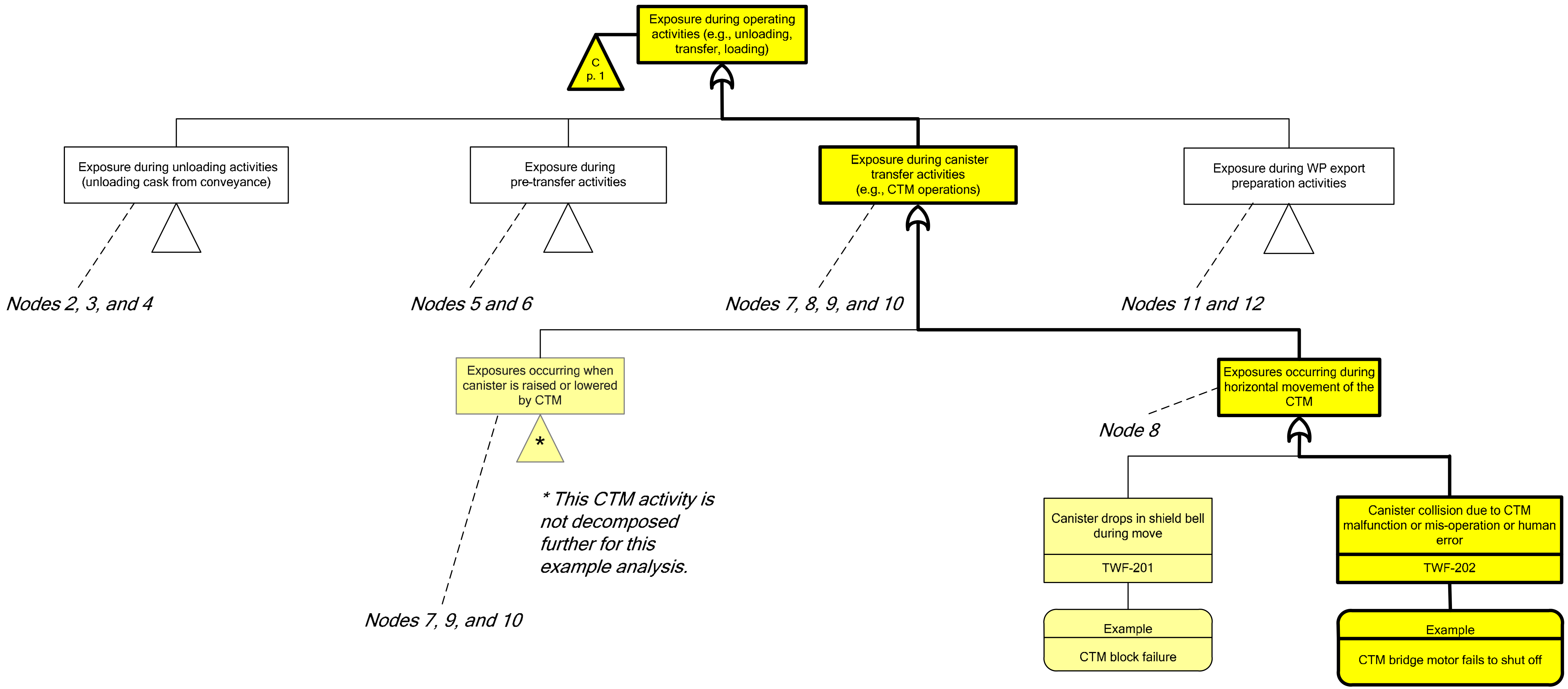
- Nodes 7, 8, 9, and 10 are essentially canister transfer activities relying heavily on the CTM, and are evaluated as such. Events for these activities tend to involve impacting the cask or canister with objects, shearing of the canister, dropping the canister, dropping objects onto the canister, and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

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

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

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

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



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

Source: Original

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

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

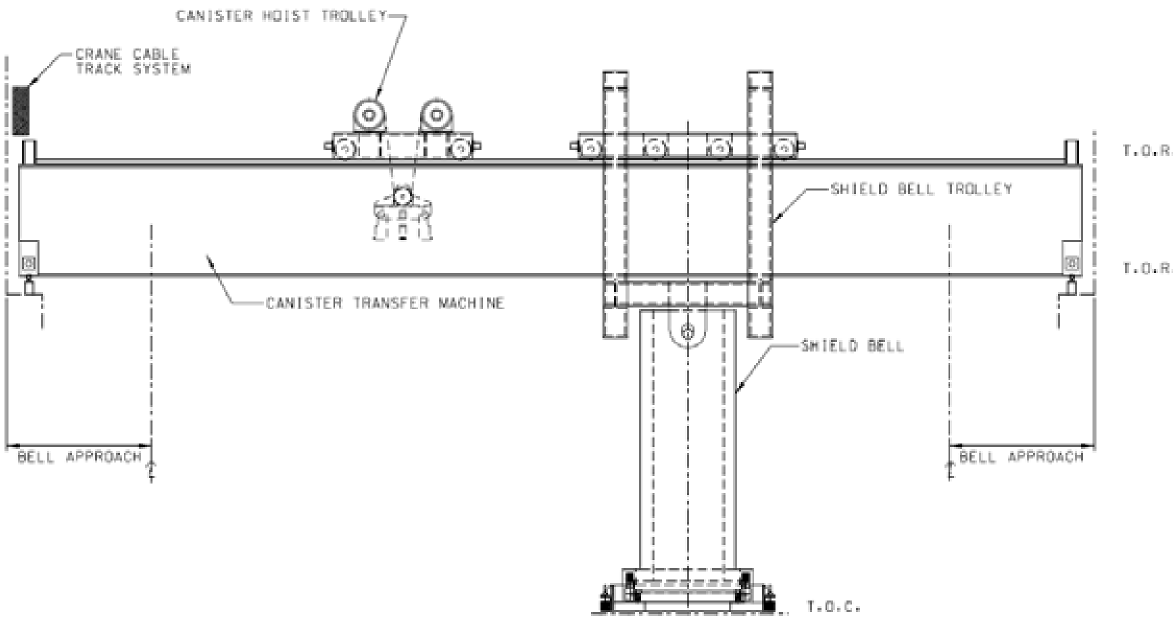
Each set of initiating events and contributors in the MLD is similarly developed and examined. The level at which initiating events are identified is the highest level for which the same system response event tree applies. Lower levels provide failure events associated with the initiating event. The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

4.3.4.3 HAZOP Development

In addition to the MLD development, an independent study of the processes identified in the PFD is conducted by a team of subject matter experts, analysts, and operations personnel. This is a HAZOP (Section 4.3.1.3), which is employed in conjunction with the MLD development to assure that the facility operations are well understood and that a comprehensive identification of initiating events is accomplished. The team evaluates each node in the PFD using a set of HAZOP parameters and deviations, and the results of the HAZOP are compared to the results of the MLD development. Any initiating event that is identified in the HAZOP but not already identified in the MLD is added and assigned an MLD index number for traceability. Thus, the MLD becomes the conduit for events identified in the HAZOP to be included in the ESDs. The HAZOP is not used for any other purpose in this analysis. The detailed breakdown of the initiating events from the MLD into contributing failure modes is achieved in fault trees as part of the quantification of the event sequences.

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

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



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

Figure 10. Schematic of the Canister Transfer Machine

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

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

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

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

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

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

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

Source: Original

For every operational node, each deviation for each parameter in the HAZOP is assessed likewise. Any other relevant information is captured in the notes column. Deviations for which safety consequences are identified are then assigned MLD index numbers to correlate the information to a specific event on the MLD. For example, the deviation involving the CTM moving too fast (Node Item Number 8.1) is assigned the MLD index number TWF-202, and the deviation entailing two-blocking (Node Item Number 8.11) is assigned the MLD index number TWF-201. Referring again to the MLD, Figure 9, these MLD index numbers are denoted for two initiating events, and the deviations identified in the HAZOP appear as contributors. “CTM moves too fast” is a contributor identified under TWF-202, and “Two-blocking of CTM crane” is a contributor for TWF-201.

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

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

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

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

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

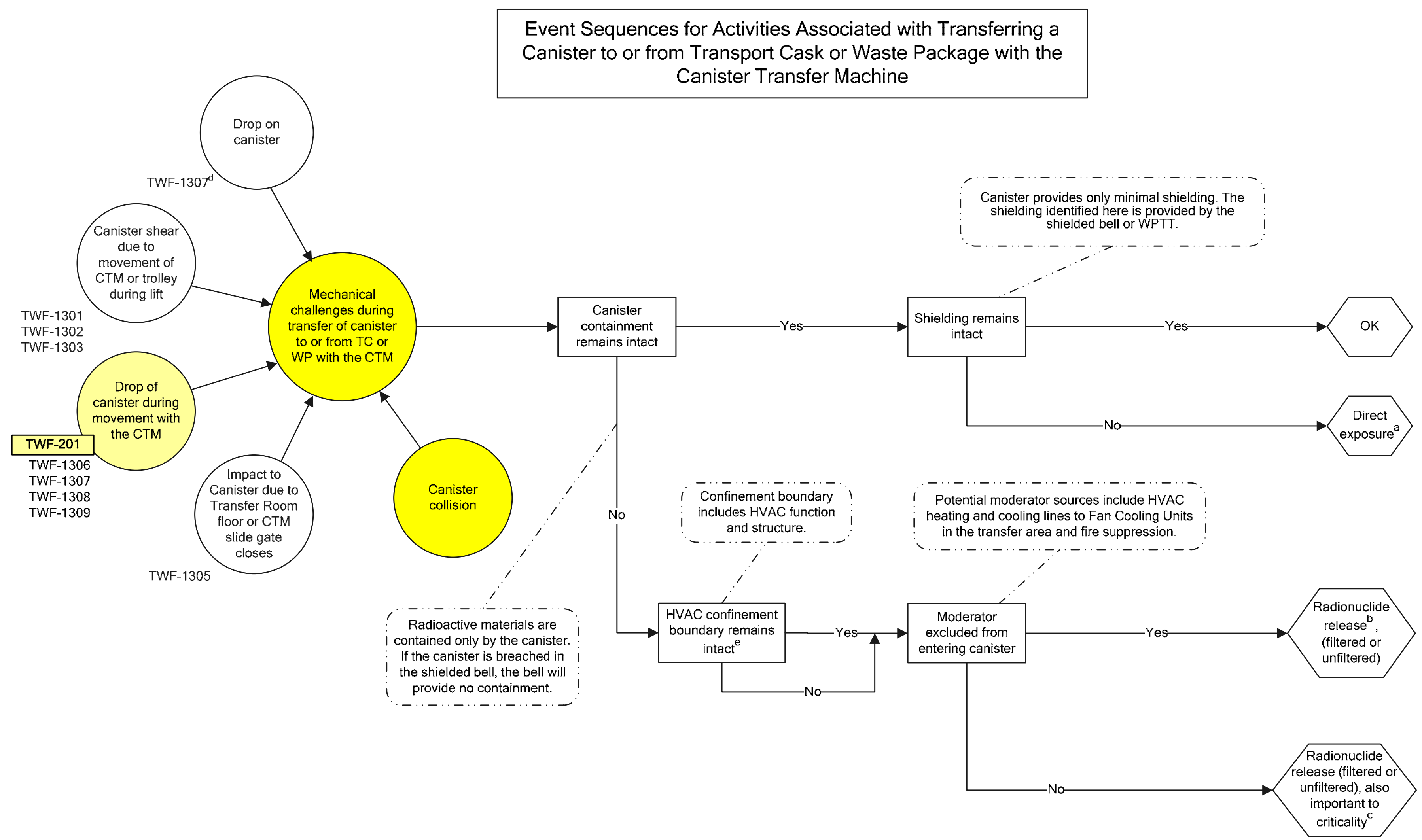
NOTE: CTM = canister transfer machine; HAZOP = hazard and operability; MLD = master logic diagram; TWF = typical waste-handling facility; Y = yes; N = no.

Source: Original

4.3.4.4 Event Sequence Diagram Development

After the HAZOP and MLD results are correlated and the MLD is finished, 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.

"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.

[b] "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.

[c] 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 movement with the CTM" (Figure 11).

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

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

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

Source: Original

Following the flow of the ESD to the right, one can see that the small bubbles point to a central, large bubble. The large bubble represents the aggregated initiating event. Each small bubble on an ESD can be considered a subset of the large bubble. Because each small bubble represents an initiating event with a unique frequency, the large bubble is an aggregated initiating event. As is discussed in the *Wet Handling Facility 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 (e.g., provided by the shield bell) 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 <u>not</u> imply an inevitable criticality event, but rather indicates that further analysis must be done to show either that the event sequence will not result in criticality or that the event sequence is Beyond Category 2.

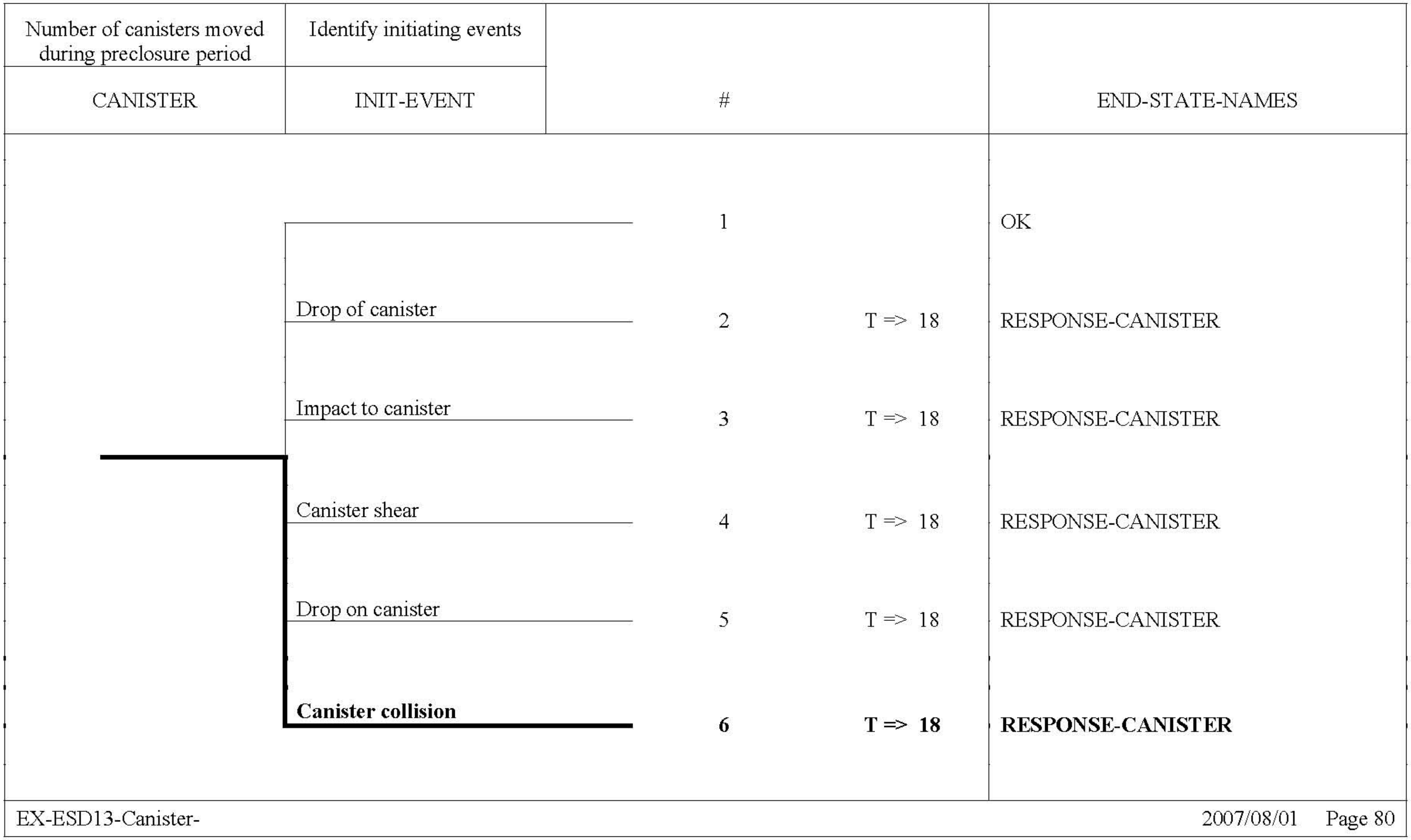
4.3.4.5 Event Tree Development

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

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

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

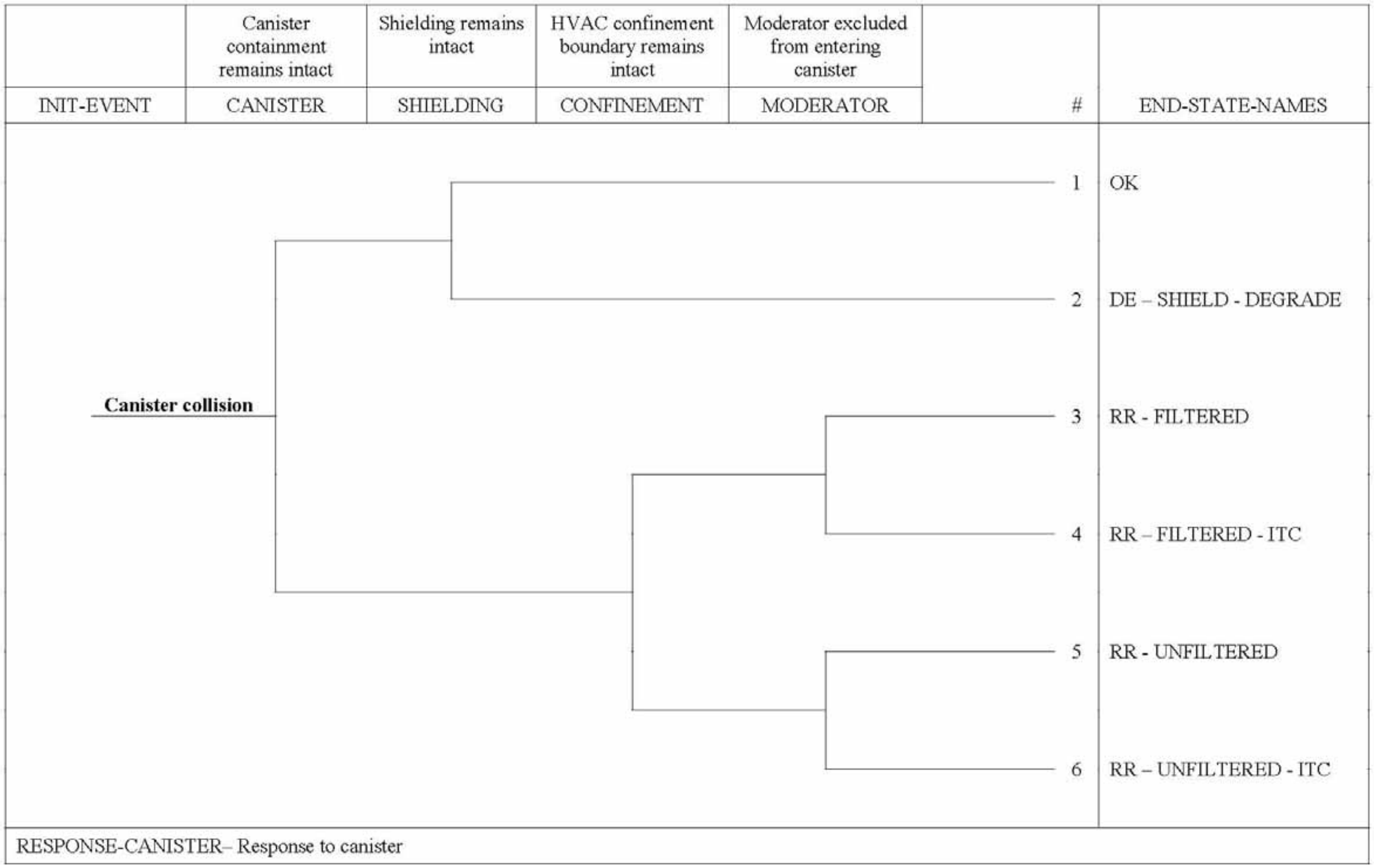
For additional details regarding the development of ESDs and event trees, refer to Section 4.3.2.



NOTE: INIT = initiating

Source: Original

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



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

Source: Original

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

5. LIST OF ATTACHMENTS

6. BODY OF CALCULATION

6.1 INITIATING EVENT ANALYSIS

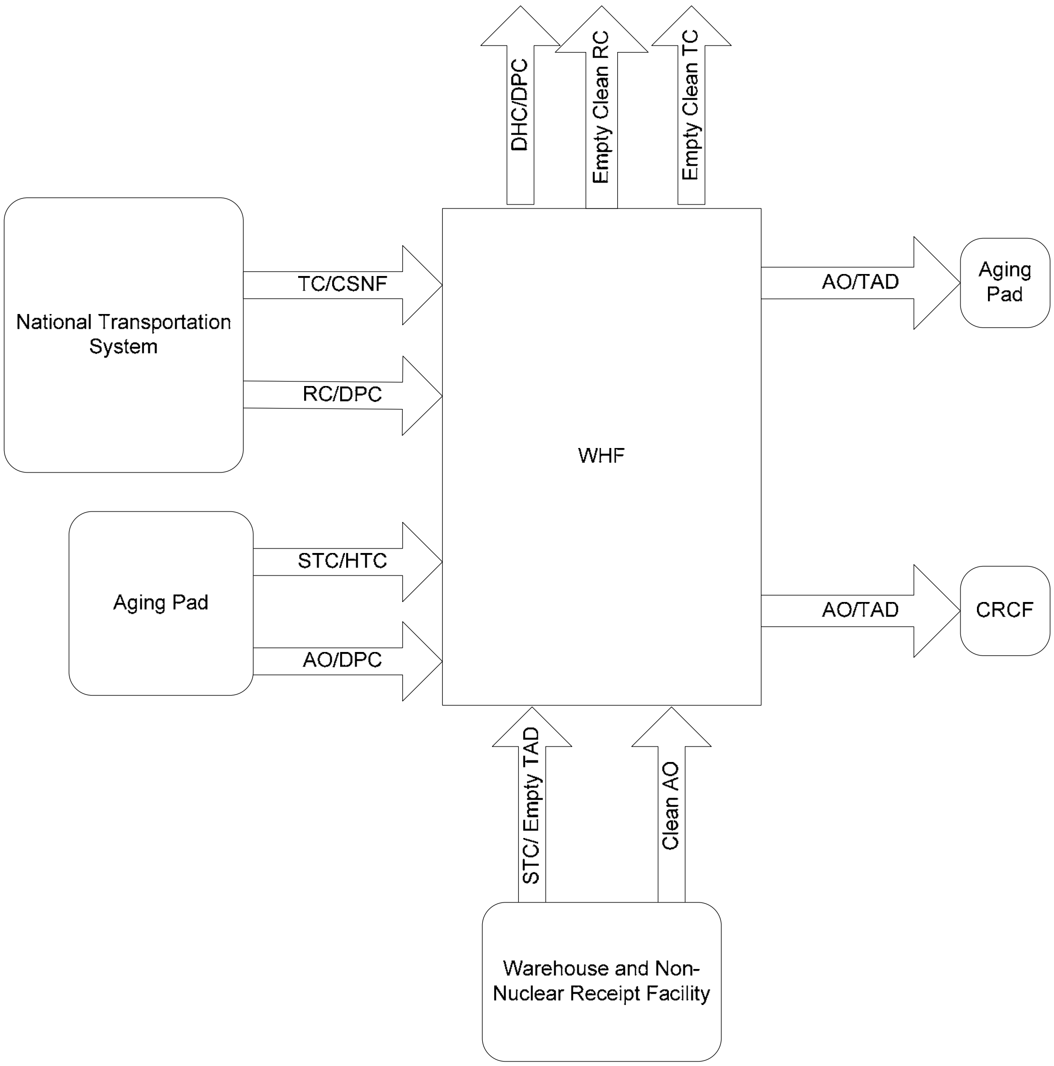
6.1.1 Introduction

Initiating events are identified for the YMP using MLDs that are verified with a HAZOP as described in Section 4. Each phase of the operations within the WHF is analyzed to ensure that a comprehensive list of initiators are identified. These initiators are identified at a level for which historical data exists, for which expert opinion can be obtained, or for which a fault tree model of causes can be developed based on equipment design and intended operations (e.g., human versus automated control). The initiating events identified in this analysis may stem from: (a) external events, which are identified in *External Events Hazards Screening Analysis* (Ref. 2.2.23), and include natural phenomena such as tornado, earthquakes, flooding, lightning, etc., and activities external to the GROA such as aircraft crash, nearby industrial facilities, etc. or (b) internal events, which include events that could occur randomly within the facility, such as mechanical or electromechanical equipment failure (e.g., crane failure), human failure events associated with the operations of the systems or components (e.g., collision with a structure due to human failure), and fires or flooding events. These initiating events are depicted in the MLD.

6.1.2 Overview of Wet Handling Facility and Its Operations

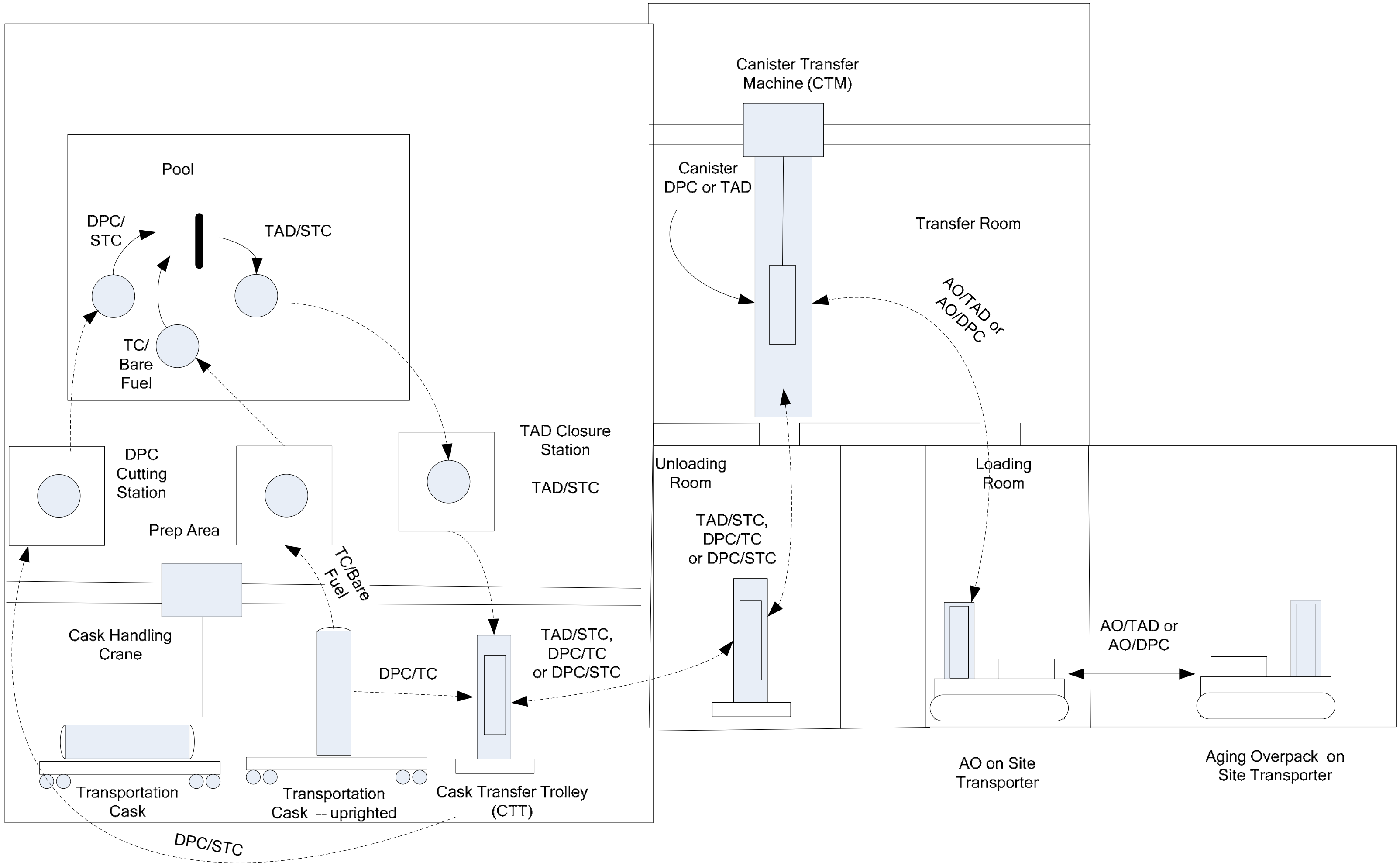
This section contains a brief overview of the WHF and its operations. The overview provides the basis for the identification of initiating events and the development of event sequences. Operational details are presented at a level that is intended to be sufficient in most cases for development of the MLD, the HAZOP, and the ESDs. Attachments A and B provide supplemental details that may be needed to understand some of the potential initiating events and the subsequent event sequences. The location of the WHF within the GROA is shown in Attachment C.

The WHF provides handling capability for a portion of the DOE-managed waste stream. The waste stream for the WHF is limited to CSNF contained in transportation casks as fuel assemblies and in DPCs. The input and output streams for the WHF is shown in Figure 14. As illustrated in Figure 15, canisters and fuel assemblies received in transportation casks by the WHF are transferred into TAD canisters in the pool then removed from the pool and welded closed, placed in aging overpacks, and carried out of the WHF on a site transporter to an Aging Pad or directly to the CRCF for placement into a waste package. The WHF does not put TAD canisters into waste packages. The primary mode of receipt of waste into the WHF is rail service. In addition, the WHF is designed to receive trucks (each of which carries a transportation cask loaded with CSNF or a DPC). For the purposes of this analysis, WHF operations are defined to include operations spanning the receipt of transportation casks on rail or truck carriers and aging overpacks with DPCs on site transporters into the WHF through the loading of TAD canisters in the pool, and export of TAD canisters in aging overpacks to the Aging Pad or CRCF (Ref. 2.2.8, Section 5.1.1).



Source: Original

Figure 14. Wet Handling Facility Generalized Input and Output Diagram



NOTE: This simplified conceptual depiction is not to scale.
AO = aging overpack; CTT = cask transfer trolley; DPC = dual-purpose canister; STC = shielded transfer cask; TAD = transportation, aging, and disposal canister; TC = transport cask.

Source: Original

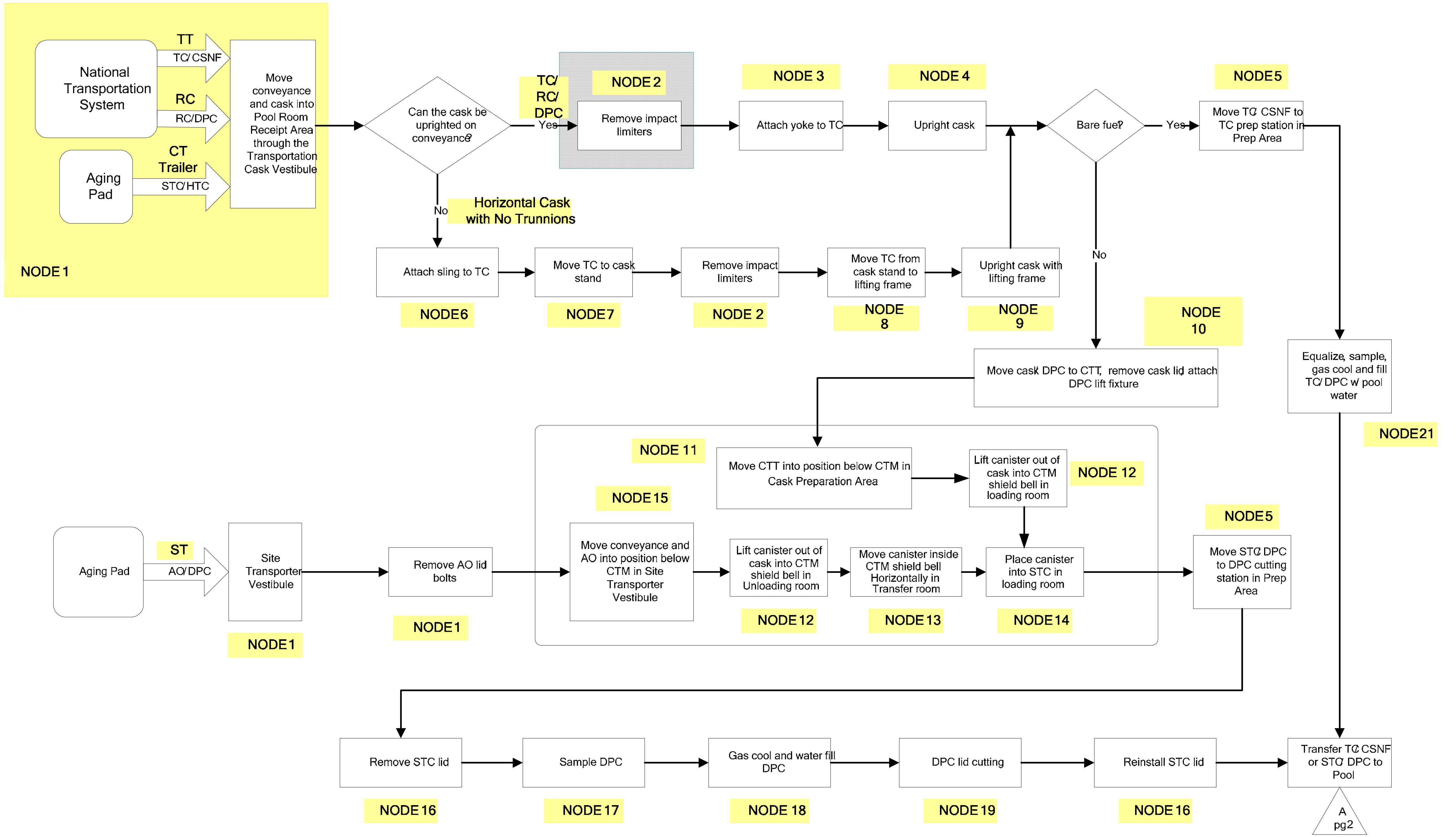
Figure 15. Schematic Diagram of WHF Mechanical Handling Operations

The WHF is a multilevel reinforced concrete structure with shear walls and shield walls approximately four feet thick. The shield walls protect personnel from exposure during the operations for which a bare canister or waste package may be present in the facility. The roof is also reinforced concrete. The elevated concrete operating floor of the Canister Transfer Area forms the ceiling of a portion of the concrete cell structure. In the WHF this area transfers TAD canisters from on-site shielded transfer casks, which are designed similar to transportation casks, to aging overpacks. 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 are present. The WHF has several unique features when compared to the other preclosure facilities. These features include rooms and corridors for preparation of DPCs, cutting open DPCs, welding TAD canisters, and the wet handling pool. The pool is 50 feet deep and is surrounded by 6 to 8 foot thick concrete walls lined with steel. The primary function of the pool is to provide wet handling to transfer SNF assemblies from transportation casks or STCs to TAD canisters. The spent fuel transfer machine (SFTM) moves fuel assemblies within the pool. The borated pool water also prevents criticality during normal operation and mishandling events.

The WHF 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 two stages of HEPA filters prior to discharging to the atmosphere at an elevated release point. The HEPAs filter radioactive particulates.

The operational summary continues with Section 6.1.2.1, and is organized according to the nodes, which are indicated in the PFD (Figures 16 and 17). The summary is based primarily on the level 2 and 3 mechanical handling block flow diagrams for the WHF. 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 WHF and other references have also been used and are cited as needed for information that is not found in the block flow diagrams (Ref. 2.2.50 and Ref. 2.2.51 through Ref. 2.2.67).

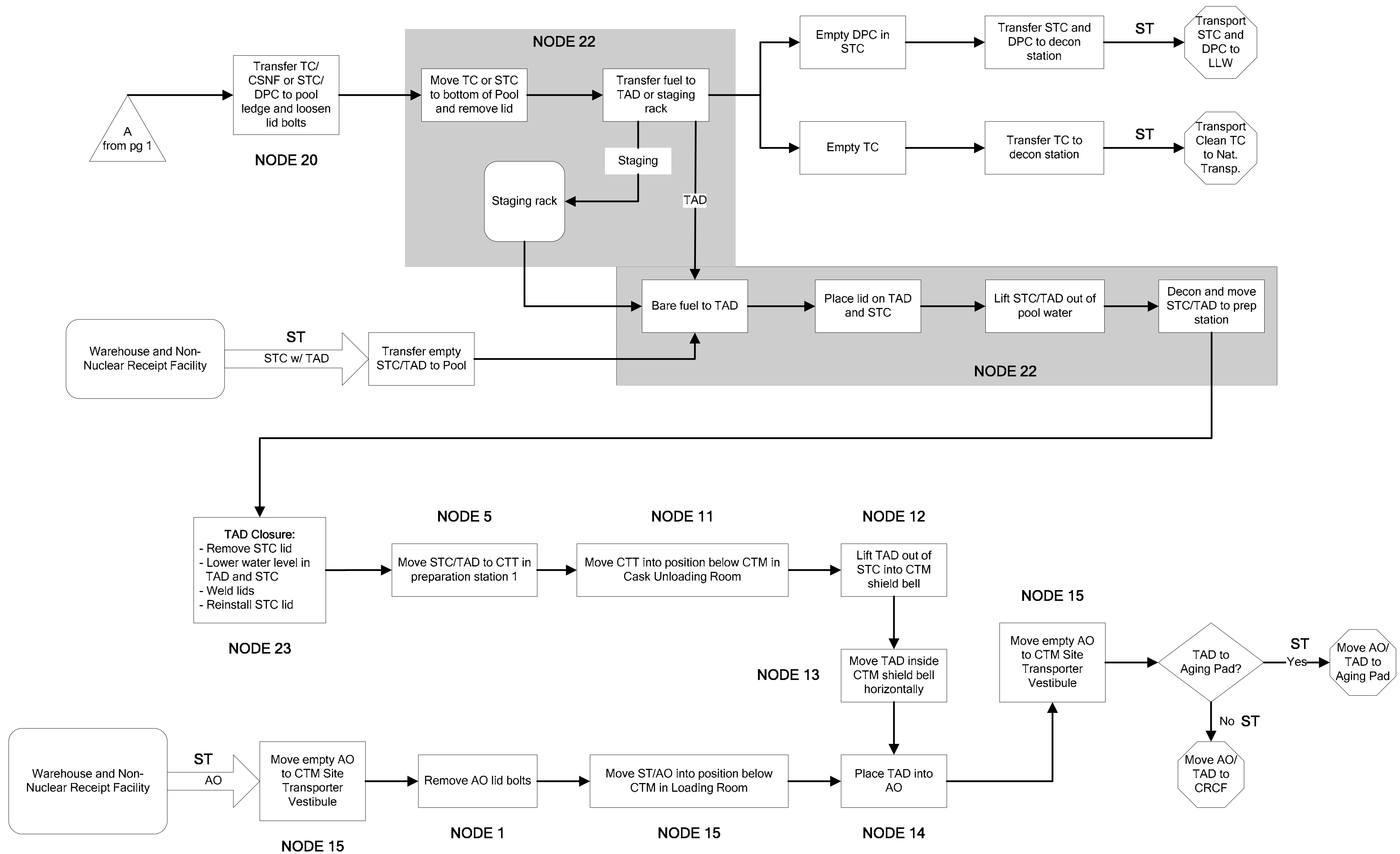
Attachment B provides more details on the operation of the WHF.



NOTE: AO = aging overpack; CRCF = Canister Receipt and Closure Facility; CSNF = commercial spent nuclear fuel; CTM = canister transfer machine; CTT = cask transfer trolley; CT Trailer = cask transfer trailer; DPC = dual-purpose canister; LLW = low level waste; HTC = transportation cask that is never upended; RC = railcar; STC = shielded transfer cask; TAD = transportation, aging, and disposal canister; TC = transportation cask; TT = truck trailer; ST = site transporter; STC = shielded transfer cask.

Source: Original

Figure 16. Wet Handling Facility Simplified Process Flow Diagram (Sheet 1 of 2)



NOTE: AO = aging overpack; CRCF = Canister Receipt and Closure Facility; CSNF = commercial spent nuclear fuel; CTT = cask transfer trolley; DPC = dual-purpose canister; LLW = low-level waste; ST = site transporter; STC = shielded transfer cask; TAD = transportation, aging, and disposal canister; TC = transportation cask.

Source: Original

Figure 17. Wet Handling Facility Simplified Process Flow Diagram (Sheet 2 of 2)

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 WHF. (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 WHF.) The overhead door to the WHF Cask Preparation Area is opened and the conveyance is parked and secured in the Cask Preparation Area (Ref. 2.2.38). If personnel barriers are present on the transportation cask after the cask is received in the WHF, they are removed at this point using the cask handling crane.

This step also applies to aging overpacks being received on site transporters in the Site Transporter Vestibule and removal of aging overpack lid bolts. The site transporter is then moved into the Site Transporter Vestibule, parked, and secured.

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.52).

6.1.2.2 Node 2: Remove Impact Limiters from Transportation Cask

Once casks are moved into the facility, handling steps may differ for different waste forms. The TTC casks must be moved to a cask stand prior to removing impact limiters. The steps associated with movement to the cask stand are described in Nodes 6 and 7. For all other casks, the impact limiters are removed by the cask handling crane while the cask is still on the truck or rail carrier. Operators use the MAP in the performance of these operational steps (Ref. 2.2.39; Ref. 2.2.46; and Ref. 2.2.47). The MAP allows personnel access to the transportation cask.

The MAP is a rail-mounted structure that bridges over the cask lying on the carrier (Ref. 2.2.11 and Ref. 2.2.12). 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.

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.52).

6.1.2.3 Node 3: Attach Yoke to Transportation Cask

The applicable yoke or lifting device is attached to the cask handling crane (Ref. 2.2.19). Cask clamps and tiedowns, which secure the cask to the carrier, are removed using the cask preparation crane. Operators use the mobile access platform in the performance of these operational steps (Ref. 2.2.52 and Ref. 2.2.54).

6.1.2.4 Node 4: Upright Transportation Cask on Its Conveyance

The cask handling crane is used to upright the cask using the yoke that was attached in Node 3.

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.52).

6.1.2.5 Node 5: Move Transportation Cask or STC 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 carrier that floats on an air film (Ref. 2.2.38; Ref. 2.2.47; and Ref. 2.2.98).

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 14* (Ref. 2.2.64) and the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 3* (Ref. 2.2.53).

6.1.2.6 Node 6: Attach Sling to Transportation Cask

For TTCs (e.g., a transportation cask that is upended using a tilt frame), a sling is used to move the transportation cask to the cask stand prior to upending. The sling is placed around the cask in this step. This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.52).

6.1.2.7 Node 7: Move Transportation Cask to Cask Stand

Once the sling is in place around the cask, it is moved using the cask handling crane to the cask stand. The cask is moved vertically on to the cask stand and the impact limiters are removed (described in Node 2).

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.52).

6.1.2.8 Node 8: Move Transportation Cask from Cask Stand to Lifting Frame

Once the impact limiters are removed from the cask, the cask handling crane is used to move the cask to the lifting frame. The cask tilting frame is an L-frame tilting device used to upright the cask and is described in the *CRCF, RF And WHF Cask Tilting Frame Mechanical Equipment Envelope* (Ref. 2.2.10).

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.52).

6.1.2.9 Node 9: Upend Cask With Lifting Frame

As described in Node 9, the TTC is placed on a lifting frame. Once the cask is secured on the lifting frame, the lifting yoke is attached to the cask handling crane. The cask is uprighted using the cask handling crane.

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 2* (Ref. 2.2.52).

6.1.2.10 Node 10: Cask Movement to CTT

The CTT is used to move the loaded transportation cask with a DPC from the Cask Preparation Area to the Cask Unloading Room. The cask is loaded onto the CTT for movement using the cask handling crane. Opening and closing the applicable shield door is required in this node.

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 14* (Ref. 2.2.64).

6.1.2.11 Node 11: Move Cask into Position Below the CTM

Once loaded with a cask the CTT is moved into position below the CTM. This applies to casks being moved from the Cask Preparation Area. For loaded aging overpacks on site transporters being moved from the Site Transporter Vestibule, the site transporter is moved into position below the CTM in the Loading Room.

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 15* (Ref. 2.2.65).

6.1.2.12 Node 12: Lift Canister Out of Cask in Canister Transfer Machine

For the transportation cask, the cask lid has been removed. For the aging overpack cask, the cask lid is still in place, though its bolts have been removed. In both the transportation task and aging overpack cases, the CTM is moved into position over the cask and the CTM slide gate and the cask port slide gate are opened (Ref. 2.2.6; Ref. 2.2.45; Ref. 2.2.47; and Ref. 2.2.9). For the aging overpack waste form, the CTM is used to remove the cask lid. Also, for aging overpack, the appropriate exchangeable grapple must be attached to the CTM grapple. 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.

The CTM is located on the second floor in the Canister Transfer Area (Ref. 2.2.6 and Ref. 2.2.45). The CTM is mounted on a bridge girder that runs on rails. The primary function of the CTM is to transfer the canister from a transportation cask or and aging overpack to a STC. The CTM has an integrated trolley mechanism with a shield compartment (or bell) capable of retaining a canister in place, while moving from port to port. The shield-bell trolley consists of a shield bell with an integrated structural frame and trolley mechanism. A sliding shield gate is provided at the bottom of the bell. The trolley mechanism is able to move along the span of the bridge girder to position the shield bell over the floor openings.

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 5* (Ref. 2.2.55).

6.1.2.13 Node 13: Horizontal CTM Movement

This step involves the horizontal movement of the CTM carrying the canister from a position over the Loading Room port to a position above the Cask Unloading Room port. Positioned below the Cask Unloading Room port is an empty STC on the CTT (Ref. 2.2.38 and Ref. 2.2.45).

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 15* (Ref. 2.2.65).

6.1.2.14 Node 14: Lower Canister Into an STC

Once the CTM is in position over the Cask Unloading Room port, the CTM slide gate and the port slide gate are opened. Next, the canister is lowered into the STC, and the port slide gate and the CTM slide gate are closed.

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 15* (Ref. 2.2.65).

6.1.2.15 Node 15: Move Aging Overpack Into Position Below CTM (Aging Overpack on Site Transporter Only)

This node depicts the movement of aging overpacks with DPCs on a site transporter into the Loading Room where the DPC in the aging overpack is positioned under the CTM, ready to be transferred into a STC for processing within the WHF. This node also applies to the movement of empty aging overpacks on site transporters coming into the facility are moved under the CTM for loading with TAD canisters. Once loaded, the aging overpack is moved to the Aging Facility or CRCF.

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 15* (Ref. 2.2.65),

6.1.2.16 Node 16: Remove STC Lid for DPC Cutting

Once the DPC is transferred into a STC, it is then moved back to the Cask Preparation Area and placed at the DPC cutting station, where the STC lid is removed in preparation for DPC cutting. The STC lid is removed using the jib crane and placed in a lid stand for storage. A shield ring is then placed over the STC/DPC annulus to provide personnel shielding during the DPC lid cutting step.

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 12* (Ref. 2.2.62).

6.1.2.17 Node 17: DPC Sampling

After the STC lid has been removed, the DPC is exposed. The DPC outer lid is removed to gain access to the access ports. The access ports are used to sample the DPC cavity to ensure that the DPC is safe for opening.

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 12* (Ref. 2.2.62).

6.1.2.18 Node 18: DPC Cooling and Filling

After the gas sampling is complete, the DPC is filled with pool water. This will provide shielding and fuel assembly cooling during the DPC lid cutting.

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 12* (Ref. 2.2.62).

6.1.2.19 Node 19: DPC Lid Cutting

Once the DPC has been prepared for lid cutting, the DPC cutting machine is moved into place over the DPC using the jib crane (Ref. 2.2.45). The DPC cutting process is automated and is outlined in *Wet Handling Facility DPC Cutting Machine Mechanical Equipment Envelope Sheet 1 of 2* (Ref. 2.2.35) and *Wet Handling Facility DPC Cutting Machine Mechanical Equipment Envelope Sheet 2* (Ref. 2.2.36).

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 12* (Ref. 2.2.62).

6.1.2.20 Node 20: Transfer of Cask to Pool Ledge

Once the DPC lid is cut, but not removed from the DPC, the shield ring is removed and the STC lid is placed back onto the STC and fastened down. The cask is moved to the staging shelf in the pool using cask handling crane with the cask handling yoke (Ref. 2.2.42).

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 12* (Ref. 2.2.62).

6.1.2.21 Node 21: Transportation Cask Sampling and Filling

The transportation cask with CSNF is moved to the Cask Preparation Area in Node 5. It is placed at the preparation station. Once it is in place, the transportation cask is sampled and filled with pool water in preparation for pool operations. Transportation cask sampling and cooling are completed through transportation cask access ports, which are uncovered during the preparation steps.

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 16* (Ref. 2.2.66).

6.1.2.22 Node 22: Pool Activities

Just prior to pool operations, the cask is sitting on the pool staging shelf. The first operation in this node is to move the cask to the bottom of the pool. This is done using the cask handling crane. Once the cask is sitting on the pool bottom, the cask lid is removed and placed in an underwater lid rack.

The spent fuel transfer machine (SFTM) is used to transfer the fuel bundles from the cask to the fuel staging rack and then into an empty TAD canister. This operation is repeated until the TAD canister is full (Ref. 2.2.42 and Ref. 2.2.45).

Once the TAD canister is filled with the appropriate fuel assemblies, the TAD canister lid is installed using the auxiliary pool crane. The STC lid is then installed using the same crane. The auxiliary pool crane is described in *Wet Handling Facility Auxiliary Pool Crane Mechanical Equipment Envelope* (Ref. 2.2.31).

The STC is then lifted to the staging shelf using the cask handling crane fitted with the cask handling yoke. Once the cask is sitting on the staging shelf, the cask handling yoke is disengaged and washed using the wash lance.

The STC is lifted out of the pool and the yoke and cask is washed using the wash lance. The cask is then moved to the TAD canister closure station.

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 6* (Ref. 2.2.56) and *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 13* (Ref. 2.2.63).

6.1.2.23 Node 23: TAD Canister Closure and Export

Once the TAD canister has been placed at the TAD canister closure station (Ref. 2.2.45), the STC lid fasteners are removed and the lid is placed in the laydown area. The auxiliary pool crane is used to move the STC lid. The STC shield ring is installed over the annulus with the jib crane and the STC drain port is opened and the annulus is partially drained into the pool.

The TAD canister drain port is opened and the TAD canister is drained partially to allow for welding. The TAD canister inner lid is then welded using the TAD canister welding machine. This equipment is described in *Wet Handling Facility TAD Canister Welding Machine Mechanical Equipment Envelope* (Ref. 2.2.78). The inner lid weld is inspected and the TAD canister is vacuum dried, inerted with Helium, and leak tested. The TAD canister outer lid is then placed on and welded into place. The outer lid weld is inspected. The welding machinery is then removed.

The STC lid is placed back on once the TAD canister is closed and the shield ring has been removed. The cask is now ready for export. The CTM is used to move the TAD canister from the STC into an aging overpack. The aging overpack is then moved on a site transporter to the Aging Facility or CRCF. Export operations have been considered in Nodes 5, 11, 12, 13, 14 and 15.

This node is described in the *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 6* (Ref. 2.2.56) and *Wet Handling Facility Mechanical Handling System Block Flow Diagram-Level 3 Sheet 15* (Ref. 2.2.65).

6.1.3 Identification of Initiating Events

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

To facilitate ESD development, a unique identification number has been assigned to each initiating event. The numbers consist of “WHF-” 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, “WHF-312” means “initiating event 12 on the page 3 of the MLD” and “WHF-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, “WHF-E202” means external initiating event 02 on page 2 of the MLD.

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

Table 9. List of External Initiating Events

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

Source: Original

Table 10. List of Internal Initiating Events

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
WHF-103	Exposure due to RC derailment leading to cask drop	D-1	E-2	F-2
WHF-104	Exposure due to RC collision leading to an impact	D-1	E-2	F-1, F-2
WHF-105	Exposure due to TT failure leading to rollover or load drop	D-1	E-2	F-1
WHF-106	Exposure due to TT collision leading to an impact	D-1	E-2	F-1
WHF-107	Exposure due to ST failure leading to rollover or load drop	D-1	E-16	F-3, F-4
WHF-108	Exposure due to ST collision leading to an impact	D-1	E-16	F-3, F-4
WHF-I301	Internal flooding caused by piping failure	D-3	—	—
WHF-I302	Internal flooding caused by actuation of fire protection	D-3	—	—
WHF-I303	Large fire event affecting the entire facility	D-3	—	F-31
WHF-I304	Fire affects TC or STC on CTT in Preparation Area	D-3	E-2	F-31
WHF-I305	Fire affects TC in Transportation Cask Vestibule (no diesel present)	D-3	E-2	F-31
WHF-I306	Fire affects TC in Cask Preparation Area	D-3	—	F-31
WHF-I307	Fire affects TC or STC in Cask Unloading Room	D-3	—	F-31
WHF-I308	Fire affects DPC in Cask Loading Room	D-3	—	F-31
WHF-I309	Fire affects STC/TAD in Site Transporter Vestibule	D-3	E-2	F-31
WHF-I310	Fire affects TC in Transportation Cask Vestibule (diesel present)	D-3	E-2	F-31
WHF-I311	Fire affects DPC at the DPC cutting station	D-3	—	F-31
WHF-I312	Fire affects TAD at TAD closure station	D-3	—	F-31
WHF-I313	Fire affects AO/TAD in bolting room	D-3	—	F-31
WHF-401	Entrance Vestibule crane drops heavy load on TC	D-4	E-3, E-4	F-5, F-6
WHF-402	Unplanned conveyance movement while Entrance Vestibule crane is attached to TC or conveyance fixtures leading to rollover	D-4	E-3, E-4	F-5, F-6
WHF-403	Impact from MAP operations	D-4	E-3, E-4	F-5, F-6
WHF-501	Cask handling crane malfunction causes TC drop	D-5	E-4, E-5	F-5, F-6
WHF-502	Cask handling crane causes unplanned conveyance movement	D-5	—	F-5, F-6
WHF-503	Unplanned conveyance movement while crane is attached to TC or conveyance fixtures	D-5	E-4	F-5,F-6
WHF-504	Cask handling crane drops object onto TC	D-5	E-4	F-5, F-6

Table 10. List of Internal Initiating Events (Continued)

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
WHF-505	Unplanned conveyance movement prior to cask clearing pedestal	D-5	—	F-5, F-6
WHF-506	Cask handling crane drops cask	D-5	E-7	F-6
WHF-508	Cask collides with object while being moved by cask handling crane	D-5	E-7	F-6
WHF-509	Impact from platform operations	D-5	E-3, E-4	F-6
WHF-510	Cask tips and drops after being placed onto CTT	D-5	E-10	F-6
WHF-511	Cask handling crane drops object on cask	D-5	—	F-5
WHF-512	Cask collides with object while being moved by cask handling crane	D-5	E-6	F-5
WHF-513	Cask handling drops cask	D-5	E-6	F-5
WHF-514	Impact from platform operations	D-5	—	F-5
WHF-515	Cask tips over and drops after being placed onto TC stand	D-5	—	F-5
WHF-601	Cask handling crane drops load onto cask	D-6	—	F-6
WHF-602	Cask handling crane malfunction causes cask stand to roll over	D-6	—	F-6
WHF-701	Unplanned conveyance movement prior to clearing pedestals leads to side impact of cask	D-7	—	F-6
WHF-702	Cask handling crane drops cask	D-7	E-8	F-6
WHF-703	Cask collides with object while being moved by cask handling crane	D-7	E-8	F-6
WHF-704	Cask tips over and drops after placed on pool ledge	D-7	—	F-20
WHF-705	Cask handling crane drops object onto cask	D-7	—	F-20
WHF-706	Cask collides with object while being moved by cask handling crane	D-7	—	F-20
WHF-707	Cask handling crane drops cask	D-7	—	F-20
WHF-708	Cask tips over and drops after placed on pool ledge	D-7	—	F-19
WHF-709	Cask handling crane drops object onto cask	D-7	E-21	F-19
WHF-710	Cask collides with object while being moved by cask handling crane	D-7	E-21	F-19
WHF-711	Cask handling crane drops cask	D-7	E-21	F-19
WHF-712	Cask handling crane drops object onto cask	D-7	—	F-6
WHF-801	Cask handling crane drops cask	D-8	E-9	F-6
WHF-802	Cask collides with object while being moved by cask handling crane leading to side impact	D-8	E-9	F-6
WHF-803	Cask tilting frame failure leads to cask drop	D-8	E-9	F-6
WHF-804	Cask handling crane malfunction leads to cask drop	D-8	E-10	F-6
WHF-805	Cask handling crane drops cask	D-8	E-10	F-6

Table 10. List of Internal Initiating Events (Continued)

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
WHF-806	Cask collides with object while being moved by cask handling crane leading to side impact	D-8	—	F-6
WHF-807	Cask handling crane drops object onto cask	D-8	—	F-6
WHF-808	Cask handling crane drops object onto cask	D-8	—	F-6
WHF-809	Cask handling crane drops object onto cask	D-8	—	F-6
WHF-810	Impact due to platform operations	D-8	—	F-6
WHF-901	Cask handling crane malfunction/misoperation catches CTT	D-9	—	F-7
WHF-902	Operation of cask preparation crane leads to cask tipover	D-9	—	F-7
WHF-903	Jib crane drops object onto cask	D-9	—	F-7
WHF-904	Cask handling crane malfunction/misoperation catches CTT	D-9	—	F-8
WHF-905	Collision between CTT and another moving vehicle	D-9	—	F-7
WHF-906	Spurious movement of CTT with crane attached leads to cask drop	D-9	—	F-7
WHF-907	Operation of cask preparation crane leads to cask tipover	D-9	—	F-8
WHF-908	Jib crane drops object onto cask	D-9	—	F-8
WHF-909	Crane malfunction leads to impact to cask	D-9	—	F-8
WHF-910	Cask impact resulting from unplanned CTT movement during installation of lid lift fixture	D-9	—	F-8
WHF-1001	Collision between CTT and another moving vehicle, facility structures, or facility equipment leading to cask impact	D-10	—	F-9
WHF-1002	Spurious movement of CTT with crane attached to lid leads to damage to cask	D-10	—	F-9
WHF-1003	Heavy load dropped onto the cask or canister	D-10	E-11	F-9
WHF-1004	Jib crane malfunction/misoperation leads to side impact	D-10	E-11	F-9
WHF-1005	Direct exposure during installation of DPC lift fixture (shine)	D-10	E-11	F-29
WHF-1006	Lid binding during removal leads to cask drop	D-10	E-11	F-9
WHF-1101	Cask Unloading Room shield door closes against CTT leading to cask impact	D-11	E-12	F-10, F-12
WHF-1102	Collision with facility structures or equipment during movement leading to cask impact	D-11	E-12	F-10
WHF-1103	CTT or cask catches crane hook or rigging during movement leading to cask impact	D-11	E-17	F-10
WHF-1104	Temporary loss of shielding while the canister is lifted from the cask into the CTM shield bell or lowered from the CTM shield bell into container	D-11	E-13, E-15	F-29

Table 10. List of Internal Initiating Events (Continued)

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
WHF-1105	Canister drops in CTM shield bell during move	D-11	—	F-13
WHF-1106	Canister collision due to CTM malfunction/misoperation leading to an impact	D-11	E-14	F-13
WHF-1201	CTT moves during cask unloading or STC loading leading to an impact	D-12	—	F-13
WHF-1202	Spurious movement of CTM bridge or trolley leading to an impact	D-12	—	F-13
WHF-1203	Canister strikes port edge, CTM slide gate, or wall leading to cask drop	D-12	—	F-13
WHF-1204	Side impact to cask during lift	D-12	E-13, E-15	F-13
WHF-1205	CTM wire rope cut leading to canister drop	D-12	E-13, E-15	F-13
WHF-1206	ST moves while loading leading to an impact	D-12	E-13, E-15	F-13
WHF-1207	Canister impact or drop caused by CTM motor failure to stop on demand	D-12	E-13, E-15	F-13
WHF-1208	Canister drop in CTM shield bell (with CTM slide gate closed) due to CTM malfunction	D-12	—	F-13
WHF-1209	Canister impact or drop from CTM failure or misoperation	D-12	E-11, E-13	F-13
WHF-1210	CTM drops object (e.g., lid) into the cask	D-12	—	F-13
WHF-1301	Jib crane drops object on TAD canister prior to or post TAD canister closure	D-13	—	F-25
WHF-1302	Bad weld	D-13	E-24	F-27
WHF-1303	Welding damages TAD canister	D-13	E-24	F-27
WHF-1306	TAD canister drying problem	D-13	E-24	F-26
WHF-1307	TAD canister inerting problem	D-13	E-24	F-26
WHF-1308	Line break	D-13	—	F-27
WHF-1401	Exposure due to collision involving the ST, facility structures, or equipment impacting loaded aging overpack	D-14	E-16	F-11
WHF-1402	Drop of heavy load onto aging overpack	D-14	E-16	F-11
WHF-1403	Inadvertent jib crane movement when lid is partially attached to aging overpack leading to tipover	D-14	—	F-11
WHF-1406	Collision between ST and another moving vehicle	D-14	E-16	F-11
WHF-1407	Spurious movement of ST due to fault in drive train or control system with jib crane attached to lid leading to tip over	D-14	E-16	F-11
WHF-1501	Impact from platform operations	D-15	—	F-24, F-28
WHF-1502	Cask handling crane drops object on STC/ TAD canister	D-15	—	F-24, F-28
WHF-1503	STD/ TAD canister collides with object while being moved by cask handling crane leading to side impact	D-15	—	F-24, F-28

Table 10. List of Internal Initiating Events (Continued)

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
WHF-1504	Cask handling crane drops STC/ TAD canister leading to an impact	D-15	—	F-24, F-28
WHF-1505	Cask tips or drops after being placed in CTT	D-15	—	F-24, F-28
WHF-1602	Cask handling crane malfunction/misoperation leads to impact to canister	D-16	—	F-16
WHF-1603	Release of material from sample line failure	D-16	E-22	F-16
WHF-1604	Erroneous sample reading (false negative) causing a potential cask overpressurization condition	D-16	—	F-16
WHF-1605	Exposure due to sample line failure caused by energetic hose whip	D-16	E-22	F-16
WHF-1606	Exposure due to water line break caused by an overpressurization condition	D-16	E-22	F-16
WHF-1608	Direct exposure from canister	D-16	E-18	F-29
WHF-1609	Jib crane malfunction/misoperation leads to impact to canister	D-16	—	F-17
WHF-1610	Release of material from sample line failure	D-16	E-18	F-17
WHF-1611	Erroneous sample reading (false negative) causing a potential radioactive material release or canister overpressurization condition	D-16	—	F-17
WHF-1612	Exposure due to sample line failure caused by energetic hose whip	D-16	E-19	F-17
WHF-1613	Exposure due to waterline break caused by an overpressurization condition	D-16	E-19	F-17
WHF-1701	Exposure due to an overpressurization condition in the DPC caused by water in contact with the hot surface of the cask lid	D-17	E-20	F-17
WHF-1702	Jib crane drops object (shield ring, cutting machine, inner lid without integrated shield plug) onto DPC with a cut inner lid	D-17	E-20	F-18
WHF-1703	Shield ring binds with STC leading to a jib crane failure	D-17	—	F-18
WHF-1704	Exposure due to inadvertent lifting of the cut inner lid leading to drop of load onto DPC	D-17	—	F-18
WHF-1802	Cask handling crane tips or drops a loaded STC/DPC or TC/CSNF onto the pool floor, causing pool damage or fuel reconfiguration	D-18	—	F-21
WHF-1803	Drop of a loaded STC/DPC or TC/CSNF resulting in splash of contaminated pool water	D-18	—	F-30
WHF-1804	Collision of loaded STC/DPC or TC/CSNF with structure	D-18	—	F-21
WHF-1806	Drop of a heavy object onto STC/DPC, TC/CSNF, or STD/TAD	D-18	—	F-21
WHF-1807	Direct exposure during lift of fuel assembly out of cask or DPC on staging rack	D-18	E-23	F-30

Table 10. List of Internal Initiating Events (Continued)

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
WHF-1808	SFTM drops a heavy object onto fuel staging rack or TAD	D-18	—	F-22
WHF-1809	SFTM drops or damages a fuel bundle during DPC or TC/CSNF unloading	D-18	E-23	F-22
WHF-1810	Spill of low-level liquid waste from pool operations	D-18	—	F-23
WHF-1901	Exposure post decontamination of DPC or TC	D-19	—	F-30
WHF-1902	Collision of an empty STC/DPC or STC/TAD with structure or object leading to contaminated water discharge	D-19		F-23
WHF-1904	Drop of unloaded STC/DPC or STC/TAD leading to contaminated water discharge	D-19	—	F-23
WHF-1905	Inadvertent discharge of contaminated water	D-19	—	F-23
WHF-1906	Discharge of contaminated water to unanticipated location	D-19	—	F-23
WHF-2001	Cask Unloading Room shield door closes against CTT leading to STC/DPC impact	D-20	—	F-14
WHF-2002	Collision with facility structures or equipment during movement leading to STC/DPC impact	D-20	—	F-14
WHF-2003	CTT or STC/DPC catches cask handling crane hook or rigging during movement leading to STC/DPC impact	D-20	—	F-14
WHF-2101	Impact from platform operations	D-21	—	F-15
WHF-2102	Cask handling crane drops object on STC/DPC	D-21	—	F-15
WHF-2103	ST/DPC collides with object while being moved by cask handling crane leading to side impact	D-21	—	F-15
WHF-2104	Cask handling crane drops STC/DPC	D-21	—	F-15
WHF-2105	Cask tip or drops after being placed in STC/DPC stand in DPC cutting station	D-21	E-11, E-13	F-15

NOTE: AO = aging overpack; CSNF = commercial spent nuclear fuel; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; ESD = event sequence diagram; MLD = master logic diagram; RC = railcar; SFTM = spent fuel transfer machine; ST = site transporter; STC = shielded transfer cask; TAD = transport, aging, and disposal canister; TC = transportation cask; TT = truck trailer.

Source: Original

6.2 DEVELOPMENT OF INTERNAL EVENT SEQUENCES

6.2.1 Introduction

The ESD technique, as described in Section 4.3.2.1, was 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-31). Sections 6.2.2 through 6.2.32 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 are considered together. The descriptions for each ESD provide the following information:

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

6.2.2 WHF-ESD-01: Activities Associated with Receipt of Transportation Cask with SNF in the Transportation Cask Vestibule and Movement into Cask Preparation Area

6.2.2.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to a transportation cask with CSNF as it is moved from the receipt area into the preparation area. This includes event sequences that arise after the outer vestibule door is closed during movement of a transportation cask into the Cask Preparation Area. A graphical depiction of this ESD can be found in Attachment F, Figure F-1. (Refer to Section 6.1.2.1, Node 1 in the PFD.) This ESD applies to uncanistered CSNF in transportation casks on truck trailers.

6.2.2.2 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. Truck trailer rollover.
2. Truck trailer collision.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a structural challenge resulting from receipt of transportation cask in the Transportation Cask Vestibule and movement into the Cask Preparation Area.

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 with impact limiters remains intact. Determining whether or not the containment boundary of the transportation cask remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the transportation cask and the strength of the transportation cask. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question of whether or not the shielding provided by the transportation cask 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 transportation cask does not remain intact (i.e., for a negative answer to the question posed by the first 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. 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 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). 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.

The ESD in Figure F-1 shows four end states; where two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in six event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates six event sequences:

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

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

3. Transportation cask containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

4. Transportation cask containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

5. Transportation cask containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

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

6.2.3 WHF-ESD-02: Activities Associated with Receipt of Transportation Cask with DPC in the Transportation Cask Vestibule and Movement into Cask Preparation Area

6.2.3.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to a transportation cask (rail cask) loaded with a DPC on a railcar that occurs during transfer from the Transportation Cask Vestibule and movement into the Cask Preparation Area after the outer vestibule door is closed. A graphical depiction of this ESD can be found in Attachment F, Figure F-2. (Refer to Section 6.1.2.1, Node 1 in the PFD). This ESD applies to CSNF in DPCs enclosed in transportation casks on railcars.

6.2.3.2 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. Railcar derailment.
2. Railcar collision.

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 resulting from receipt of a rail cask in the Transportation Cask Vestibule and movement into the Cask Preparation Area.

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 with impact limiters remains intact. Determining whether or not the containment boundary of the transportation cask remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the transportation cask and the strength of the transportation cask. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the shielding provided by the transportation cask 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 transportation cask does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), whether or not a radionuclide release occurs depends on whether or not the canister (DPC) containment boundary remains intact. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the canister containment remains intact, radionuclide release is avoided, but a direct exposure occurs due to an implied deformation of shielding caused by cask breach. Otherwise, the containment 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. 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 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). 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.

The ESD in Figure F-2 shows five end states; where two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in seven event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates seven event sequences:

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

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

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

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

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

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

6.2.4 WHF-ESD-03: Activities Associated with Receipt of Aging Overpack in the Site Transporter Vestibule

6.2.4.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to an aging overpack loaded with a DPC on a site transporter that occurs during receipt in the Site Transporter Vestibule. This ESD includes activities that occur after the outer vestibule door is closed. A graphical depiction of this ESD can be found in Attachment F, Figure F-3. (Refer to Section 6.1.2.1, Node 1 in the PFD). This ESD applies to CSNF in DPCs contained in aging overpacks on site transporters.

6.2.4.2 Initiating Events

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

1. Site transporter collision.
2. Site transporter rollover.

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 resulting from receipt of an aging overpack containing a DPC.

6.2.4.3 System Response

After the structural challenge to the aging overpack containing a DPC has occurred, the first pivotal event asks whether the DPC canister containment boundary remains in intact. Determining whether or not the containment boundary of the DPC remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the DPC and the strength of the DPC.

The aging overpack provides no confinement, but does provide shielding. The next pivotal event to be considered is whether the aging overpack shielding remains intact. If the DPC remains intact (as considered in the first pivotal event) and the aging overpack shielding remains intact, there is no radioactive release and there is no direct exposure and the end state is OK. If the DPC remains intact and the aging overpack shielding fails, then a direct exposure of radiation to personnel occurs.

If the containment boundary of the DPC does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), then radionuclide release occurs. If the DPC has failed, the availability of HVAC confinement and the potential for moderator intrusion is considered. First, a pivotal event asks whether HVAC confinement is maintained. 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 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). 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.

The ESD in Figure F-3 shows four end states; where two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in six event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates six event sequences:

1. DPC containment and aging overpack shielding remain intact (no radiation exposure).

2. DPC containment remains intact and aging overpack shielding is lost, resulting in direct exposure.

3. DPC containment fails resulting in radioactive release, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

4. DPC containment fails resulting in radioactive release, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

5. DPC containment fails resulting in radioactive release, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6. DPC containment fails resulting in radioactive release, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

6.2.5 WHF-ESD-04: Activities Associated with Receipt of Horizontal STC/DPC in the Transportation Cask Vestibule and Movement into the Preparation Area

6.2.5.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to a horizontal STC/DPC that occurs during receipt in the Transportation Cask Vestibule and movement of the horizontal STC/DPC into the Cask Preparation Area. This ESD includes activities that occur after the outer vestibule door is closed. A graphical depiction of this ESD can be found in Attachment F, Figure F-4. (Refer to Section 6.1.2.1, Node 1 in the PFD). This ESD applies to CSNF in DPCs contained in horizontal STCs on cask tractor trailers.

6.2.5.2 Initiating Events

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

1. Cask tractor trailer collision.
2. Cask tractor trailer rollover.

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 resulting from receipt of a horizontal STC/DPC in the Transportation Cask Vestibule and movement into the Cask Preparation Area.

6.2.5.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the containment boundary of the STC remains intact. Determining whether or not the containment boundary of the STC remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the STC and the strength of the STC. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the shielding provided by the STC 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 STC does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), whether or not a radionuclide release occurs depends on whether or not the DPC containment boundary remains intact. Determining whether or not the containment boundary of the DPC remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the DPC and the strength of the DPC. If the DPC containment remains intact, radionuclide release is avoided, but a direct exposure occurs due to an implied deformation of shielding caused by cask breach. Otherwise, the containment boundaries of both the cask and the DPC 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. 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 DPC. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator enters the breached DPC, 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). 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.

The ESD in Figure F-4 shows five end states, two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in seven event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates seven event sequences:

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

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

3. STC containment fails, DPC containment remains intact, but implied deformation of shielding causes direct exposure.

4. STC containment fails, DPC containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

5. STC containment fails, DPC containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

6. STC containment fails, DPC containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

7. STC containment fails, DPC containment fails, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.6 WHF-ESD-05: Activities Associated with Transportation Cask/CSNF Removal of Impact Limiters, Upending, and Removal from Conveyance and Transfer to Preparation Station

6.2.6.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to a transportation cask with CSNF resulting from removal of impact limiters, upending, and removal from conveyance and transfer to a preparation station. A graphical depiction of this ESD can be found in Attachment F, Figure F-5. (Refer to Section 6.1.2.2 through 6.1.2.4, Nodes 2, 3 and 4 in the PFD). This ESD applies to uncanistered CSNF in transportation casks on truck trailers

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

1. Transportation cask tip over.
2. Side impact to transportation cask
3. Drop of heavy load on transportation cask/CSNF.
4. Drop on transportation cask at operational height.
5. Drop of transportation cask above operational height.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a structural challenge during transportation cask/CSNF removal from conveyance and transfer to preparation station.

6.2.6.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the containment boundary of the transportation cask remains intact. Determining whether or not the containment boundary of the transportation cask remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the transportation cask and the strength of the transportation cask. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the shielding provided by the transportation cask 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 transportation cask does not remain intact (i.e., for a negative answer to the question posed by the first 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. 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 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). 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.

The ESD in Figure F-5 shows four end states; where two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in six event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates six event sequences:

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

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

3. Transportation cask containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

4. Transportation cask containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

5. Transportation cask containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

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

6.2.7 WHF-ESD-06: Activities Associated with Removal of Impact Limiters, Upending, and Removal of Transportation Cask from Conveyance and Transfer to CTT

6.2.7.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to a transportation cask/DPC that occurs during removal of impact limiters, upending, and removal of transportation cask from conveyance and transfer to CTT. A graphical depiction of this ESD can be found in Attachment F, Figure F-6. For casks with trunnions (Refer to Section 6.1.2.1, Nodes 2, 3 and 4 in the PFD) that can be uprighted on the conveyance, this ESD applies to the following waste forms:

- CSNF in DPCs contained in rail casks (railcar to CTT)
- CSNF in DPCs contained in horizontal STCs (cask tractor trailer to CTT).

For casks without trunnions (Refer to Section 6.1.2.2 through 6.1.2.4 and Sections 6.1.2.6 through 6.1.2.9, Nodes 2, 3, 4, 6, 7, 8, 9 and 10 (transfer activities only) in the PFD) that must be uprighted with a lifting frame, this ESD applies to CSNF in DPCs contained in transportation casks that are upended with a tilting frame (TTC) (railcar, cask stand then to CTT).

6.2.7.2 Initiating Events

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

1. Crane malfunction causes cask stand or conveyance to tip over.
2. Side impact to cask.
3. Drop of heavy load on cask.
4. Drop of cask at operational height.
5. Drop of cask above operational height.
6. Unplanned carrier movement.

The groups are summarized by a generic initiating event, which is represented by the big bubble in the ESD. The big bubble represents structural challenges during cask removal and transfer from conveyance to CTT.

6.2.7.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the containment boundary of the transportation cask remains intact. Determining whether or not the containment boundary of the transportation cask remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the transportation cask and the strength of the transportation cask. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the shielding provided by the transportation cask 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 transportation cask does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), whether or not a radionuclide release occurs depends on whether or not the DPC containment boundary remains intact. Determining whether or not the containment boundary of the DPC remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the DPC. If the DPC containment remains intact, radionuclide release is avoided, but a direct exposure occurs due to an implied deformation of shielding caused by a transportation cask breach. Otherwise, the containment boundaries of both the transportation cask and the DPC 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. 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 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). 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.

The ESD in Figure F-6 shows five end states, two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in seven event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates seven event sequences:

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

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

3. Transportation cask containment fails, DPC containment remains intact, but implied deformation of shielding causes direct exposure.

4. Transportation cask containment fails, DPC containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

5. Transportation cask containment fails, DPC containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

6. Transportation cask containment fails, DPC containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

7. Transportation cask containment fails, DPC containment fails, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.8 WHF-ESD-07: Activities Associated with Cask Preparation Activities (i.e., Installation of Lid Lift Fixture on Transportation Cask/DPC)

6.2.8.1 Overall Description

This ESD delineates the event sequences that arise after structural challenges associated with the installation of cask lid lift fixture on transportation cask/DPC, or transportation cask/DPC. A graphical depiction of this ESD can be found in Attachment F, Figure F-7. [Refer to Section 6.1.2.10, Node 10 (non-transfer activities) in the PFD.] This ESD applies to CSNF in DPCs contained in transportation casks on CTT.

6.2.8.2 Initiating Events

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

1. Impact to cask.
2. Drop of heavy load on cask.
3. Cask drop.
4. Mishap results in cask tipping over.

The groups are summarized by a generic initiating event, which is represented by the big bubble in the ESD. The big bubble represents structural challenges associated with cask preparation activities that include installation of the lid lift fixture.

6.2.8.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the containment boundary of the cask, either a transportation cask or shielded transfer cask, remain intact. Determining whether or not the containment boundary of the cask remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the cask and the strength of the cask. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the shielding provided by the cask 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 cask does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), whether or not a radionuclide release occurs depends on whether or not the DPC containment boundary remains intact. Determining whether or not the containment boundary of the DPC remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the DPC and the strength of the DPC canister. If the canister containment remains intact, radionuclide release is avoided, but a direct exposure occurs due to an implied deformation of shielding caused by transportation 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. 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 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). 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.

The ESD in Figure F-7 shows five end states; where two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in seven event sequences.

In summary, for each waste form and each initiating event group (little bubbles), the ESD delineates seven event sequences:

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

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

3. Transportation cask containment fails, DPC containment remains intact, but implied deformation of shielding causes direct exposure.

4. Transportation cask containment fails, DPC containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

5. Transportation cask containment fails, DPC containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

6. Transportation cask containment fails, DPC containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

7. Transportation cask containment fails, DPC containment fails, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.9 WHF-ESD-08: Activities Associated with Cask Preparation Activities (i.e. Installation of Cask Lid Lift Fixture – Transportation Cask/CSNF)

6.2.9.1 Overall Description

This ESD delineates the event sequences that arise from structural challenges associated with the installation of lid lift fixture on transportation cask/CSNF. A graphical depiction of this ESD can be found in Attachment F, Figure F-8. (Refer to section 6.1.2.5, Node 5 in the PFD.) This ESD applies to uncanistered CSNF in a transportation cask on truck trailer.

6.2.9.2 Initiating Events

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

1. Impact to cask.
2. Drop of heavy load on cask.
3. Dropped cask.
4. Mishap results in cask tipping over.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents structural challenges associated with the installation of lid lift fixture on transportation cask containing uncanistered CSNF.

6.2.9.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the containment boundary of the transportation cask with remains intact. Determining whether or not the containment boundary of the transportation cask remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the transportation cask and the strength of the transportation cask. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the shielding provided by the transportation cask 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 transportation cask does not remain intact (i.e., for a negative answer to the question posed by the first 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. 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 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). 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.

The ESD in Figure F-8 shows four end states; where two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered) resulting in six event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates six event sequences:

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

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

3. Transportation cask containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

4. Transportation cask containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

5. Transportation cask containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

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

6.2.10 WHF-ESD-09: Activities Associated Cask Preparation (i.e., Lid Removal, or Installation of DPC Lid Lift Fixture for STC/DPC or Transportation Cask/DPC)

6.2.10.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to a transportation cask with DPC or STC with DPC associated with cask preparation activities (i.e., installation of cask lid lift fixture). A graphical depiction of this ESD can be found in Attachment F, Figure F-9. (Refer to section 6.1.2.10, Node 10 in the PFD). This ESD applies to the following waste forms:

- CSNF in DPCs contained in STCs on CTT
- CSNF in DPCs contained in a transportation cask on CTT.

With the lid removed, the cask provides no containment or shielding.

6.2.10.2 Initiating Events

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

1. Drop of cask.
2. Impact to cask.
3. Drop of heavy load on cask.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a structural challenge associated with the installation of the lid lift fixture on a transportation casks or STCs containing DPCs.

6.2.10.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the containment boundary of the canister (DPC) with remains intact. The cask in this case provides no confinement since the lid is removed. Determining whether or not the containment boundary of the DPC remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the transportation cask and the strength of the transportation cask. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the shielding provided by the transportation cask 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 DPC does not remain intact (i.e., for a negative answer to the question posed by the first 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. 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 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). 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.

The ESD in Figure F-9 shows four end states; where two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in six event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates six event sequences:

1. DPC containment and shielding remain intact (no radiation exposure).
2. DPC containment remains intact, but deformation of shielding causes direct exposure.
3. DPC containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.
4. DPC containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.
5. DPC containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.
6. DPC containment fails, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.11 WHF-ESD-10: Activities Associated with Transfer of Cask on CTT from Preparation Area to Cask Unloading Room

6.2.11.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to a transportation cask that contains a DPC. This includes transfer of the transportation cask/DPC from Cask Preparation Area to Cask Unloading Room. With the lid lifting fixture on, the transportation cask provides shielding but does not provide containment since the transportation cask lid is unbolted (refer to section 6.1.2.10, Node 10 in the PFD). This ESD applies to CSNF in DPCs contained in transportation casks on CTT. A graphical depiction of this ESD can be found in Figure F-10.

6.2.11.2 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 collision with facility structures or equipment.
2. CTT or cask catches crane hook/rigging resulting in tip over.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents structural challenges associated with casks that have lid lift fixtures.

6.2.11.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the DPC canister remains intact. If the DPC canister remains intact, no radioactive release occurs. However, there remains the question whether or not the shielding provided by the lid lifting fixture 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 DPC does not remain intact (i.e., for a negative answer to the question posed by the first 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. 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 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). 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.

The ESD in Figure F-10 shows four end states; where two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in six event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates six event sequences:

1. DPC containment and DPC lid lifting fixture remain intact (no radiation exposure).

2. DPC containment remains intact and lid lifting fixture shielding fails due to deformation, resulting in direct exposure.

3. DPC containment fails resulting in radioactive release, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

4. DPC containment fails resulting in radioactive release, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

5. DPC containment fails resulting in radioactive release, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

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

6.2.12 WHF-ESD-11: Activities Associated with Transfer of an Aging Overpack/DPC or Aging overpack/TAD Canister on Site Transporter, through Site Transporter Vestibule, Aging Overpack Access Platform, and Loading Room (Receipt or Export)

6.2.12.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to an aging overpack during transfer of an aging overpack/DPC or aging overpack/TAD canister on a site transporter, through the Site Transporter Vestibule, aging overpack access platform, and Loading Room (receipt or export). A graphical depiction of this ESD can be found in Attachment F, Figure F-11. (Refer to section 6.1.2.15, Node 15 in the PFD). This ESD applies to CSNF in DPCs contained in aging overpacks on site transporters.

6.2.12.2 Initiating Events

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

1. Drop of heavy load on aging overpack/DPC or TAD canister.
2. Site transporter collision with another vehicle, facility structures, or equipment.
3. Aging overpack/DPC or TAD canister tip over due to spurious site transporter movement or jib crane malfunction.
4. Side impact to aging overpack/TAD canister.

The aging overpack provides shielding but not containment or confinement.

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 resulting from receipt of an aging overpack containing a DPC. The aging overpack provides shielding but no confinement.

6.2.12.3 System Response

After the structural challenge to the canister in an aging overpack has occurred, the first pivotal event asks whether the DPC remain intact and contains the radionuclides. If the DPC remains intact (a positive response to the first pivotal event), then the next question (second pivotal event) to be asked is whether the aging overpack shielding remains intact. If the aging overpack shielding is intact, then the end state is OK otherwise direct exposure occurs.

If the DPC does not remain intact, a radionuclide release occurs. Determining whether or not the containment boundary of the DPC remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the DPC and the strength of the DPC. For breach of the DPC canister, the availability of HVAC confinement and the potential for moderator intrusion is considered. First, a pivotal event asks whether HVAC confinement is maintained. 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 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 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). 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.

The ESD in Figure F-11 shows four end states; where two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in six event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates six event sequences:

1. DPC containment and aging overpack shielding remain intact (no radiation exposure).

2. DPC containment remains intact, but aging overpack shielding loss causes direct exposure.

3. DPC containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

4. DPC containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

5. DPC containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

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

6.2.13 WHF-ESD-12: Event Sequences Associated with Aging Overpack (DPC or TAD Canister) on Site Transporter or STC/TAD Canister on CTT Colliding with Cask Loading Shield Door

6.2.13.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge from an aging overpack/DPC, aging overpack/TAD canister or STC/TAD canister collision with Cask Loading Room or Cask Unloading Room shield door. A graphical depiction of this ESD can be found in Attachment F, Figure F-12. (Refer to Section 6.1.2.15, Node 15 on the PDF). This ESD applies to the following waste forms:

- CSNF in DPCs contained in aging overpacks on site transporters (import to WHF)

- CSNF in TAD canisters contained in aging overpacks on site transporters (export from WHF)

- CSNF in TAD canisters contained in STCs on CTTs (internal transfer in WHF to aging overpacks).

The first two waste forms are contained in an aging overpack on a site transporter and both are denoted by aging overpack/site transporter. The third waste form is contained in a STC on a CTT and is denoted by STC/CTT.

Both the aging overpack and STC provide shielding but not confinement. The STC lid is not fastened.

6.2.13.2 Initiating Events

The individual initiating events that were identified in the MLD are indicated on the ESD by one initiating event identifier (one big bubble):

1. Structural challenge from an aging overpack/DPC or aging overpack/TAD canister or STC/TAD canister collision with Cask Loading Room or Cask Unloading Room shield door.

6.2.13.3 System Response

The first pivotal event addresses a structural challenge to aging overpack/site transporter or STC/CTT from impact with the shield door: Door remains on track and does not fall onto aging overpack/site transporter or STC/CTT. If the door remains on track only initial impact of the conveyance and door is considered. If the door does not remain on its tracks, it may fall onto the conveyance with its waste container.

After the structural challenge to the aging overpack/site transporter or STC/CTT has occurred, the second pivotal event asks whether the canister (DPC, STC, or TAD canister) remain intact from one or both impacts (as appropriate) and contains radionuclides. If the canister remains intact (a positive response to the second pivotal event), then the next question (third pivotal event) to be asked is whether the aging overpack/STC shielding remains intact. If the aging overpack/STC shielding is intact, then the end state is OK – otherwise direct exposure occurs.

If the canister does not remain intact, a radionuclide release occurs. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the canister. For breach of the canister, the availability of HVAC confinement and the potential for moderator intrusion is considered. First, a pivotal event asks whether HVAC confinement is maintained. 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 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 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). 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.

The ESD in Figure F-12 shows four end states; where two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in six event sequences. In addition, for each sequence we ask whether the shield door falls on the CTT/site transporter during collision. This results in twelve event sequences:

In summary, for each waste form, the ESD delineates twelve event sequences:

1. Aging overpack/site transporter or STC/CTT collides with the shield door and the shield door does not fall on the aging overpack/site transporter or STC/CTT – canister containment and aging overpack/STC shielding remain intact (no radiation exposure).

2. Aging overpack/site transporter or STC/CTT collides with the shield door and the shield door falls on the aging overpack/site transporter or STC/CTT – canister containment and aging overpack/STC shielding remain intact (no radiation exposure).

3. Aging overpack/site transporter or STC/CTT collides with the shield door and the shield door does not fall on the aging overpack/site transporter or STC/CTT – canister containment remains intact, but loss of aging overpack/STC shielding causes direct exposure.

4. Aging overpack/site transporter or STC/CTT collides with the shield door and the shield door falls on the aging overpack/site transporter or STC/CTT – canister containment remains intact, but loss of aging overpack/STC shielding causes direct exposure.

5. Aging overpack/site transporter or STC/CTT collides with the shield door and the shield door does not fall on the aging overpack/site transporter or STC/CTT – canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

6. Aging overpack/site transporter or STC/CTT collides with the shield door and the shield door falls on the aging overpack/site transporter or STC/CTT – canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

7. Aging overpack/site transporter or STC/CTT collides with the shield door and the shield door does not fall on the aging overpack/site transporter or STC/CTT – canister containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

8. Aging overpack/site transporter or STC/CTT collides with the shield door and the shield door falls on the aging overpack/site transporter or STC/CTT – canister containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

9. Aging overpack/site transporter or STC/CTT collides with the shield door and the shield door does not fall on the aging overpack/site transporter or STC/CTT – canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

10. Aging overpack/site transporter or STC/CTT collides with the shield door and the shield door falls on the aging overpack/site transporter or STC/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. Aging overpack/site transporter or STC/CTT collides with the shield door and the shield door does not fall on the aging overpack/site transporter or STC/CTT – canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

12. Aging overpack/site transporter or STC/CTT collides with the shield door and the shield door falls on the aging overpack/site transporter or STC/CTT – canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.14 WHF-ESD-13: Activities Associated with Transfer of a Canister to or from an Aging Overpack, STC, or Transportation Cask with the CTM

6.2.14.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge resulting from transfer of a canister to or from an aging overpack, STC, or transportation cask with the CTM. A graphical depiction of this ESD can be found in Attachment F, Figure F-13. (Refer to Section 6.1.2.12 through 6.1.2.14, Nodes 12, 13 and 14). This ESD applies to the following waste forms:

- CSNF in DPCs contained in aging overpacks on site transporters.
- CSNF in DPCs contained in rail casks on CTTs.
- CSNF in TAD canisters contained in aging overpacks on site transporters.
- CSNF in TAD canisters contained in STCs on CTTs.

Aging overpacks provide shielding but not confinement. The same applies to rail casks, and STCs since their lids are not fastened when moving to the CTM.

6.2.14.2 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 five groups (represented as little bubbles), as follows:

1. Drop of heavy load on canister.
2. Canister impact due to movement of CTM, CTT, or site transporter during lift.
3. Canister dropped during transfer at operational height.
4. Canister dropped during transfer above operational height.
5. Side impact.
6. Canister drop inside CTM shielding bell.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a structural challenge resulting from lifting or lowering of canister during transfer.

6.2.14.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the canister (DPC, STC, or TAD canister) remains intact. If the canister remains intact, confinement of the radionuclides occurs and the next pivotal event to be considered is whether the shielding is provided by the CTM bell, Cask Loading Room, and loading room shielding structure. 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 canister does not remain intact, radionuclide release will occur. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the containment boundary remains intact, no radioactive release occurs. 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), a radionuclide release is inevitable. The subsequent pivotal event provides 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. 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 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). 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.

The ESD in Figure F-13 shows four end states, the two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in six event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates six event sequences:

1. Canister containment and shielding provided by the CTM bell, Cask Loading Room, and Loading Room shielding structure remain intact (no radiation exposure).

2. Canister containment remains intact, but deformation 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.

6.2.15 WHF-ESD-14: Activities Associated with the Transfer of Transportation Cask/DPC from the Canister Unloading Room to the Preparation Station

6.2.15.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge during movement of transportation cask/DPC on CTT from the Cask Unloading Room to the preparation station. A graphical depiction of this ESD can be found in Attachment F, Figure F-14. (Refer to Section 6.1.2.5, Node 5 in the PFD.) This ESD applies to the following waste form: CSNF in DPCs contained in STCs on CTTs.

The STC is bolted and provides confinement.

6.2.15.2 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. Side impact to CTT-transportation cask/DPC.
2. CTT or transportation cask/DPC catches crane hook/rigging leading to tip over.

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 during movement of transportation cask/DPC on CTT from the Cask Unloading Room to the preparation station. The transportation cask at this point has a bolted lid.

6.2.15.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the containment boundary of the STC remains intact. If the containment boundary of the STC remains intact, no radioactive release occurs. However, there remains the question whether or not the shielding provided by the STC 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 STC does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), whether or not a radionuclide release occurs depends on whether or not the canister containment boundary remains intact. Determining whether or not the containment boundary of the canister (DPC) remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the DPC canister. If the canister containment remains intact, radionuclide release is avoided, but a direct exposure occurs due to an implied deformation of shielding caused by cask breach. Otherwise, the containment 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. 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 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). 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.

The ESD in Figure F-14 shows five end states, two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in seven event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates seven event sequences:

1. STC containment and shielding remain intact (no radiation exposure).
2. STC containment remains intact, but deformation of transportation cask shielding causes direct exposure.
3. STC containment fails; canister remains intact causes direct exposure. Shielding failure is implied with STC containment failure causes direct exposure.
4. STC containment fails, DPC canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.
5. STC containment fails, DPC canister containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.
6. STC containment fails, DPC canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.
7. STC containment fails, DPC canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.16 WHF-ESD-15: Activities Associated with the Transfer of STC/DPC from the Preparation Station to the DPC Cutting Station

6.2.16.1 Overall Description

This ESD delineates the event sequences that arise from structural challenges during movement of STC/DPC from the preparation station to the DPC cutting station. A graphical depiction of this ESD can be found in Attachment F, Figure F-15. (Refer to Section 6.1.2.5, Node 5 in the PFD.) This ESD applies to the following waste form: CSNF in DPCs contained in STCs on CTTs.

The STC is bolted and provides confinement.

6.2.16.2 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 five groups (represented as little bubbles), as follows:

1. Drop of STC/DPC at operational height.
2. Drop of STC/DPC above operational height.
3. Drop of heavy load on STC/DPC.
4. Side impact to STC/DPC.
5. STC/DPC tips over after being in placed in DPC cutting station.

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 resulting from receipt of a transportation cask in the Transportation Cask Vestibule and movement into the Cask Preparation Area. STC shielding is provided by a bolted lid.

6.2.16.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the containment boundary of the STC remains intact. Determining whether or not the containment boundary of the STC remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the STC and the strength of the STC. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the shielding provided by the STC 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 STC does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), whether or not a radionuclide release occurs depends on whether or not the canister containment boundary remains intact. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the DPC canister. If the canister containment remains intact, radionuclide release is avoided, but a direct exposure occurs due to an implied deformation of shielding caused by cask breach. Otherwise, the containment 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. 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 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). 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.

The ESD in Figure F-15 shows five end states; where two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in seven event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates seven event sequences:

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

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

3. STC containment fails, DPC containment remains intact, but implied deformation of shielding causes direct exposure.

4. STC containment fails, DPC containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

5. STC containment fails, DPC containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

6. STC containment fails, DPC containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

7. STC containment fails, DPC canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.17 WHF-ESD-16: Activities Associated with Transportation Cask/CSNF Preparation at the Preparation Station

6.2.17.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge during transportation cask/CSNF preparation activities prior to moving to pool. A graphical depiction of this ESD can be found in Attachment F, Figure F-16. (Refer to Section 6.1.2.5, Node 5.) This ESD applies to the following waste form: Uncanistered CSNF in a transportation cask on a CTT.

6.2.17.2 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. Impact to transportation cask valve.
2. Sampling line break.
3. Transportation cask overpressure.

The erroneous introduction of a large amount of water could result in a continuous release of steam and lead to cask overpressure. Additionally, a drop of an object onto the cask with the valves exposed or a non-pressurized sample line break could lead to a release. The groups are summarized by a generic initiating event, which is represented by the big bubble in the ESD. The big bubble represents structural challenges to the transportation cask during transportation cask/CSNF preparation activities prior to moving to the pool.

6.2.17.3 System Response

Direct release of radionuclides can occur during sampling if the sampling line breaks. Additionally, if the transportation cask suffers an impact, damage to the exposed cask valves also results in a loss of confinement, and a radionuclide release occurs. At this point, the availability of HVAC confinement and the potential for moderator intrusion is addressed. First, a pivotal event asks whether HVAC confinement is maintained. 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 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). 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.

The ESD in Figure F-16 shows two end states that result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in four event sequences.

In summary, for transportation cask/CSNF and for each initiating event group (little bubble); the ESD delineates four event sequences:

1. Transportation cask containment fails and HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

2. Transportation cask containment fails and HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

3. Transportation cask containment fails and HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

4. Transportation cask containment fails and HVAC confinement fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.18 WHF-ESD-17: Activities Associated with Transportation Cask/DPC Preparation at the DPC Cutting Station

6.2.18.1 Overall Description

This ESD delineates the event sequences that arise from structural challenges during transportation cask/DPC preparation activities prior to DPC lid cutting. A graphical depiction of this ESD can be found in Attachment F, Figure F-17. (Refer to Section 6.1.2.16 through 6.1.2.18, Nodes 16, 17, and 18 in the PFD.) This ESD applies to the following waste form: CSNF in DPCs contained in STCs.

6.2.18.2 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. Impact to canister valves.
2. Sampling line break.
3. Overpressurization of canister.

The erroneous introduction of a large amount of water could result in a continuous release of steam and lead to cask overpressure. Additionally, a drop of an object onto the cask with the valves exposed or a non-pressurized sample line break could lead to a lesser release such as a "puff" release. 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 during transportation cask/DPC preparation activities prior to DPC lid cutting.

6.2.18.3 System Response

Direct release of radionuclides can occur during sampling if the sampling line breaks. A release can also occur if the jib crane drops the shield ring on the DPC canister. The DPC canister valves are exposed and will fail on impact, which results in a loss of containment.

If release of radionuclides occurs, the availability of HVAC confinement and the potential for moderator intrusion is addressed. First, a pivotal event asks whether HVAC confinement is maintained. 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 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). 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.

The ESD in Figure F-17 shows two end states; where each end state results in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in four event sequences.

In summary, for transportation cask/DPC and for each initiating event group (little bubble); the ESD delineates four event sequences:

1. Transportation cask containment fails and HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

2. Transportation cask containment fails and HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

3. Transportation cask containment fails and HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

4. Transportation cask containment fails and HVAC confinement fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.19 WHF-ESD-18: Activities Associated with the STC/DPC Preparation Activities at the DPC Cutting Station

6.2.19.1 Overall Description

This ESD delineates the event sequences that arise from structural challenges with the STC/DPC Preparation Activities at the DPC Cutting Station. A graphical depiction of this ESD can be found in Attachment F, Figure F-18. (Refer to Section 6.1.2.19, Node 19 in the PFD). This ESD applies to the following waste form: CSNF in DPCs contained in STCs.

6.2.19.2 Initiating Events

The initiating event that was identified in the MLD is indicated on the ESD by its initiating event identifiers The only initiating event identified for this ESD is the drop of heavy load on canister vent or port line.

The big bubble represents a structural challenge during STC/DPC preparation activities prior to DPC lid cutting.

6.2.19.3 System Response

Direct release of radionuclides can occur if the jib crane drops an object on the DPC canister vent or port line.

If release of radionuclides occurs, the availability of HVAC confinement and the potential for moderator intrusion is addressed. First, a pivotal event asks whether HVAC confinement is maintained. 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 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). 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.

The ESD in Figure F-18 shows two end states, two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in four event sequences.

In summary, for STC/DPC and for each initiating event group (little bubble); the ESD delineates four event sequences:

1. STC containment fails and HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

2. STC containment fails and HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

3. STC containment fails and HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

4. STC containment fails and HVAC confinement fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.20 WHF-ESD-19: Activities Associated with Transfer of STC/DPC from DPC Cutting Station to Pool Ledge

6.2.20.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to a STC with a DPC during the transfer from the DPC Cutting Station to the pool ledge. A graphical depiction of this ESD can be found in Attachment F, Figure F-19. (Refer to Section 6.1.2.20, Node 20 of the PFD.) This ESD applies to the following waste form: CSNF in DPCs contained in STCs.

The DPC lid is cut and provides no containment when challenged. A minimum number of fasteners on the STC are tightened to ensure proper containment.

6.2.20.2 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 five groups (represented as little bubbles), as follows:

1. Drop of cask at operational height.
2. Drop of cask above operational height.
3. Cask tips over.
4. Side impact to cask.
5. Drop of heavy load on cask.

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 DPC from the DPC cutting station to the pool ledge.

6.2.20.3 System Response

After the mechanical challenge has occurred, the first pivotal event asks whether the event occurred over the pool or the facility floor. The DPC lid has been cut and the STC fasteners have been tightened. Events that occur over or in the pool have a different response than those that occur on the pool room floor due to the unique environment created by the borated water. The responses for both the pool and pool room floor are outlined in the following paragraphs.

A drop into the pool might result in a failure of the STC (i.e., cask). The first pivotal event asks whether the containment boundary of the STC remains intact. Determining whether or not the containment boundary of the STC remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the STC and the strength of the STC. If the containment boundary remains intact, no radioactive release occurs. If the STC does not remain intact, a radionuclide release to the pool occurs. Note that the pool also provides personnel shielding. The subsequent pivotal event asks whether or not the boration concentration is maintained in the pool. If adequate boration concentration is maintained, the affirmative case, criticality will not occur. The release is represented by the Radionuclide Release end state. In the negative case, (boration concentration is lost), the corresponding event sequences terminate in a radionuclide release that must be further evaluated with respect to criticality (which is indicated as Also Important to Criticality). 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. Pool water provides particulate removal so that a particulate release to the WHF air does not occur. However, the pool water does not filter non-soluble gases such as noble gases. HVAC is also ineffective at filtering noble gases. The term “filtered” for this study means that HVAC is filtering particulates, so a pool-related release is not given the name “filtered release” with respect to the end state. Radionuclide releases to the WHF pool are categorized as gaseous unfiltered releases in the event trees.

If the event occurs on or over the floor of the pool room, the first pivotal event asks whether the containment boundary of the STC remains intact. Determining whether or not the containment boundary of the STC remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the STC and the strength of the STC. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the shielding provided by the STC 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 STC does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), whether or not a radionuclide release occurs depends on whether or not the DPC containment boundary remains intact. Because the DPC lid is cut, this pivotal event always has a negative result. The containment boundaries of both the cask and the DPC 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. 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 DPC. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator enters the breached DPC, 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). 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.

The ESD in Figure F-19 shows eight end states, with two end states resulting in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (i.e., the release is filtered) or HVAC confinement fails (i.e., release is unfiltered) resulting in ten event sequences.

In summary, for each waste form and each initiating event group (little bubble), the ESD delineates ten event sequences:

1. Event occurs over or in the pool, the STC remains intact, and adequate boration control is maintained (no radiation exposure).

2. Event occurs over or in the pool, the STC fails, and adequate boration control is maintained resulting in a gaseous unfiltered radionuclide release.

3. Event occurs over or in the pool, the STC fails, and adequate boration control is not maintained resulting in a gaseous unfiltered radionuclide release, also important to criticality.

4. Event does not occur over or in the pool (i.e., in the pool room floor area), STC containment and shielding remain intact (no radiation exposure)

5. Event does not occur over or in the pool (i.e., in the pool room floor area), STC containment remains intact, but deformation of STC shielding causes direct exposure

6. Event does not occur over or in the pool (i.e., in the pool room floor area), STC containment fails, DPC containment remains intact, but implied deformation of shielding causes direct exposure

7. Event does not occur over or in the pool (i.e., in the pool room floor area), STC containment fails, DPC containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release

8. Event does not occur over or in the pool (i.e., in the pool room floor area), STC containment fails, DPC containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release

9. Event does not occur over or in the pool (i.e., in the pool room floor area), STC containment fails, DPC containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality

10. Event does not occur over or in the pool (i.e., in the pool room floor area), STC containment fails, DPC containment fails, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.21 WHF-ESD-20: Activities Associated with Transfer of Transportation Cask/CSNF from Preparation Station to Pool Ledge

6.2.21.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to a transportation cask with bare CNSF during the transfer from the preparation station to the pool ledge. A graphical depiction of this ESD can be found in Attachment F, Figure F-20. (Refer to Section 6.1.2.20, Node 20 of the PFD.) This ESD applies to the following waste form: CSNF in transportation casks.

The transportation cask lid is bolted and provides containment when challenged.

6.2.21.2 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 five groups (represented as little bubbles), as follows:

1. Drop of cask at operational height.
2. Drop of cask above operational height.
3. Cask tips over.
4. Side impact to cask.
5. Drop of heavy load on cask.

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 transportation cask with CSNF from the preparation station to the pool ledge.

6.2.21.3 System Response

After the initiating event has occurred, the first pivotal event asks if the event occurred over the pool. Events that occur over or in the pool have a different response than those that occur on the pool room floor due to the unique environment created by the borated water. The responses for both the pool and pool room floor are outlined in the following paragraphs.

If a cask is dropped in the pool, the depth and configuration of the pool could result in the cask landing in a variety of configurations. The first pivotal event asks whether the containment boundary of the transportation cask remains intact. Determining whether or not the containment boundary of the transportation cask remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the transportation cask and the strength of the cask. If the containment boundary remains intact, no radioactive release occurs. The subsequent pivotal event asks whether or not the boration concentration is maintained in the pool. If adequate boration concentration is maintained, the affirmative case, criticality will not occur. The release is represented by the Radionuclide Release end state. The pool provides shielding of personnel so there is no need to include this pivotal event if cask breach occurs in the pool. In the negative case, (boration concentration is lost), the corresponding event sequences terminate in a radionuclide release that must be further evaluated with respect to criticality (which is indicated as Also Important to Criticality). 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. Pool water provides particulate removal so that a particulate release to the WHF air does not occur. However, the pool water does not filter non-soluble gases such as noble gases. HVAC is also ineffective at filtering noble gases. The term "filtered" for this study means that HVAC is filtering particulates, so a pool-related release is not given the name "filtered release" with respect to the end state. Radionuclide releases to the WHF pool are categorized as gaseous unfiltered releases in the event trees.

If the event occurs on or over the floor of the pool room, and the structural challenge to the transportation cask/CSNF has occurred, the second pivotal event asks whether the cask containment boundary remains in intact. Determining whether or not the containment boundary of the cask remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the cask and the strength of the cask.

The next pivotal event to be considered is whether the transportation cask shielding remains intact. If the cask remains intact and the cask shielding is not deformed, there is no radioactive release and there is no direct exposure and the end state is OK. If the cask shielding deforms due to the impact, then a direct exposure of radiation to personnel occurs.

If the containment boundary of the transportation cask does not remain intact, then radionuclide release occurs. If the cask has failed, the availability of HVAC confinement and the potential for moderator intrusion is considered. First, a pivotal event asks whether HVAC confinement is maintained. 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 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). 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.

The ESD in Figure F-20 shows six end states, with four end states resulting in radioactive release. Of these four radioactive release end states, two end states (that do not occur in the pool) are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in eight event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates nine event sequences:

1. Event occurs over or in the pool, the cask integrity is maintained, and adequate boration control is maintained (no radiation release)

2. Event occurs over or in the pool, the cask fails, and adequate boration control is maintained, resulting in a gaseous unfiltered radionuclide release.

3. Event occurs over or in the pool, the cask fails, and adequate boration control is not maintained resulting in a gaseous unfiltered radionuclide release, also important to criticality.

4. Event does not occur over or in the pool (i.e., in the pool room floor area), transportation cask containment is maintained, and no shielding deformation occurs (no radiation exposure)

5. Event does not occur over or in the pool, transportation containment remains intact, and transportation shielding is deformed, resulting in direct exposure

6. Event does not occur over or in the pool, transportation cask containment fails resulting in radioactive release, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release

7. Event does not occur over or in the pool, transportation cask containment fails resulting in radioactive release, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release

8. Event does not occur over or in the pool, transportation cask containment fails resulting in radioactive release, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality

9. Event does not occur over or in the pool, transportation cask containment fails resulting in radioactive release, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

6.2.22 WHF-ESD-21: Activities Involving Lowering of STC/DPC or Transportation Cask/CSNF to the Pool Floor

6.2.22.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to a cask that occurs during lowering of the cask to the pool floor. A graphical depiction of this ESD can be found in Attachment F, Figure F-21. (Refer to Section 6.1.2.22, Node 22 of the PFD.) This ESD applies to the following waste forms:

- CSNF in DPCs contained in STCs
- Uncanistered CSNF in a transportation cask.

Release into the pool is considered a gaseous unfiltered release. Because of the potential drop height, the ability of the cask or STC to maintain integrity is not included in this event sequence. In effect, this means that the cask or STC is modeled as failing open in this ESD.

6.2.22.2 Initiating Events

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

1. Drop of STC/DPC or transportation cask/CSNF.
2. Impact to STC/DPC or transportation cask/CSNF.
3. Tipover of STC/DPC or transportation cask/CSNF.
4. Drop of heavy load onto STC/DPC or transportation cask/CSNF.

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 while lowering STC/DPC or transportation cask/CNSF into the pool.

6.2.22.3 System Response

The initiating event assures a radionuclide release and all releases in the pool are categorized as gaseous unfiltered releases. The first pivotal event asks whether the containment boundary of the transportation cask remains intact. Determining whether or not the containment boundary of the cask remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the transportation cask and the strength of the cask. If the containment boundary remains intact, no radioactive release occurs. If the cask fails, a radioactive release occurs, but the release is filtered because of the surrounding water. The subsequent pivotal event asks whether or not the boration concentration is maintained in the pool. If adequate boration concentration is maintained, the affirmative case, criticality will not occur. The release is represented by the Radionuclide Release end state. In the negative case, (boration concentration is lost), the corresponding event sequences terminate in a radionuclide release that must be further evaluated with respect to criticality (which is indicated as Also Important to Criticality). 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. Pool water provides particulate removal so that a particulate release to the WHF air does not occur. However, the pool water does not filter non-soluble gases such as noble gases. HVAC is also ineffective at filtering noble gases. The term “filtered” for this study means that HVAC is filtering particulates, so a pool-related release is not given the name “filtered release” with respect to the end state. Radionuclide releases to the WHF pool are categorized as gaseous unfiltered releases in the event trees.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates three event sequences:

1. Adequate boration control is maintained and cask remains intact (no radiation exposure).

2. Cask fails and adequate boration control is maintained, resulting in a gaseous unfiltered radionuclide release.

3. Cask fails and adequate boration control is not maintained resulting in a gaseous unfiltered radionuclide release, also important to criticality.

6.2.23 WHF-ESD-22: Pool Activities Involving Transfer of Fuel Assembly to TAD Canister or Fuel Staging Rack

6.2.23.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge during transfer of fuel assemblies to a TAD canister or fuel staging rack. A graphical depiction of this ESD can be found in Attachment F, Figure F-22. (Refer to Section 6.1.2.22, Node 22 of the PFD.) This ESD applies to all fuel assemblies.

6.2.23.2 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. Drop of heavy load onto fuel staging rack or TAD canister.
2. Drop of fuel bundle.

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 during fuel transfer activities. It is assumed that if the spent fuel assemblies are dropped and damaged, that radioactive particulates are removed by the pool water resulting in a gaseous unfiltered release.

6.2.23.3 System Response

The initiating event is modeled as a radionuclide release and all releases in the pool are filtered. Therefore, the only remaining pivotal event pertains to criticality. The pivotal event asks whether or not the boration concentration is maintained in the pool. If adequate boration concentration is maintained, the affirmative case, criticality will not occur. The release is represented by the Radionuclide Release end state. In the negative case, (boration concentration is lost), the corresponding event sequences terminate in a radionuclide release that must be further evaluated with respect to criticality (which is indicated as Also Important to Criticality). 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. Pool water provides particulate removal so that a particulate release to the WHF air does not occur. However, the pool water does not filter non-soluble gases such as noble gases. HVAC is also ineffective at filtering noble gases. The term “filtered” for this study means that HVAC is filtering particulates, so a pool-related release is not given the name “filtered release” with respect to the end state. Radionuclide releases to the WHF pool are categorized as gaseous unfiltered releases in the event trees.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates two event sequences:

1. Adequate boration control is maintained resulting in a gaseous unfiltered radionuclide release.

2. Adequate boration control is not maintained resulting in a gaseous unfiltered radionuclide release, also important to criticality.

6.2.24 WHF-ESD-23: Activities Associated with Handling of Low Level Liquid Waste

6.2.24.1 Overall Description

This ESD delineates the event sequences that arise after a spill of contaminated water due to a mishandling of low level liquid waste during pool operations. A graphical depiction of this ESD can be found in Attachment F, Figure F-23.

6.2.24.2 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 five groups (represented as little bubbles), as follows:

1. Mishap in pool cleanup system.
2. Mishap in pool recirculation system.
3. Drop of container full of pool water during empty DPC or cask export.
4. Improper decontamination of DPC/STC results in spill of pool water.
5. Spill of pool water due to collision during DPC cask export.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a spill of contaminated water.

6.2.24.3 System Response

After the spill of decontaminated water has occurred, a direct exposure results. No pivotal events are identified for this ESD. If any of the initiating events occur, the event sequence terminates in a direct exposure to radiation.

6.2.25 WHF-ESD-24: Activities Associated with the Transfer of STC/Canister from the Pool Ledge to the TAD Canister Closure Station

6.2.25.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge resulting from collisions of the STC/TAD canister with structure or equipment. This includes events that occur while the TAD canister is not closed and the STC/TAD canister being transferred from the pool ledge to the TAD canister closure station. A graphical depiction of this ESD can be found in Attachment F, Figure F-24. (Refer to Section 6.1.2.22, Node 22 of the PFD.) This ESD applies to the following waste form: CSNF in TAD canisters contained in STCs.

The TAD canister lid is not attached and does not provide containment when challenged. A minimum number of fasteners are on the STC and are tightened to ensure proper containment.

6.2.25.2 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 five groups (represented as little bubbles), as follows:

1. Drop of the STC/TAD canister at operational height.
2. Drop of the STC/TAD canister above operational height.
3. Impact to the STC/TAD canister.
4. Cask tip over during placement at TAD canister closure station.
5. Drop of heavy load on the STC/TAD canister.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a structural challenge resulting from the transfer of the STC/TAD canister from the pool ledge to the TAD canister closure Station.

6.2.25.3 System Response

After the mechanical challenge has occurred, the first pivotal event asks whether the event occurred over the pool or the facility floor. The TAD canister lid is not attached and the STC lid fasteners have been tightened. Events that occur over or in the pool have a different response than those that occur on the pool room floor due to the unique environment created by the borated water. The responses for both the pool and pool room floor are outlined in the following paragraphs.

A drop into the pool might result in a failure of the STC. The first pivotal event asks whether the containment boundary of the STC remains intact. Determining whether or not the containment boundary of the STC remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the STC and the strength of the STC. If the containment boundary remains intact, no radioactive release occurs and shielding of personnel is provided by the pool water. The subsequent pivotal event asks whether or not the boration concentration is maintained in the pool. If adequate boration concentration is maintained, the affirmative case, criticality will not occur. The release is represented by the Radionuclide Release end state. In the negative case, (boration concentration is lost), the corresponding event sequences terminate in a radionuclide release that must be further evaluated with respect to criticality (which is indicated as Also Important to Criticality). 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. Pool water provides particulate removal so that a particulate release to the WHF air does not occur. However, the pool water does not filter non-soluble gases such as noble gases. HVAC is also ineffective at filtering noble gases. The term “filtered” for this study means that HVAC is filtering particulates, so a pool-related release is not given the name “filtered release” with respect to the end state. Radionuclide releases to the WHF pool are categorized as gaseous unfiltered releases in the event trees.

If the event occurs on or over the floor of the pool room, the first pivotal event asks whether the containment boundary of the STC remains intact. Determining whether or not the containment boundary of the STC remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the STC and the strength of the STC. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question as to whether or not the shielding provided by the STC 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 STC does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), whether or not a radionuclide release occurs depends on whether or not the TAD canister containment boundary remains intact. In this case, the TAD canister lid is not attached and the pivotal event always results in a failed TAD canister and 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. 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 TAD 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 enters the breached TAD 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). 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.

The ESD in Figure F-19 shows eight end states, with two end states resulting in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (i.e., the release is filtered) or HVAC confinement fails (i.e., release is unfiltered) resulting in ten event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates ten event sequences:

1. Event occurs over or in the pool, the STC remains intact, and adequate boration control is maintained (no radiation exposure).

2. Event occurs over or in the pool, the STC fails, and adequate boration control is maintained resulting in a gaseous unfiltered radionuclide release.

3. Event occurs over or in the pool, the STC fails, and adequate boration control is not maintained resulting in a gaseous unfiltered radionuclide release, also important to criticality.

4. Event does not occur over or in the pool (i.e., in the pool room floor area), STC containment and shielding remain intact (no radiation exposure).

5. Event does not occur over or in the pool (i.e., in the pool room floor area), STC containment remains intact, but deformation of STC shielding causes direct exposure.

6. Event does not occur over or in the pool (i.e., in the pool room floor area), STC containment fails, TAD canister containment remains intact, but implied deformation of shielding causes direct exposure.

7. Event does not occur over or in the pool (i.e., in the pool room floor area), STC containment fails, TAD canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

8. Event does not occur over or in the pool (i.e., in the pool room floor area), STC containment fails, TAD canister containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

9. Event does not occur over or in the pool (i.e., in the pool room floor area), STC containment fails, TAD canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

10. Event does not occur over or in the pool (i.e., in the pool room floor area), STC containment fails, TAD canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.26 WHF-ESD-25: Activities Associated with the Preparation of STC/TAD Canister and Closure of TAD Canister

6.2.26.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge that occurs during the assembly and closure of the STC. A graphical depiction of this ESD can be found in Attachment F, Figure F-25. (Refer to Section 6.1.2.23, Node 23 of the PFD.) This ESD applies to the following waste form: CSNF in TAD canisters contained in STCs.

6.2.26.2 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. Object dropped onto an STC/TAD canister.
2. Side impact to an STC/TAD canister.

6.2.26.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether containment boundary of the TAD canister remains intact. Determining whether or not the containment boundary of the TAD canister remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the containment boundary remains intact, no radioactive release occurs.

If the containment boundary of the TAD canister do not remain intact (i.e., for a negative answer to the question posed by the first 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. 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 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). 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.

The ESD in Figure F-25 shows three end states, with two end states resulting in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in five event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates five event sequences:

1. TAD canister containment remains intact (no radiation exposure).

2. TAD canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

3. TAD canister containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

4. TAD canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

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

6.2.27 WHF-ESD-26: Activities Associated with Closure of TAD Canister – TAD Canister Drying and Inerting Process

6.2.27.1 Overall Description

This ESD delineates the event sequences that arise after a challenge resulting from failure to fully drain the TAD canister before it is sealed. A graphical depiction of this ESD can be found in Attachment F, Figure F-26. (Refer to Section 6.1.2.23, Node 23 of the PFD.) This ESD applies to the following waste form: CSNF in TAD canisters contained in STCs.

6.2.27.2 Initiating Events

The individual initiating events that were identified in the MLD are indicated on the ESD by one initiating event identifier (one big bubble): Failure to fully drain the TAD canister.

The big bubble represents the condition where water is not fully drained from a TAD canister.

6.2.27.3 System Response

If the TAD is not fully dried, a latent overpressure can occur. The first pivotal event asks if an overpressure occurs due to a failure to fully dry the TAD canister. If the TAD canister is not fully dried and no overpressure occurs, then no radionuclide release occurs. If the overpressure does occur, then a radionuclide release will result. An overpressure of the TAD canister is a slowly developing event and would occur after the TAD canister is transferred out of the WHF and is outside of a filtered environment (e.g., on the aging pad). The overpressure event always results in an unfiltered radionuclide release.

1. TAD canister does not overpressure and containment remains intact (no radiation exposure).

2. TAD canister containment fails due to overpressure, resulting in an unfiltered radionuclide release.

6.2.28 WHF-ESD-27: Activities Associated with TAD Canister Closure Process

6.2.28.1 Overall Description

This ESD delineates the event sequences that arise after a containment boundary failure resulting from the welding, drying, and inerting activities associated with TAD canister closure. A graphical depiction of this ESD can be found in Attachment F, Figure F-27. (Refer to Section 6.1.2.23, Node 23 of the PFD). This ESD applies to CSNF in a TAD canister.

6.2.28.2 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. Bad welds – incomplete or cracked.
2. Line break during drying and inerting.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents a containment boundary failure resulting from TAD canister closure activities.

6.2.28.3 System Response

After the containment boundary has been compromised, a radionuclide release occurs. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion. First, a pivotal event asks whether HVAC confinement is maintained. 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 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). 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.

The ESD in Figure F-27 shows two end states, with both end states resulting in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered.) resulting in four event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates four event sequences:

1. HVAC confinement is maintained and moderator intrusion is prevented, resulting in a filtered radionuclide release

2. HVAC confinement fails and moderator intrusion is prevented, resulting in an unfiltered radionuclide release

3. HVAC confinement is maintained and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality

4. HVAC confinement fails and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.29 WHF-ESD-28: Activities Associated with STC/TAD Canister from TAD Canister Closure Station to CTT in the Preparation Station

6.2.29.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to a STC that contains a TAD canister during exporting activities. (Refer to Section 6.1.2.5, Node 5 of the PFD.) A graphical depiction of this ESD can be found in Attachment F, Figure F-28. This ESD applies to the following waste form: CSNF in TAD canisters contained in STCs.

6.2.29.2 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 five groups (represented as little bubbles), as follows:

1. Drop of heavy load on STC/TAD canister.
2. Drop STC/TAD canister at operational height.
3. Drop of STC/TAD canister from above operational height.
4. Impact to STC/TAD canister.
5. Site transporter/TAD canister tip over.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents structural challenges during exporting of a STC/TAD canister from the WHF.

6.2.29.3 System Response

After the structural challenge has occurred, the first pivotal event asks whether the containment boundary of the STC remains intact. The STC lid has been fastened to ensure proper containment. Determining whether or not the containment boundary of the STC remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the STC and the strength of the STC. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question as to whether or not the shielding provided by the STC 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 STC does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), whether or not a radionuclide release occurs depends on whether or not the canister containment boundary remains intact. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the TAD canister. If the canister containment remains intact, radionuclide release is avoided, but a direct exposure occurs due to an implied deformation of shielding caused by cask breach. Otherwise, the containment 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. 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 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). 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.

The ESD in Figure F-28 shows five end states; where two end states result in radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (i.e., the release is filtered) or HVAC confinement fails (i.e., release is unfiltered.) resulting in seven event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates seven event sequences:

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

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

3. STC containment fails, TAD containment remains intact, but implied deformation of shielding causes direct exposure.

4. STC containment fails, TAD containment fails, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release.

5. STC containment fails, TAD containment fails, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release.

6. STC containment fails, TAD containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality.

7. STC containment fails, TAD canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented, resulting in an unfiltered radionuclide release, also important to criticality.

6.2.30 WHF-ESD-29: Direct Exposure Event Sequences for Activities Associated with Cask Preparation or CTM Movement

6.2.30.1 Overall Description

This ESD delineates the event sequences that result in direct exposures from cask preparation activities and CTM movement. A graphical depiction of this ESD can be found in Attachment F, Figure F-29. (Refer to Sections 6.1.2.10, 6.1.2.12, 6.2.1.16, 6.2.1.17, and 6.2.1.21, Nodes 10, 12, 16, 17 and 21 of the PFD). This ESD applies to all CSNF waste forms received by the WHF.

6.2.30.2 Initiating Events

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

1. Failure to install shield ring properly.
2. Temporary loss of shielding while canister lifted from cask in CTM.
3. Failure to install DPC lift fixture properly.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents direct exposure due to cask preparation or CTM movement activities.

6.2.30.3 System Response

There are no pivotal events associated with these events. If a loss of shielding occurs, a direct exposure will result. All initiating events lead to direct exposure sequence end states.

6.2.31 WHF-ESD-30: Direct Exposure Event Sequences for Activities Associated with Pool Operations

6.2.31.1 Overall Description

This ESD delineates the event sequences that result in direct exposures due to pool operations. A graphical depiction of this ESD can be found in Attachment F, Figure F-30. (Refer to Section 6.1.2.22, Node 22 of the PFD). This ESD applies to all CSNF waste forms received by the WHF.

6.2.31.2 Initiating Events

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

1. Fuel assembly lifted too high during transfer.
2. Exposure due to splash of pool water.
3. Improper decontamination of empty transportation casks or DPCs.

The groups are summarized by an aggregated initiating event, the big bubble in the ESD. The big bubble represents direct exposure due to pool operations.

6.2.31.3 System Response

There are no pivotal events associated with these events. If a loss of shielding or exposure to contaminated pool water occurs, a direct exposure will result. All initiating events lead to direct exposure sequence end states.

6.2.32 WHF-ESD-31: Events Sequences for Fires Occurring in the WHF

6.2.32.1 Overall Description

This ESD delineates the event sequences that occur when a fire threatens waste forms in the WHF. 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-31). There are no specific node associations between this event sequence and the PFD because fire event sequences might occur in any location. This ESD applies to all waste forms handled in the WHF.

6.2.32.2 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 nine groups (represented as little bubbles), as follows:

1. Localized fire threatens transportation cask in the Transportation Cask Vestibule.

2. Localized fire threatens transportation cask or STC in the Preparation Area.
3. Localized fire threatens transportation cask or STC in the Cask Unloading Room.
4. Localized fire threatens DPC in the cask transfer machine.
5. Localized fire threatens STC/DPC at the DPC cutting station.
6. Localized fire threatens STC/TAD canister at the TAD canister closure station.
7. Localized fire threatens STC/TAD canister in the Site Transporter Vestibule or Loading Room.
8. Localized fire threatens STC/TAD canister in the Bolting Room.
9. Large fire threatens waste forms anywhere in the WHF.

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.

6.2.32.3 System Response

After a localized or large fire has occurred and the waste form has been thermally challenged, the first pivotal event asks whether the containment boundary of the canister remains intact. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that the event 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, or, 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 protect the canister contained within may be considered in the analysis. If the canister remains intact, radionuclide release is avoided; the end state is OK. Otherwise, the containment boundary of the canister has been breached and a radionuclide release is inevitable.

However, there remains the question as to whether or not the shielding provided by the cask 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.

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 moderator is prevented from entering the breached canister. In the case of a fire, the analysis of this pivotal event is subject to the expectation that fire-suppression water would be in abundant supply. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the Radionuclide Release end state. In the negative case, that is, if moderator enters the breached canister, the corresponding event sequences terminate in either a filtered or an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as Also Important to Criticality). 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.

No direct exposure scenarios are identified for fire events because the fire would normally lead to personnel evacuation.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates six event sequences. The ESD in Figure F-31 shows three end states. Two of them correspond to radioactive release. These two end states are further categorized depending upon whether the HVAC confinement is maintained (the release is filtered) or HVAC confinement fails (release is unfiltered) resulting in five event sequences.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates six event sequences:

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

2. Canister remains intact but shielding fails, resulting in direct exposure.

3. Canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented resulting in a filtered radionuclide release.

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

5. Canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented resulting in a filtered radionuclide release, also important to criticality.

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

6.3 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. For ESDs that have more than one initiating event (little bubble), there is a pair of corresponding event trees, one for the initiating events and the other for the corresponding system response. Although all initiating events in a given initiator event tree transfer to the same system response event tree, the pivotal event conditional probabilities may depend on the initiating event. For ESDs with only one initiating event, a single event tree (incorporating the initiating event and the system response), suffices. In cases for which the initiating event or events apply to more than one waste form, a corresponding initiator event tree (or combined initiator and response event tree) is constructed for each waste form. This is necessary because the frequency of occurrence of an end state is proportional to the number of waste forms, and the number of waste forms is different for different waste-form types. Attachment G presents the event trees. Table G-1 shows the correlation between the event trees in Attachment G and the ESDs in Attachment F.

7. RESULTS AND CONCLUSIONS

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

- An MLD for the WHF (Attachment D) that identifies potential initiating events for event sequences
- A set of ESDs for the WHF (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
WET HANDLING FACILITY LAYOUT AND EQUIPMENT SUMMARY

A1 PURPOSE OF THIS ATTACHMENT

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

A2 FACILITY OVERVIEW

As shown in the general arrangement drawings cited in Section A3, the WHF is 350 ft long and 85 ft wide with a 73 ft ancillary structure on the north side and a 102 ft ancillary structure on the south side that are attached, but are outside of the main structure footprint. The ancillary structures serve as entrance and exit vestibules. The waste-handling operations take place in the central area of the building. Section 6.1.2 of this analysis provides an operational overview of the WHF. In particular, Figure 15 in Section 6.1.2 provides a schematic representation of the facility and its operations and Figures 16 and 17 provide a simplified process flow diagram.

A3 ROOM AND EQUIPMENT DESCRIPTIONS

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.

- *Wet Handling Facility General Arrangement Legend and General Notes* (Ref. 2.2.39)
- *Wet Handling Facility General Arrangement Ground Floor Plan* (Ref. 2.2.38)
- *Wet Handling Facility General Arrangement Second Floor Plan* (Ref. 2.2.44)
- *Wet Handling Facility General Arrangement Plan Below Elevation +40′ -0″* (Ref. 2.2.40)
- *Wet Handling Facility General Arrangement Plan Below Elevation +93′ -0″* (Ref. 2.2.41)
- *Wet Handling Facility General Arrangement Roof Plan* (Ref. 2.2.43)
- *Wet Handling Facility General Arrangement Plan Sections A and B* (Ref. 2.2.45)

- *Wet Handling Facility General Arrangement Sections C and E* (Ref. 2.2.46)
- *Wet Handling Facility General Arrangement Sections F and G* (Ref. 2.2.47)
- *Wet Handling Facility General Arrangement Pool Plan and Sections D, H, J* (Ref. 2.2.42).

A3.1 TRANSPORTATION CASK VESTIBULE (1001)

The Transportation Cask Vestibule: (1) receives transportation casks from the truck or rail buffer areas, (2) receives empty STCs from storage, (3) receives STCs with empty TAD canisters from the Warehouse and Non-Nuclear facility, (4) receives aging overpacks with vertically loaded DPCs from either the RF or from the Aging Facility, and (5) receives horizontal STCs with loaded DPCs from the Aging Facility.

The Transportation Cask Vestibule is constructed of insulated metal panels on a steel frame and is an ancillary structure outside of the main WHF reinforced concrete structure and provides no confinement. A confinement door separates the vestibule from the main WHF reinforced concrete structure. The Transportation Cask Vestibule is equipped with a 20-ton double girder semi-gantry crane that extends into the Cask Preparation Area of the WHF.

The Transportation Cask Vestibule interfaces with rail cars and trucks from the rail car and truck buffer area respectively, and site transporters. This area is also used to receive other parts for processing (e.g., STCs, TAD canisters, etc.), from the warehouse.

The following equipment is used in operations in the Transportation Cask Vestibule:

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. Although the MAP is stored in the Cask Transportation Vestibule, it is moved into the Cask Preparation Area when it is in operation.

The equipment is shown in Ref. 2.2.11; Ref. 2.2.12; Ref. 2.2.13; and Ref. 2.2.14.

Transportation Cask Vestibule Crane

The transportation cask vestibule crane is a 20-ton semi-gantry that is used for transportation cask receipt operations. The transportation cask vestibule crane aids removal and replacement of the impact limiters and personnel barriers to and from the transportation casks. The transportation cask vestibule crane is capable of traversing between the Cask Preparation Area and the Transportation Cask Vestibule. The transportation cask vestibule crane traverses in the north-south direction. The cask handling crane has the following design features:

- The main hoist is rated at 20 tons
- The bridge is about 39 ft wide
- The bridge travel along rails about 250 ft. long.

The equipment is shown in *Wet Handling Facility Entrance Vestibule Crane Mechanical Equipment Envelope* (Ref. 2.2.37).

A3.2 CASK PREPARATION AREA (1016)

The cask preparation area operations include: (1) receipt of transportation casks containing loaded DPCs or SNF assemblies and transfers them into the pool, (2) receives aging overpacks with DPCs and transfers them into the pool, (3) receives STCs with empty TAD canisters and transfers them into the pool, (4) performs DPC cutting operations, (5) performs TAD canister closure operations after pool operation are complete, (6) receives empty STCs for processing DPCs, (7) exports empty transportation casks, (8) exports STCs containing loaded TAD canisters, (9) exports STCs containing empty DPCs, and (10) exports empty STCs.

Although the Cask Preparation Area is open, there are four stations that are set up to perform unique operations, including: (1) cask preparation station 1, (2) DPC cutting station, (3) cask preparation station 2, and (4) TAD canister closure station. Their function and equipment is outlined in sections A.3.2.1 through A.3.2.4.

The following equipment is used in operations in the Cask Preparation Area (individual station equipment is listed in sections A.3.2.1 through A.3.2.4):

Cask Handling Crane

The function of the cask handling crane is to: (1) transfer the transportation cask from the railcar or truck trailer to the preparation stations 1 and 2, (2) transfer empty STCs from railcar or truck trailer to preparation station 1, (3) transfer STCs loaded with DPC from preparation station 1 to DPC cutting station, (4) transfer STCs with cut DPCs from DPC cutting station to the pool, (5) transfer STCs with empty TAD canisters from conveyance to the preparation station 2 and subsequently to the pool, (6) transfer transportation cask from preparation station 2 to the pool, (7) transfer STC with loaded TAD canister from the pool to the TAD canister closure station and then to the preparation station 1, and (8) transfer STCs with empty DPCs or empty transportation casks out of the pool to Cask Preparation Area for export to LLWF or Non-Nuclear Warehouse. The cask handling crane is a top-running, double-girder type with a top-running trolley. The cask handling crane has the following design features:

- The main hoist is rated at 200 tons
- The bridge is about 99 ft wide
- The bridge travel (along rails) is about 256 ft. long
- The elevation of the rail for the bridge is about 53 ft above the floor of the building.

This equipment is shown in Ref. 2.2.33; Ref. 2.2.84; Ref. 2.2.85; and Ref. 2.2.86.

Cask Handling Yoke

The cask handling yoke or lift bail is used by the cask handling crane to transfer casks and STCs. The arm positions are adjustable to accommodate various cask types.

This equipment is shown in *CRCF, RF, WHF and IHF Cask Handling Yoke Mechanical Equipment Envelope* (Ref. 2.2.19).

Cask Stand

This equipment is only used with the TTC transportation cask and is used in the RF, CRCF, and WHF. The cask stand is a structural steel frame used to support the TTC cask while the impact limiters are removed. The cask stand is pre-staged in the Cask Preparation Area as required. Mechanical equipment envelope details are provided in *Receipt Facility Horizontal Cask Stand Mechanical Equipment Envelope* (Ref. 2.2.30).

Cask Tilting Frame

This equipment is only used with the TTC transportation cask. The cask tilting frame is used to upend the TTC transportation cask from a horizontal position to a vertical position. The cask tilting frame has the capacity to upend a loaded TTC rail cask and is pre-staged in the Cask Preparation Area as required. Mechanical equipment envelope details are provided in *CRCF, RF and WHF Cask Tilting Frame Mechanical Equipment Envelope* (Ref. 2.2.10).

Cask Transfer Trolley

The CTT is used for moving STCs and transportation casks between preparation station 1, located in 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 design features:

- Trolley dimensional envelope is approximately 16 ft by 16 ft by 22 ft 6 in. tall
- The trolley features a structural metal frame on a platform. Restraining brackets secure the transportation cask within the frame
- The rated capacity of the trolley is 265 tons maximum for a loaded transportation cask.

The equipment is shown in Ref. 2.2.98. Control system design details are provided in Ref. 2.2.21.

Cask Transfer Trolley Cask Pedestals

To handle the different sizes of casks, as well as accommodate the pivot device on the end of the cask, various pedestals are used in the bottom of the cask transfer trolley. The pedestal is loaded into the cask transfer trolley using the cask handling crane and rigging.

TTC Lifting Beam

The TTC lifting beam is used with rigging to move the TTC transportation cask from the rail car to the cask stand and then on to the cask tilting frame after the impact limiters and personnel barriers have been removed. The TTC lifting beam is pre-staged in the Cask Handling Area prior to receipt of a TTC transportation cask.

Lid Adapter Stands 1 and 2

Lid adapter stand 1 and 2 are used to stage adapters for transportation casks and DPCs that are handled in the Cask Preparation Area. The lid adapter stand is a floor mounted structural steel frame that is pre-staged as required.

Rail Cask Lid Adapters 1 and 2

Rail cask lid adapters 1 and 2 are used to aid the removal and replacement of rail cask lids. The rail cask lid adapter is bolted to existing bolt holes on the rail cask lid and provides an interface that allows lid lifting grapple 1 to 6 to engage and raise the lid after bolt removal. The rail cask lid adapter is installed at preparation station 1 or 2.

Truck Cask Handling Frame

The truck cask handling frame is a structural steel frame capable of supporting the truck cask and providing stability during cask preparation activities at preparation station 1 or 2 and fuel transfer operations in the bottom of the pool. The truck cask handling frame design includes trunnions that are positioned and sized to interface with the cask handling yoke and pool cask handling yoke.

Truck Cask Lid Adapters 1 and 2

Truck cask lid adapters 1 and 2 are used to aid the removal and replacement of truck cask lids. Truck cask lid adapter is bolted to existing bolt holes on the truck cask lid and provides an interface that allows truck cask lid lifting grapple 3 to engage and raise the lid after bolt removal. The truck cask lid adapter is installed at preparation station 1 or 2.

A3.2.1 Cask Preparation Area – Cask Preparation Station 1

Preparation station 1 is a steel structured platform that interfaces with the CTT. The CTT transfers a transportation cask or STC underneath the platform. Preparation station 1 is accessed by stairs to allow personnel to access the top of the cask. It is used for the preparation of transportation casks before placement into the pool or transfer to the cask unloading room. A removable shield plate with access ports is located on the platform. The shield plate can be rotated to position the access ports over lid bolts and other lid features (e.g., ports).

The following equipment is used in operations in the cask preparation station 1:

Lid Lifting Grapple 2

Lid lifting grapple 2 is used for the removal and replacement of transportation cask and STC lids at preparation station 1. The grapple interfaces with preparation station 1 jib crane and resides on lid lifting grapple stand 2 when not in use. The grapple can also interface with the auxiliary pool crane.

The equipment is shown in *Wet Handling Facility Lid Lifting Grapple Mechanical Equipment Envelope* (Ref. 2.2.49).

Lid Lifting Grapple Stand 2

Lid lifting grapple stand 2 is used to stage lid lifting grapple 2 when it is not in use. Lid lifting grapple stand 2 is a structural steel frame that is located at preparation station 1.

The equipment is shown in *Nuclear Facilities Grapple Stand Mechanical Equipment Envelope* (Ref. 2.2.26).

Preparation Station 1 Jib Crane

Preparation station 1 jib crane is located at preparation station 1 and is used to handle transportation cask lids and lid adapters. The jib crane is mounted to a separate column than preparation station 1, making the jib crane support structure independent of the preparation station 1 structure. The jib crane boom can swing in an arc to cover the operating area and has a movable hoist to allow the hoist to be positioned over the item to be lifted. The hoist is rated at 10 tons.

The equipment is shown in *Wet Handling Facility Jib Cranes Mechanical Equipment Envelope* (Ref. 2.2.48).

Truck Cask Lid Lifting Grapple 1

Truck cask lid lifting grapple 1 is used for handling the truck cask lid adapter at preparation station 1. The grapple interfaces with preparation station 1 jib crane and resides on truck cask lid lifting grapple stand 1 when not in use. The grapple can also interface with the auxiliary pool crane.

The equipment is shown in *Nuclear Facilities Grapple Stand Mechanical Equipment Envelope* (Ref. 2.2.26).

Truck Cask Lid Lifting Grapple Stand 1

Truck cask lid lifting grapple stand 1 is used to stage truck cask lid lifting grapple 1 when it is not in use. Truck cask lid lifting grapple stand 1 is structural steel frame that is located at preparation station 1.

The equipment is shown in *Wet Handling Facility Truck Cask Lid Lifting Grapple Mechanical Equipment Envelope* (Ref. 2.2.83).

A3.2.2 Cask Preparation Area – DPC Cutting Station

The DPC cutting station is a steel structure used for cutting the lids off of DPCs prior to placement into the pool for fuel transfer. The DPC cutting station allows personnel to access the top of the STC and DPC for all the operations associated with DPC cutting and preparation for placement into the pool. The station is enclosed on four sides with shielding to minimize dose to nearby workers and has an open roof to allow crane access. The station has a door and a hinged platform to allow the cask handling crane to load and unload an STC containing a DPC.

The following equipment is used in operations in the DPC cutting station:

DPC Cutting Jib Crane

The DPC cutting jib crane is located at the DPC cutting station and is used to handle the STC lids, DPC cutting machine, DPC cutting shield plug adapter, and the DPC cutting shield ring. The jib crane transfers transportation casks and STCs within the Cask Preparation Area. The jib crane is mounted to a separate column than the DPC cutting station, making the jib crane support structure independent of the DPC cutting station structure. The jib crane boom can swing in an arc to cover the operating area and has a movable hoist to allow the hoist to be positioned over the item to be lifted. The hoist is rated at 10 tons.

The equipment is shown in *Wet Handling Facility Jib Cranes Mechanical Equipment Envelope* (Ref. 2.2.48).

DPC Cutting Machine

The DPC cutting machine cuts the lids off the DPC in order to gain access to the SNF assemblies. The DPC cutting machine includes the following sub-components: the DPC cutting machine base plate is bolted to the top of DPC adapter plate type 1, 2 or 3, which in turn is bolted to the top of the DPC lid or shield plug being cut (there are several types of adapter plates that allow the DPC cutting machine to be attached to the various types of DPC); a rotating platform is attached to the top of the DPC cutting machine base plate to rotate the machine 360 degrees around the vertical center axis of the lid or shield plug; a radial drive assembly that is attached to the rotating platform that can be adjusted horizontally to various radii; a axial drive assembly that is attached to the end of the radial drive assembly that can be adjusted vertically at various heights relative to the lid or shield plug; a tilting drive assembly that is attached to the end of the axial drive assembly; and a spindle holding an end mill cutter that is attached to the tilting drive assembly. The various adapter plates and drives used on the DPC cutting machine allow the end mill cutter to be positioned across a range of horizontal, vertical, and angular positions in order to cut open all of the types of DPCs expected to be received in WHF. An integral vacuum system collects metal cuttings as they are generated.

The DPC cutting machine is moved into position using the DPC cutting jib crane and is staged onto the DPC cutting machine stand when not in use.

The equipment is shown in Ref. 2.2.35 and Ref. 2.2.36.

DPC Cutting Shield Ring

The DPC cutting shield ring is used with an STC that contains a DPC to shield personnel during the set-up of the DPC cutting machine on a DPC and removal of the machine after cutting. The DPC cutting shield ring is a round plate that covers the gap between the DPC and the STC. The shield ring is placed onto the DPC by the DPC cutting jib crane using rigging gear.

Lid Lifting Grapple 1

Lid lifting grapple 1 is used for the removal and replacement of STC lids at the DPC cutting station. The grapple interfaces with the DPC cutting station jib crane and resides on lid lifting grapple stand 1 when not in use. The grapple can also interface with the auxiliary pool crane.

The equipment is shown in *Wet Handling Facility Lid Lifting Grapple Mechanical Equipment Envelope* (Ref. 2.2.49).

Lid Lifting Grapple Stand 1

Lid lifting grapple stand 1 is used to stage lid lifting grapple 1 when it is not in use. Lid lifting grapple stand 1 is a structural steel frame that is located at the DPC cutting station.

The equipment is shown in *Nuclear Facilities Grapple Stand Mechanical Equipment Envelope* (Ref. 2.2.26).

Shield Plug Lift Adapter Stand

The shield plug lift adapter stand is used for pre-staging the shield plug lift adapter prior to use The shield plug lift adapter stand is a structural steel frame that is located at the DPC cutting station.

STC Lid Rack 1

STC lid rack 1 is used for STC lid staging during DPC cutting operations. STC lid rack 1 is a floor mounted structural steel frame that is located at the DPC cutting station.

A3.2.3 Cask Preparation Area – Cask Preparation Station 2

Preparation station 2 is a steel structure used for the preparation of transportation casks and TAD canisters before placement into the pool and for DPC draining after the DPC is unloaded and removed from the pool. Preparation station 2 allows personnel to access the top of the transportation cask or the STC that contains the TAD canister or DPC. Preparation station 2 is accessed by stairs and has a hinged platform that can be raised to allow the cask handling crane to load and unload the transportation cask or STC.

The following equipment is used in operations in the cask preparation station 2:

Lid Lifting Grapple 3

Lid lifting grapple 3 is used for the removal and replacement of STC and TAD canister lids at preparation station 2. The grapple interfaces with preparation station 2 jib crane and resides on lid lifting grapple stand 3 when not in use. The grapple can also interface with the auxiliary pool crane.

The equipment is shown in *Wet Handling Facility Lid Lifting Grapple Mechanical Equipment Envelope* (Ref. 2.2.49).

Lid Lifting Grapple Stand 3

Lid lifting grapple Stand 3 is used to stage lid lifting grapple 3 when it is not in use. Lid lifting grapple stand 3 is structural steel frame that is located at preparation station 2.

The equipment is shown in *Nuclear Facilities Grapple Stand Mechanical Equipment Envelope* (Ref. 2.2.26).

Preparation Station 2 Jib Crane

Preparation station 2 jib crane is located at preparation station 2 and is used to handle transportation cask lids and lid adapters. The jib crane is mounted to a separate column than preparation station 2, making the jib crane support structure independent of the preparation station 2 structure. The jib crane boom can swing in an arc to cover the operating area and has a movable hoist to allow the hoist to be positioned over the item to be lifted. The hoist is rated at 10 tons.

The equipment is shown in *Wet Handling Facility Jib Cranes Mechanical Equipment Envelope* (Ref. 2.2.48).

Truck Cask Lid Lifting Grapple Stand 2

Truck cask lid lifting grapple stand 2 is used to stage truck cask lid lifting grapple 2 when it is not in use. Truck cask lid lifting grapple stand 2 is a structural steel frame that is located at preparation station 2.

The equipment is shown in *Nuclear Facilities Grapple Stand Mechanical Equipment Envelope* (Ref. 2.2.26).

Truck Cask Lid Lifting Grapple 2

Truck cask lid lifting grapple 2 is used for handling the truck cask lid adapter at preparation station 2. The grapple interfaces with preparation station 2 jib crane and resides on truck cask lid lifting grapple stand 2 when not in use. The grapple can also interface with the auxiliary pool crane.

The equipment is shown in *Wet Handling Facility Truck Cask Lid Lifting Grapple Mechanical Equipment Envelope* (Ref. 2.2.83).

A3.2.4 Cask Preparation Area – TAD Canister Closure Station

The TAD canister closure station is a steel structure used for TAD canister closure operations prior to export from the WHF. The TAD canister closure station allows personnel to access the top of the STC and TAD canister for all the operations associated with TAD canister closure, including welding, draining, drying etc. The station is enclosed on four sides with shielding to minimize dose to nearby workers and has an open roof to allow crane access. The station has a door and a hinged platform to allow the cask handling crane to load and unload an STC containing a TAD canister.

The following equipment is used in operations in the TAD canister closure station:

Lid Lifting Grapple 4

Lid lifting grapple 4 is used for the removal and replacement of STC and TAD canister lids at the TAD canister closure station. The grapple interfaces with the TAD canister closure station jib crane and resides on lid lifting grapple stand 4 when not in use. The grapple can also interface with the auxiliary pool crane.

The equipment is shown in *Wet Handling Facility Lid Lifting Grapple Mechanical Equipment Envelope* (Ref. 2.2.49).

Lid Lifting Grapple Stand 4

Lid lifting grapple stand 4 is used to stage lid lifting grapple 4 when it is not in use. Lid lifting grapple stand 4 is structural steel frame that is located at the TAD canister closure station.

The equipment is shown in *Nuclear Facilities Grapple Stand Mechanical Equipment Envelope* (Ref. 2.2.26).

STC Lid Rack 2

STC lid rack 2 is used for STC lid staging during TAD canister closure operations. STC lid rack 2 is a floor mounted structural steel frame that is located at the TAD canister closure station.

TAD Canister Welding Machine

The TAD canister welding machine is a remotely operated system used to weld the TAD canister lids in order to permanently seal the TAD canister. The TAD canister welding machine includes the following sub-components: a rotating platform is attached to the base plate of the TAD canister welding machine to rotate the machine 360 degrees around the vertical center axis of the lid; a radial drive assembly that is attached to the rotating platform that can be adjusted horizontally to various radii; an axial drive assembly that is attached to the end of the radial drive assembly that can be adjusted vertically at various heights relative to the lid; a tilting drive assembly that is attached to the end of the axial drive assembly; and a welding electrode with a wire feeder. The various drives used on the TAD canister welding machine allow the welder to be positioned across a range of horizontal, vertical, and angular positions in order to weld the TAD canister lids.

The TAD canister welding machine is moved into position using the TAD canister closure jib crane and is staged on the TAD canister welding machine stand when not in use.

Mechanical equipment envelope details are provided in *Wet Handling Facility TAD Canister Welding Machine Mechanical Equipment Envelope* (Ref. 2.2.78)

TAD Canister Welding Machine Stand

The TAD canister welding machine stand is used for staging the TAD canister welding machine when it is not in use. The TAD canister welding machine stand is a structural steel frame that is located at the TAD canister closure station.

TAD Canister Closure Jib Crane

The TAD canister closure jib crane is located at the TAD canister closure station and is used to handle transportation cask lids and lid adapters. The jib crane is mounted to a separate column than the TAD canister closure station, making the jib crane support structure independent of the TAD canister closure station structure. The jib crane boom can swing in an arc to cover the operating area and has a movable hoist to allow the hoist to be positioned over the item to be lifted. The hoist is rated at 10 tons.

The equipment is shown in *Wet Handling Facility Jib Cranes Mechanical Equipment Envelope* (Ref. 2.2.48).

TAD Canister Closure Shield Ring

The TAD canister closure shield ring is used with an STC that contains a TAD canister to shield personnel during the set-up of the TAD canister welding machine and removal of the machine after welding The TAD canister closure shield ring is a round plate that covers the gap between the TAD canister and the STC. The shield ring is placed on the TAD canister by the TAD canister closure jib crane and rigging gear. When not in use, the shield ring is staged on the TAD canister closure shield-ring stand.

TAD Canister Closure Shield Ring Rack

The TAD canister closure shield ring rack is used for staging the DPC cutting shield ring when it is not in use. The DPC shield ring rack is a structural steel frame that is pre-staged at the TAD canister closure station as required.

TAD Canister Lid Rack 1

TAD canister lid rack 1 is used for TAD canister lid staging in preparation for TAD canister closure operations. TAD canister lid rack 1 is a structural steel frame that is located at the TAD canister closure station.

A3.3 POOL AREA (P001)

Pool area operations include: (1) receipt and transfer into the pool of transportation casks containing loaded DPCs or SNF assemblies , (2) receipt and transfer into the pool STCs with DPCs, (3) receipt and transfer into the pool of STCs with empty TAD canisters, (4) DPC cutting operations, (5) transfer of SNF assemblies from DPCs or transportation casks to TAD canisters, (6) TAD canister closure operations, (7) receipt of empty STCs for loading with DPCs, (8) export of empty transportation casks, (9) export of STCs containing loaded TAD canisters, (10) export of STCs containing unloaded DPCs, and (11) export of empty STCs.

The spent fuel pool is located in the west part of the room. The main equipment access ways into the pool area are through the Transportation Cask Vestibule and the canister transfer station. The pool area is equipped with a 200-ton cask handling bridge crane, a 20-ton auxiliary bridge crane, and a SFTM. Additionally, the rails of the 20-ton crane from the Transportation Cask Vestibule extend across the pool area.

Within the pool room, there will be four preparation stations: (1) preparation station 1, is used mainly for cask transfer preparation, (2) DPC cutting station is for cutting DPC lids and preparation for in-pool processing, (3) preparation station 2 is for preparation of transportation cask with uncanistered SNF prior to in-pool processing, and (4) TAD canister closure station is for welding TAD canisters lids to the TAD canisters and preparation for exporting the TAD canisters. These preparation stations are previously discussed in Section A.3.2.1 through A.3.2.4. In addition, there will be a spent fuel pool where CSNF fuel assemblies are removed from the DPCs of transportation casks and either placed into a TAD canister or into a staging rack. The pool is built of concrete and lined with stainless steel.

The following P&IDs describe pool layout, equipment and instrumentation (Ref. 2.2.68, Ref. 2.2.69, Ref. 2.2.70, Ref. 2.2.71, Ref. 2.2.72, Ref. 2.2.32, and Ref. 2.2.28).

The following equipment operates in this area:

Auxiliary Pool Crane

The auxiliary pool crane is double girder, top-running type crane located in the Cask Preparation Area. The hoist is rated at 10 tons. The auxiliary pool crane is primarily used for transportation cask, TAD canister, STC, and DPC lid removal/replacement in the pool, however it can also be used to support cask preparation, DPC cutting, and TAD canister closure operations in the Cask Preparation Area if required.

The auxiliary pool crane has the following design features:

- The crane dimensional envelope is approximately 98 ft by 256 ft 0 in., on a 53 ft. 3 in. clearance envelope elevation
- The estimated bridge weight is 35 tons with a trolley estimated weight of 5 tons.

Mechanical equipment envelope details are provided in Ref. 2.2.31 and Ref. 2.2.87.

Auxiliary Lid Rack 1-4

Auxiliary lid racks 1 through 4 are floor mounted structural steel frames that are located on the pool floor. The racks are used for staging transportation cask, STC, or TAD canister lids as required.

BWR Lifting Grapple

The BWR lifting grapple is used to transfer BWR assemblies from a DPC or transportation cask into the SNF staging rack or a TAD canister. The BWR lifting grapple is remotely connected to the SFTM in the pool. A local control interface provides indication to the operator that the grapple is connected to the SFTM and indicates when the grapple is connected to a fuel assembly. Hardwired interlocks prevent the SFTM from raising the grapple unless an engaged or disengaged signal is provided. The BWR lifting grapple is staged on the SFTM grapple staging rack when not in use.

Crush Pads

There are five crush pads located in the pool and decontamination pit. The crush pads are designed to prevent loss of pool integrity given a drop of a transportation cask or STC during transfer into or out of the pool or decontamination pit. The crush pads are 2 ft. thick and consist of energy absorbing material contained by upper and lower distribution plates. The crush pad edges and the seams between the pads are sealed to minimize displacement and to prevent trapping fissile material or contamination. The following crush pads are located in the pool room:

- Crush pad 1 is located on the staging shelf in the pool
- Crush pad 2 is located on the pool floor
- Crush pad 3 is an located on the floor of the decontamination pit
- Crush pad 4 is located on the staging shelf in the DPC unloading bay in the pool
- Crush pad 5 is located on the floor in the unloading bay in the pool.

DPC Unloading Bay Gate

The DPC unloading bay gate is located in the pool between the DPC unloading bay and the rest of the pool. The DPC unloading bay gate allows passage of SNF assemblies from the DPC to either the spent nuclear fuel staging rack or a TAD canister. The gate allows the unloading bay to be isolated from the rest of the pool if there is significant debris and contaminants in the water after the DPC has been opened. The gate is moved using the cask handling crane.

Slide gate details are provided in *Nuclear Facilities Slide Gate Process and Instrumentation Diagram* (Ref. 2.2.27)

DPC Transfer Station

The DPC transfer station is used to stage and secure an STC containing a DPC prior to transfer of SNF assemblies from the DPC. The DPC transfer station is a floor mounted structural steel frame located in the DPC unloading bay in the pool.

Decontamination Pit Cover

The decontamination pit cover is used to cover the decontamination pit. The cover provides shielding and containment when a transportation cask or STC is being decontaminated in the decontamination pit. The cover is strong enough to prevent a transportation cask or STC from penetrating the cover and falling into the pit.

Pool Cask Handling Yoke

The pool cask handling yoke is used by the cask handling crane to transfer transportation casks and STCs between the pool staging shelf and the pool floor. The pool cask handling yoke is described in *CRCF, RF, WHF, and IHF Cask Handling Yoke Mechanical Equipment Envelope.* (Ref. 2.2.19). The yoke has an estimated weight of 15 tons, and a lift capacity of 200 tons. The yoke has two lifting arms that connect to the trunnions on the transportation cask or STC. The arm positions are adjustable to accommodate the various diameters of casks. The arms are manually adjusted by moving the hooks to the required position.

When not in use, the pool cask handling yoke is staged in the cask handling yoke stand.

Pool Yoke Lift Adapter

The pool yoke lift adapter is used to transfer transportation casks and STCs between the staging shelf in the pool and the pool bottom. The pool yoke lift adapter is rated to handle a load of 200 tons and interfaces with the cask handling crane and the pool cask handling yoke. The pool yoke lift adapter is sized such that the cask handling crane is never submerged in the pool. The pool yoke lift adapter is staged on the pool yoke lift adapter stand when not in use.

Spent Fuel Transfer Machine (SFTM)

The SFTM is used to transfer SNF assemblies from a DPC or transportation cask to either a TAD canister or the SNF staging rack. The bridge of the SFTM accommodates a viewing platform allowing personnel to observe pool operations. The SFTM interfaces with the PWR lifting grapple and BWR lifting grapple. The SFTM operates in the pool only and traverses in the east-west direction.

Mechanical equipment envelope details are provided in Ref. 2.2.6 and Ref. 2.2.76.

Spent Nuclear Fuel Staging Rack

The SNF staging rack is located in the pool and is used to stage PWR and BWR SNF assemblies. The purpose of the SNF staging rack is to enable the blending of fuel assemblies for thermal management and to allow for loading and unloading flexibility. The design of the SNF staging rack ensures that there is adequate fuel assembly spacing and neutron absorption to prevent criticality. A protective wall is adjacent to the SNF staging rack to ensure that large objects cannot collide with it damaging both the rack and SNF assemblies.

Mechanical equipment envelope details are provided in Ref. 2.2.73; Ref. 2.2.74; and Ref. 2.2.75.

STC/TAD Canister Transfer Station

The STC/TAD canister transfer station is used to stage and secure the STC and TAD canister prior to the transfer of SNF assemblies into the TAD canister. The STC/TAD canister transfer station is a floor mounted structural frame located in the WHF pool.

Mechanical equipment envelope details are provided in Ref. 2.2.79 and Ref. 2.2.80.

Siphon Tube Shear Tool

The siphon tube shear tool is a remotely-operated shear tool that is located in the WHF pool. The siphon tube shear tool is used to cut the siphon tube on DPCs that have a siphon tube connected to the shield plug. When the shield plug is raised by the auxiliary pool crane, the siphon tube shear tool is moved to the location of the tube, near to where it connects to the shield plug, and then cuts the tube, allowing the cut-off section to remain with the DPC. All of the motions of the siphon tube shear tool are pneumatically driven. The siphon tube shear tool is mounted on the pool wall but can be fully removed from the pool to perform maintenance.

Deep Remediation Station

The deep remediation station is used to stage and secure a cask that is required to be set aside in the WHF pool for remediation. The deep remediation station is a floor mounted structural frame located in the WHF pool.

SFTM Grapple Staging Rack

The SFTM grapple staging rack is a floor mounted structural steel frame used for staging the PWR lifting grapple and BWR lifting grapple. The SFTM grapple staging rack is located in the WHF pool.

Shield Plug Lift Adapter

The shield plug lift adapter is used to aid in the removal of the DPC shield plugs in the WHF pool. The shield plug lift adapter is bolted to existing bolt holes in the DPC shield plug and provides an interface that allows lid lifting grapple 6 to engage and raise the shield plug in the pool. The shield plug lift adapter is installed at the DPC cutting station prior to placing the STC containing the DPC in the pool. The shield plug lift adapter is staged on the shield plug lift adapter stand when not in use.

Rail Cask Lid Rack

The rail cask lid rack is a floor mounted structural steel frame used for staging the rail cask lid during fuel transfer operations in the pool. The rail cask lid rack is located on the pool floor.

Rail Cask Transfer Station

The rail cask transfer station is used to stage and secure the rail cask prior to transfer of SNF assemblies from the cask. The rail cask transfer station is a floor mounted structural steel frame located in the WHF pool.

Mechanical equipment envelope details are provided in Ref. 2.2.79 and Ref. 2.2.80.

STC Lid Rack 3

STC lid rack 3 is used for STC lid staging during fuel transfer operations in the WHF pool. STC lid rack 3 is a floor mounted structural steel frame that is located in the WHF pool next to the STC/TAD canister transfer station.

STC Lid Rack 4

STC lid rack 4 is used for STC lid staging during fuel transfer operations in the WHF pool. STC lid rack 4 is a floor mounted structural steel frame that is located in the WHF pool next to the DPC transfer station.

TAD Canister Lid Rack 2

TAD canister lid rack 2 is used for TAD canister lid staging in the pool during fuel transfer into the TAD canister. TAD canister lid rack 2 is a structural steel frame that is located in the pool.

Truck Cask Lid Lifting Grapple 3

Truck cask lid lifting grapple 3 is used for the removal and replacement of truck cask lids in the WHF pool. The grapple interfaces with the long reach grapple adapter and the auxiliary pool crane.

Truck Cask Lid Rack

The truck cask lid rack is used for truck cask lid staging during transfer operations in the pool. The truck cask lid rack is a floor mounted structural steel frame that is located in the main section of the pool.

Truck Cask Transfer Station

The truck cask transfer station is used to stage and secure the truck cask handling frame containing a truck cask prior to transfer of SNF assemblies from the cask. The truck cask transfer station is a floor mounted structural steel frame located in the WHF pool.

Mechanical equipment envelope details are provided in Ref. 2.2.79 and Ref. 2.2.80.

Lid Lifting Grapple 6

Lid lifting grapple 6 is used for the removal and replacement of transportation cask and STC lids in the pool. The grapple interfaces with the long reach grapple adapter and the auxiliary pool crane.

Long Reach Grapple Adapter

The long reach grapple adapter attaches to the auxiliary pool crane and lid lifting grapple 6 or transportation cask lid lifting grapple 3 to aid removal and replacement of transportation cask, STC, TAD canister, and DPC lids. The long reach grapple adapter allows the crane hook to remain above the pool water level while the grapple is used for lid transfers in the pool. The long reach grapple adapter is staged on the long reach grapple adapter stand when not in use.

Long Reach Grapple Adapter Stand

The long reach grapple adapter stand is used to stage the long reach grapple adapter in a vertical orientation in the pool when it is not in use. The stand allows parts of the adapter to remain above the pool water level to allow personnel to connect the adapter to the auxiliary pool crane hook.

Long Reach Tool Adapter

The long reach tool adapter is used to aid removal of lid bolts on transportation casks and STCs in the pool. The long reach tool adapter resides on the long reach tool adapter stand adjacent to the pool when not in use.

Long Reach Tool Adapter Stand

The long reach tool adapter stand is used to stage the long reach tool adapter when it is not in use. The long reach tool adapter stand is a floor mounted structural steel frame located adjacent to the pool.

PWR Lifting Grapple

The PWR lifting grapple is used to transfer PWR assemblies from a DPC or transportation cask into the SNF staging rack or a TAD canister. The PWR lifting grapple is remotely connected to the SFTM in the pool. A local control interface provides indication to the operator that the grapple is connected to the SFTM and indicates when the grapple is connected to a fuel assembly. Hardwired interlocks prevent the SFTM from raising the grapple unless an engaged or disengaged signal is provided. The PWR lifting grapple is staged on the SFTM grapple staging rack when not in use.

A3.4 CASK UNLOADING ROOM (1008)

The Cask Unloading Room (1) receives transportation casks containing loaded DPCs for transfer to STCs, (2) receives STCs with loaded TAD canisters for transfer to an aging overpack, (3) receives an unloaded STC for the acceptance of a loaded TAD canister from an aging overpack or loaded DPC from the shielded canister transfer machine, and (4) exports an unloaded STC.

This area interfaces with the Pool Room to receive and export rail casks and STCs. Additionally, this area interfaces with the Canister Transfer Room for the transfer of DPCs and TAD canisters.

Cask Transfer Trolley Door

The cask transfer trolley door provides equipment and personnel access to the Cask Unloading Room. The cask transfer trolley door is a single-slide open type door, made up of 16 in. thick steel plate and weighing approximately 199 tons. The 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. The weight of the door is supported by Hilman rollers under the bottom of the door, which run in a floor-recessed channel. The channel is covered with hinged plates to provide a level floor when the door is moved. The plates are lifted up by a slide ramp, located on both ends of the door, as the door moves.

Mechanical equipment envelope details are provided in *Nuclear Facilities Equipment Shield Door-Type 1 Mechanical Equipment Envelope* (Ref. 2.2.25). The door is interlocked with the cask port slide gate so that both cannot be opened at the same time during normal operations. The door also has an obstruction sensor that halts door travel when an obstacle is detected in the pathway of the door. Control system design details are provided in *Nuclear Facilities Equipment Shield Door Process and Instrumentation Diagram* (Ref. 2.2.24).

A3.5 LOADING ROOM (1007)

The Loading Room receives aging overpacks with loaded DPCs for transfer to an STC and receives unloaded aging overpacks for the acceptance of loaded TAD canisters.

This area interfaces with the Site Transporter Vestibule to receive and export aging overpacks. Additionally, this area interfaces with the Canister Transfer Room for the transfer of DPCs and TAD canisters.

Overpack Transfer Door

The overpack transfer door provides equipment and personnel access to the Loading Room. The overpack transfer door is a single slide open type door, made up of 16 in. thick steel plate and weighing approximately 209 tons. The 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. The weight of the door is supported by Hilman rollers under the bottom of the door, which run in a floor-recessed channel. The channel is covered with hinged plates to provide a level floor when the door is moved. The plates are lifted up by a slide ramp, located on both ends of the door, as the door moves.

Mechanical equipment envelope details are provided in *Nuclear Facilities Equipment Shield Door-Type 1 Mechanical Equipment Envelope* (Ref. 2.2.25). The door is interlocked with the cask port slide gate so that both cannot be opened at the same time during normal operations. The door also has an obstruction sensor that halts door travel when an obstacle is detected in the pathway of the door. Control system design details are provided in *Nuclear Facilities Equipment Shield Door Process and Instrumentation Diagram* (Ref. 2.2.24).

A3.6 SITE TRANSPORTER VESTIBULE (1023)

The Site Transporter Vestibule is used to receive and export aging overpacks that are empty or contain DPCs and TAD canisters. A site transporter enters the Site Transporter Vestibule to access the Loading Room (Room 1007) or the Cask Unloading room (Room 1008) where an aging overpack is loaded or unloaded.

Site transporters move sealed and overpack canisters out of the WHF via the Site Transporter Vestibule. The vestibule is located outside of the reinforced concrete WHF footprint, and is constructed of metal panels on a steel frame. The vestibule has no confinement function.

Aging Overpack Access Platform

The aging overpack access platform is a steel structured platform that interfaces with the site transporter. The site transporter transfers an aging overpack underneath the platform. The aging overpack access platform is accessed by stairs to allow personnel to access the top of the aging overpack for lid bolt removal and installation. A removable shield plate with access ports is located on the platform. The shield plate can be rotated to position the access ports over each of the aging overpack lid bolts.

Site transporter

The site transporter is a track mounted transportation vehicle used to secure and transport transportation casks and aging overpacks loaded or unloaded located at the repository. The site transporter lift boom is located below the top of the cask or aging overpack for load carrying operations. The site transporter dimensional envelope is approximately 23 ft by 17 ft 6in. by 23 ft in height with a maximum extended height of 26 ft. The inside radius of the transporter is 15 ft. The transporter weighs approximately 70 tons with a load carrying capacity of 210 tons. The transporter is powered by a diesel engine for operations outside the WHF. The transporter is powered by a WHF electrical system inside the facility. Site transporter mechanical equipment envelope details are provided in *Site Transporter Mechanical Equipment Envelope* (Ref. 2.2.99).

A3.7 CANISTER TRANSFER ROOM (2004)

The Canister Transfer Room is used for the transfer of DPCs and TAD canisters between transportation casks, STCs, and aging overpacks. This area interfaces with the Cask Transfer Room and the Overpack Transfer Room for the transfer of DPCs and TAD canisters. Additionally, this area interfaces with the Transfer Machine Maintenance Room for transfer of STC lids, rail cask lids, and overpack lids.

Canister Transfer Machine

The primary function of the NOG-1, Type 1 CTM is to transfer DPCs into or out of an aging overpack or out of a canister from the transportation cask to an STC or an aging overpack. The CTM is a specialized bridge crane, which runs on rails, and is mounted on a pair of bridge girders that run on rails supported by the building walls. The CTM features a shielded compartment (the shield bell), which houses the canister while moving from port to port. The CTM has two trolleys: the canister-hoist trolley and the shield-bell trolley. Although the two trolleys can move independently when required, they are mechanically locked together when performing a canister transfer operation. The bridge moves along its rails and the trolley moves along the bridge to position the shield bell over the ports to the rooms below. The CTM hoist has alternative grapples to handle the variety of DPCs. 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.

Mechanical equipment envelope details are provided in Ref. 2.2.6. Control system design details are provided in Ref. 2.2.15; Ref. 2.2.16; Ref. 2.2.17; and Ref. 2.2.18.

CTM Maintenance Crane

The CTM maintenance crane is located above the canister transfer machine in the Canister Transfer Room. The CTM maintenance crane is a NOG-1, Type 1 overhead crane rated at 15 ton capacity located in the Canister Transfer Room. Crane performance is provided in *Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder)* (Ref. 2.2.3). The CTM maintenance crane is used to aid in maintaining the canister transfer machine, removal of STC lids, and maintaining other heavy equipment. Mechanical equipment envelope details are provided in *Wet Handling Facility CTM Maintenance Crane Mechanical Equipment Envelope* (Ref. 2.2.34). Control system design details are provided in *CRCF, RF, WHF, and IHF CTM Maintenance Crane Process and Instrumentation Diagram* (Ref. 2.2.22).

CTM Canister Grapple

The CTM canister grapple is integral to the canister transfer machine. The grapple is used to lift lids from transportations casks, STCs, and aging overpacks, and also lifts TAD canisters and DPCs during canister transfer operations. Mechanical equipment envelope details are provided in *CRCF, RF, WHF, and IHF CTM Canister Grapple Mechanical Equipment Envelope* (Ref. 2.2.20).

Cask Port Slide Gate

The cask port slide gate is located in the operating deck, between the Canister Transfer Room and the Cask Unloading Room. The gate assembly consists of two opposing sliding shield gates mounted on heavy duty bearing blocks and single edge V-slides, a 1 to 1-1/2 in. thick cover plate, two linear actuator drives (one for each gate) and a pre-fabricated fitted embed for proper fit-up of the assembly. A 1/2-hp motor for each gate provides a gate travel speed of approximately 2 inches per second. Platform mechanical equipment envelope details are provided in *CRCF, IHF, RF, & WHF * Port Slide Gate Mechanical Equipment Envelope* (Ref. 2.2.9).

Lid Lifting Grapple Stand 5

Lid lifting grapple stand 5 is used to stage lid lifting grapple 5 when it is not in use. Lid lifting grapple stand 5 is a structural steel frame that is located in the Canister Transfer Room.

The equipment is shown in *Wet Handling Facility Lid Lifting Grapple Mechanical Equipment Envelope* (Ref. 2.2.49).

Overpack Port Slide Gate

The overpack port slide is located in the operating deck, between the Canister Transfer Room and the Loading Room. The gate assembly consists of two opposing sliding shield gates mounted on heavy duty bearing blocks and single edge V-slides, a 1 to 1 1/2 inch thick cover plate, two linear actuator drives (one for each gate) and a pre-fabricated fitted embed for proper fit-up of the assembly. A 1/2-hp motor for each gate provides a gate travel speed of approximately 2 inches per second. Platform mechanical equipment envelope details are provided in *CRCF, IHF, RF, & WHF * Port Slide Gate Mechanical Equipment Envelope* (Ref. 2.2.9).

Lid Lifting Grapple 5

Lid lifting grapple 5 is used for the removal and replacement of transportation cask and STC lids in the Cask Unloading Room. The grapple interfaces with the CTM maintenance crane and resides on lid lifting grapple stand 5 when not in use.

A3.8 POOL EQUIPMENT ROOM

The Pool Equipment Room provides space for the pool water treatment and cooling system equipment. The pool water treatment and cooling system: (1) removes contamination and other particulates from the WHF Pool water to reduce radiation levels at the pool, (2) removes dissolved radionuclides and other ionic species from the WHF Pool water to reduce radiation levels at the pool and reduce the conductivity of the pool water to control corrosion, and (3) removes excess decay heat from the WHF Pool water to maintain the temperature of the pool at the required temperature.

The pool water treatment and cooling system consists of the equipment listed below:

- Pool water treatment pumps, strainer, filters
- Pool water treatment ion exchangers
- Pool water cooling pumps
- Pool water heat exchangers
- Pool water chiller unit
- WHF pool underwater vacuums.

ATTACHMENT B
WET HANDLING FACILITY OPERATIONAL SUMMARY

B1 INTRODUCTION

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

A summary of WHF operations is presented to provide the context within which the event sequences were developed.

B2 FACILITY OVERVIEW

This attachment describes the mechanical handling operation in the WHF. Operations described include:

- Receipt of DPCs in a transportation cask on a railcar
- Receipt of CSNF in a transportation cask on a truck trailer
- Receipt of DPCs in aging overpacks on a site transporter
- Processing of waste forms in the pool
- Export of empty DPCs in STCs to the Low Level Waste Facility
- Export of empty transportation casks to Non-Nuclear Warehouse
- Transfer of loaded TAD canisters in STCs from the pool to TAD canister closure station
- TAD canister closure
- Export of TAD canisters out of the WHF.

These operations are presented according to the nodes of the WHF PFD, Figures 16 and 17. Two types of casks must be upended in the WHF. One type of cask can be upended directly on the railcar to a vertical orientation for unloading. Casks handled in this manner are referred to as VTCs. The other type of cask must be transferred from the railcar in a horizontal orientation to a tilting frame that is used to upend the cask into a vertical orientation for unloading. These casks are referred to as TTCs. The major pieces of mechanical handling equipment, including overhead bridge cranes, the CTT, the CTM, the SFTM, the pool, and associated lifting fixtures and devices are described in Attachment A. It should be noted that some operations do not have a node assigned to them in the PFD because they do not involve a waste form; these operations include export of empty DPCs in STCs or empty transportation casks. Since these operations do not involve waste form handling or processing, no discussion is provided in this Attachment.

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 WASTE FORM IN THE ENTRANCE VESTIBULE AND MOVEMENT INTO THE PREPARATION AREA

This node applies to waste forms received at the WHF in either a transportation cask or aging overpack. Transportation casks are received by rail car or truck cask in the Transportation Cask Vestibule. Aging overpacks returning from the aging pads are received on site transporters in the Site Transporter Vestibule.

Pre-job Plan

Before the transportation cask or aging overpack and conveyance reach the WHF, a crewmember is notified of the type of cask/conveyance to expect. According to this information, the crewmember will determine the appropriate procedures and equipment that is used to process this cask type. He/she will also communicate this information to all the crewmembers involved in the processing of this cask.

Receipt of Loaded Cask in Entrance Vestibule and Stabilize for Unloading

- The crew is at the entrance of the WHF to facilitate movement of the transportation cask into the WHF. The transportation cask, whether on a railcar or truck, is conveyed to the WHF 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 WHF Transportation Cask Vestibule. At this point the crew verifies that the waste form received matches the pre-job plan.
- The inner shield door is opened and the conveyance is moved into the Cask Preparation Area and the crew sets the conveyance brakes and chocks the wheels.

Receipt of Aging Overpack on an Site Transporter in Site Transporter Vestibule and Stabilize for Unloading

- The crew is at the entrance of the WHF to facilitate movement of the site transporter into the WHF by determining the appropriate procedures, equipment and personnel to be used for the type of cast received
- Once the site transporter reaches the facility, the crew opens the overhead door and directs the conveyance into the WHF Site Transporter Vestibule. At this point the crew verifies that the waste form received matches the pre-job plan.
- The crew removes the aging overpack lid bolts once the site transporter is secured in the Site Transporter Vestibule.

B4 NODE 2: REMOVE IMPACT LIMITERS

Before the cask can be upended, the impact limiters must be removed. For VTCs this is accomplished while the cask is still on the railcar. For TTCs, this is done while the cask is on the cask stand. Access to the impact limiters is provided by the mobile access platform (MAP) for VTCs and by a scissors lift for TTCs while in the cask stand.

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 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. Once removed, the bolts are counted and the crew supervisor checks off bolt removal on the checklist. Once bolt removal is verified, the crane operator, using the cask preparation crane, removes and stores the impact limiters.

B5 NODES 3-9: 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 WHF Cask Preparation Area. For TTC casks with DPCs, uprighting operations are unique. Nodes 6-9 describe the operations unique to TTC cask handling.

B5.1 NODE 3: PREPARE CASK FOR UPENDING

To prepare the VTCs for upending, the cask handling yoke is attached to the cask and to 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. The bolts are counted and the crew supervisor checks off bolt removal.

B5.2 NODE 4: UPEND TRANSPORTATION CASK ON CONVEYANCE

The crane operator upends the transportation cask using the 200-ton cask handling crane with yoke. The crew then uses common tools and the MAP to unbolt the constraints on the bottom half of the cask so the cask can be lifted. This step is verified.

B5.3 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, which is like a cage that locks into position. Once the cask is secure in the CTT, the crew disengages the crane from the cask. This step is defined in training and must be signed off (checklist) prior to continuing operations.

This node also applies to movement of STCs containing DPCs to the DPC cutting station from the Loading Room.

B5.4 NODE 6: ATTACH SLING TO TRANSPORTATION CASK (TTC ONLY)

The crane operator will lower the crane into position so that the crewmembers can place the sling around the cask in order to move the TTC cask. Once in position, the crewmembers will place the sling around the cask and shackle it to the crane. Proper sling attachment is verified attached.

B5.5 NODE 7: MOVE TRANSPORTATION CASK TO CASK STAND (TTC ONLY)

Once the sling is secured around the cask, the crane operator will initiate the lift and the crewmembers will ensure that the load is leveled. The crane operator will lift the cask vertically until it clears the railcar. Once the transportation cask is past the railcar, the crane operator will lower the cask to the proper height for movement. The proper height for movement is defined as approximately six inches above the highest obstacle in the movement path. The operator will move the 200-ton cask handling crane so as to locate the cask over the cask stand. Once aligned, the signaling crewmember will signal the crane operator to lower the cask. The crane operator will lower the cask, and then the crewmembers, ensuring stable placement, will detach the slings from the crane.

Once the transportation cask has been moved to the cask stand, the impact limiters are removed, as described in Node 2.

B5.6 NODE 8: MOVE TRANSPORTATION CASK FROM CASK STAND TO CASK TILTING FRAME (TTC ONLY)

Once the cask tilting frame is in place and the impact limiters removed, the crane operator and crewmember will retrieve and attach the cask sling to the 200-ton cask handling crane hook. The crane operator lowers the 200-ton cask handling crane hook into position so that the slings can be attached to the hook. Once in position, the crewmembers will attach the sling to the crane hook and ensure that, when lifted, the load is leveled. Upon signal from the crewmember, the crane operator will raise the cask. The crane operator will then clear the cask stand and lower the crane to the proper height for movement. The crane operator will move the crane so as to locate the cask over the L-frame. When properly positioned and the placement area is clear, the signaling crewmember will signal the crane operator that it is okay to lower the cask. The crane operator will then proceed to lower the cask at or below the maximum allowable speed. Once the cask is lowered and stable, the crewmember will disengage the sling and the crane hook will lift in preparation for the next operation.

B5.7 NODE 9: UPRIGHT CASK WITH CASK TILTING FRAME (TTC ONLY)

Once the cask is placed on the tilting frame, the crane operator can place the cask sling on its stand and retrieve and attach the yoke. The operator will move the crane over the transportation cask. The crane operator lowers the crane hook into position so that the yoke arms are lined up with the trunnion. There is a verification of the alignment of the second trunnion. Once the yoke is aligned, the signaling crewmember signals the operator to close the yoke arms. The crewmembers will check to ensure that the yoke arms have attained an adequate amount of engagement through visual examination. The crane operator will see on his/her controller that the crane is bearing weight. The operator raises the cask. Since the bottom of the cask remains stationary, the operator will move the crane to remain directly above the upper trunnions. Once the cask is fully upright, he will stop raising the cask.

B6 NODE 10: CASK MOVEMENT TO CTT

The transportation cask/DPC is removed from the railcar and placed on the CTT, and prepared for movement into the Cask Preparation Area. The operator will move the crane so that the cask is over the CTT. Once properly positioned, the crane operator will lower the cask onto the CTT. Once the cask is properly loaded, the crewmember will secure the transportation cask to the CTT.

B7 NODES 11-15: CTM OPERATIONS

B7.1 NODE 11: MOVE CASK INTO POSITION BELOW THE CTM

This node applies to CTTs moving casks from the Cask Preparation Area into the Cask Unloading Room, and aging overpacks containing DPCs on site transporters being moved from the Site Transporter Vestibule into the Loading Room.

Using the CTT, the crew will open the Cask Unloading Room shield door, move the transportation cask from the preparation station 1 in the Cask Preparation Area to the Cask Unloading Room and position and secure the cask under the cask port (air hoses disconnected). The shield door is then closed.

Similarly, the crew will open the shield door of the Loading Room, move the aging overpack on the site transporter from the Site Transporter Vestibule into the Loading Room and position and secure the cask under the cask port. The shield door is then closed. This node applies only to aging overpacks loaded with DPCs. The process for receiving empty aging overpacks is described in Node 15.

B7.2 NODE 12: LIFT CANISTER OUT OF CASK IN CTM

With the skirt on the CTM shield bell lowered and CTM slide gate and port slide gate open, the operator will lower the cask lid grapple, engage the grapple, and lift the cask lid off the cask. Once the cask lid is above the port slide gate, the operator will then close the port slide gate, lift the bell skirt up and move the cask lid to the cask storage recess in the floor. After storing the cask lid, the operator will then return the CTM to the canister access port, lower the bell skirt, open the port slide gate, lower the canister grapple, engage the grapple, and lift the canister into the CTM shield bell. Grapple engagement is verified visually and via an indicator.

B7.3 NODE 13: HORIZONTAL CTM MOVEMENT

Once the canister is raised past the port access, the operator will close the port slide gate; the canister is continually raised into the CTM shield bell. Once the canister is completely inside the CTM shield bell, the CTM slide gate will close. The operator may then lift the CTM shield bell skirt in preparation for movement. The CTM operator uses a remote control and camera to move the CTM to the cask port. Once positioned, the operator will lower the skirt of the CTM.

B7.4 NODE 14: CANISTER LOWERED INTO STC

The STC has been positioned and verified secure in the Cask Unloading Room using the CTT. The operator will remotely lower the canister into position in the STC and disengage and retract the grapple. Once the grapple is raised, the CTM slide gate will close. The operator may then lift the CTM skirt and move the CTM away from the cask port access.

B7.5 NODE 15: MOVE AGING OVERPACK INTO POSITION BELOW THE CTM (AGING OVERPACK ON SITE TRANSPORTER ONLY)

The crew will move the empty aging overpack on the site transporter from the Site Transporter Vestibule into the Loading Room and position and secure the cask under the cask port. The shield door is then closed. The aging overpack is then loaded with a TAD that has just been assembled in the pool.

Export of TAD Canisters

Once the TAD canister inside the STC is sealed and ready for exporting out of the WHF, the shield ring is removed and the STC lid is placed back onto the STC. The STC/TAD canister is then moved from the TAD canister closure station to CTT preparation station 1 using the cask handling crane. From here, the STC/TAD canister is moved to the Cask Unloading Room, where the TAD canister is transferred from the STC to an empty aging overpack on the site transporter located in the Loading Room. The transfer of the TAD canister involves the same steps described in Section B.7 – CTM Operations. Once the TAD canister is placed inside the aging overpack, the site transporter carrying the loaded aging overpack is driven out of the Loading Room to the aging overpack access platform (in the Site Transporter Vestibule) where the aging overpack lid is bolted to the aging overpack. From there, the aging overpack, on a site transporter, exits the Site Transporter Vestibule.

B8 NODE 16: REMOVE STC LID FOR DPC LID CUTTING

From above the DPC cutting station, the crane operator will remove the STC lid using the jib crane with grapple and stage it on the lid stand. The crane operator lowers the jib crane into position over the STC lid and engages the grapple. The crane operator will move the jib crane to the lid stand. He will follow the safe load path indicated on the floor. The crane operator will place the lid on the lid stand and disengage the grapple. The operator will then place a shield ring above the annulus between the cask and the DPC to provide personnel shielding during the DPC lid cutting process.

B9 NODE 17: DPC SAMPLING

Prior to sample the DPC cavity, the DPC outer lid has to be cut and removed from the DPC to provide access to the DPC access ports. Port cover plates have to be cut and removed, and quick-disconnect access valves have to be attached to the ports.

To sample the DPC, a crewmember must plug a hose into the quick-disconnect drain port to start flow. Once connected, a crewmember will take a reading of the gas that is being removed and verify that the DPC is safe for opening. After the sample is taken, the remainder of the gas is vented, the valve closed and the hose removed. Details are provided in *Wet Handling Facility Transportation Cask/DPC/STC Cavity Gas Sampling System Piping & Instrument. Diagram* (Ref. 2.2.82).

B10 NODE 18: DPC COOLING AND FILLING

After gas sampling is complete, the crewmembers will connect the water supply and return lines to the cask via quick-disconnect connections and then feed the return line into the Pool. Once the hoses are set up, the crewmember will slowly turn on the water and fill the cask until it is full. The cask is full when water flows from the return hose instead of air – this indication is a lack of bubbles coming from the return hose in the pool. When filled to the level needed for DPC cutting (a space is left at the top without water), the crewmember will disconnect both hoses.

B11 NODE 19: DPC LID CUTTING

Crane operator retrieves DPC cutting machine and lowers the jib crane, with the hook, into position over the DPC cutting machine in the staging area, engages the hook and lifts the DPC cutting machine to proper height for movement. The crane operator then moves the DPC cutting machine to the cask. The crane operator will move the jib crane so as to locate the DPC cutting machine over the DPC in the STC in the DPC cutting station. The crane operator can align the DPC cutting machine over the cask roughly on his/her own, but final alignment is directed by the signaling crewmember.

When properly positioned over the cask, the signaling crewmember will signal the crane operator that it is okay to lower the DPC cutting machine into place. The crane operator will then proceed to lower the DPC cutting machine. Once the DPC cutting machine is in place and bolted, the crewmember will disengage the hook, and the crane will lift to its maximum height in preparation for the next operation.

Once the DPC cutting machine is in place on the DPC, the operator will start the machine and cut the inner lid weld. Once this task is completed, the cutting machine is unbolted and ready to be removed from the DPC lid.

The crane operator lowers the jib crane into position over the cutting machine and engages the hook. Once engaged properly, the crane operator lifts the cutting machine and clears the cask, then lowers the machine to the proper height for movement. The crane operator will move the jib crane to the cutting machine stand and will place the cutting machine on the stand and disengage the hook.

B12 NODE 20: TRANSFER OF CASK TO POOL LEDGE

Once the lid is cut (but not removed from the DPC), the shield ring is removed and the STC lid is placed back onto the STC and fastened. The cask is then moved to the staging shelf in the pool using the cask handling crane with the cask handling yoke. If the cask is a truck cask, this is moved in the cask handling frame also using the cask handling crane with the cask handling yoke. The following activities are similar for all cask handling crane operations and are described once herein. The operator will move the crane over the cask or STC. The crane operator then lowers the crane hook into position so that the yoke arms are lined up with the trunnion. Operator is positioned on the floor in view of the crewmembers on either side of the cask or STC. There is a signaling crewmember next to the cask or STC who helps guide the crane operator's movements.

Once the yoke is aligned, the signaling crewmember signals the operator to close the yoke arms. The crewmembers will verify that the yoke arms are engaged. If the arms are sufficiently engaged on both sides, the crane operator will know by an indicator on his/her controller and the signaling crewmember will signal the operator to raise the crane a slight amount to put pressure on the arms. The crane operator will see on his/her controller that the crane is bearing weight.

The operator will raise the cask or STC to the proper height for movement. Once properly positioned, the crewmember will signal the crane operator to lower the cask into the pool and onto the staging shelf. The crane operator will then disengage the yoke, lift the crane out of the pool, wash the yoke and move it to the yoke stand.

The crane operator is able to see crane movements inside the pool by looking over the edge of the pool and also via a camera fed to a monitor located on his/her controller.

B13 NODE 21: TRANSPORTATION CASK SAMPLING AND FILLING

To sample the cask with uncanistered CSNF, a crewmember must first uncover the cask access ports, attach a hose into the quick-disconnect sampling port and then open the valve to start flow. Once connected, a crewmember will take a reading in the Gas Sampling Room of gas that is being removed and verify that the cask is safe for opening. After the sample is taken, the remainder of the gas should be vented, the valve closed, and the hose removed. Details are provided in *Wet Handling Facility Transportation Cask/DPC/STC Cavity Gas Sampling System Piping & Instrumentation Diagram* (Ref. 2.2.82).

After gas sampling is complete, the crewmembers will connect the water supply and return lines to the cask via quick disconnect connections and then feed the return line into the pool. Once the hoses are set up, the crewmember will slowly turn on the water and fill the cask until it is full. The cask is full when water flows from the return hose instead of air – this indication is a lack of bubbles coming from the return hose in the pool. When full, the crewmember will disconnect both hoses. The cask is then moved to the pool staging shelf as described in Node 20.

B14 NODE 22: POOL ACTIVITIES

Move Transportation Cask to Position in Bottom of Pool

The crane operator will move the crane over the cask. Operator is standing at the edge (near the ledge) of the pool looking down and will also have a camera view of the crane operations from his/her controller. The crane operator will follow a process similar to that described in Node 20 to engage and disengage the yoke and trunnion.

Once the yoke is properly engaged, the crane operator will lift and move the cask to clear the staging shelf, and then lower the cask to the proper height for movement. He/she will then move the cask into position on the bottom of the pool, disengage the yoke, lift the crane out of the pool and wash the yoke. Lid fasteners will then be removed when the cask or STC is secured at the bottom of the pool.

Remove Cask Lid and Place on Lid Rack

The crane operator lowers the auxiliary pool crane into position over the cask or STC. Operator is positioned on the floor at the ledge of the pool. There is a camera underwater that the crane operator can use to verify positioning. Once positioned, the crane operator will engage the lid lifting grapple to the lid adapter on the cask or STC lid.

Once the grapple is engaged, the crane operator will begin to raise the cask or STC lid out of the pool. Once the lid is out of the pool, a crewmember will wash off the grapple and lid, and the crane operator will lower the lid to the proper movement height. He will base this on a visual inspection.

The crane operator will move the auxiliary pool crane over the appropriate lid stand in the staging area. He will then set down the lid and disengage the grapple.

For a STC with a DPC inside, once the STC lid is removed and placed on the lid stand, the auxiliary pool crane is moved back to the DPC inside the STC for removal of the DPC lid. The DPC lid lifting task is performed using the same steps outlined for the cask or STC lid removal.

Transfer Fuel Bundle

The SFTM is used with BWR lifting grapples or PWR lifting grapples to move the SNF assemblies from a DPC or a transportation cask into the SNF staging rack.

The SFTM operator will attach the correct fuel assembly grapple to the SFTM and then position the grapple over the SNF assembly to be moved. Once in position, the operator will engage the grapple and lift the assembly to the proper height under water for movement. He/she will then move the SFTM laterally to a position over the staging rack or TAD canister, lower the assembly into the rack or TAD canister, disengage the grapple and lift the SFTM. There must be positive indication of grapple engagement before a lift can occur.

This operation will repeat until the TAD canister is full: 21 PWR assemblies or 48 BWR assemblies.

Install TAD Canister Lid

The crane operator will use the auxiliary pool crane to retrieve the TAD canister lid: the crane operator will move the crane to the lid, engage grapple, then lift the lid to proper position for movement. He/she will then move the lid over the pool and lower it into position over the TAD canister. He/she is positioned on the pool room floor at the ledge of the pool. There is a camera underwater that the crane operator can use to verify positioning. Once positioned, the crane operator will disengage the lid lifting grapple.

Install STC Lid

Once the lid lifting grapple is disengaged from the TAD canister lid, the crane operator will lift the crane and wash off the grapple and long reach adapter. He will then move the auxiliary pool crane over to the STC lid rack, engage the grapple to the STC lid, and lift the STC lid to the proper height for movement. The crane operator will then move the lid over the pool into a position over the cask and then lower the lid onto the STC. He/she will assess alignment visually with the aid of a camera. Once in place, the crane operator will disengage the grapple from the lid and lift the crane. Operator will then lift the crane and wash the grapple and adapter. Lid fasteners are tightened prior to lifting the STC/TAD canister out of the pool.

Lift STC to Staging Shelf

The crane operator will move the crane so as to locate the crane over the STC containing a loaded TAD canister. He/she is standing at the edge (near the ledge) of the pool looking down and will have a camera view of the crane operations from his/her controller. The crane operator will then lower the crane into position so that the yoke arms are lined up with the trunnion.

Once the yoke is properly engaged, the crane operator will move the cask into position on the staging shelf of the pool, lower the cask onto the shelf, disengage the yoke, and lift the crane hook out of the pool.

Wash Cask Pool Handling Yoke Over Pool and Place on Cask Pool Handling Yoke Stand

Once the cask pool handling yoke is disengaged from the STC/TAD canister, it is lifted out of the pool and washed over the pool using the wash lance. The crane operator will then use the cask handling crane to place the cask pool handling yoke onto the cask pool handling yoke stand. He/she will follow the indicated safe load path marked on the floor.

Lift STC Out of Pool

The STC/TAD canister is lifted out of the pool using the cask handling crane with the cask handling yoke. In preparation for this step, the cask handling yoke is attached to the cask handling crane. The process of yoke and trunnion engagement and disengagement and the intermediate lifting activities have been summarized in Node 20.

The crane operator is able to see crane movements inside the pool by looking over the edge of the pool and also via a camera fed to a monitor located on his/her controller.

Wash Lifting Yoke and Exterior of STC Over Pool

While the STC/TAD canister is suspended over the pool, a crewmember will wash the cask handling yoke and the exterior of the STC over the pool using the wash lance. The crew is cognizant of the boron pool concentration during this operation since boron concentration is sampled routinely; the wash lance has a trigger mechanism, so it will not stay on (discharge water) unless the crew member is pressing on the trigger.

Move STC to the TAD Canister Closure Station

The STC/TAD canister is moved to the TAD canister closure station using the cask handling crane with the cask handling yoke.

The operator will lower the STC/TAD canister to the proper height for movement (6 inches above highest obstacle in the movement path) and then move the STC to the TAD canister closure station. He/she will follow the indicated safe load path marked on the floor. He/she will do this visually, with the help of a crewmember alongside the STC. At the TAD canister closure station, a crewmember will open the hinged platform to allow the STC to pass through. When in the proper position in the closure station, the crane operator will lower the cask to the floor of the closure station and disengage the yoke. The crewmember will close the hinged platform so there is a proper working platform around the STC.

B15 NODE 23: TAD CLOSURE

Remove STC Lid Bolts

When the STC is in place in the TAD canister closure station, the crew will use common tools to remove the STC lid bolts.

Remove STC Lid and Place in Laydown Area

The auxiliary pool crane is used with the lid lifting grapple to remove the STC lid. The STC lid is placed in a laydown area.

The crane operator lowers the auxiliary pool crane hook into position over the STC. He/she is positioned on the floor in view of the crewmembers on either side of the STC. After positioning, crewmembers will connect the crane hook to the STC lid using a grapple.

Upon confirmation signal from the signaling crewmember, the crane operator will begin to lift the STC lid. Once the lid is raised, the crane operator will clear the STC and then lower the lid to the proper movement height. The crane operator will move auxiliary pool crane over the lid stand in the laydown area and then set down the lid and disengage the grapple.

Install STC Shield Ring Over Annulus

The crew will use the jib crane to install a STC shield ring over the annulus.

Open STC Drain Port and Drain Annulus Between STC and TAD Canister

The crew will then connect a hose to the STC drain port and allow the annulus between the STC and TAD canister to partially drain into the pool. After draining to just below the TAD canister lid, the crew will disconnect the hose.

Open TAD Canister Drain Port

Crewmembers open the TAD canister drain port.

Drain TAD Canister (Partially)

The TAD canister is partially drained into the pool by vacuum through the shield plug siphon port until the water has reached the proper level below the lid, but above the fuel. The TAD canister closure activities are performed on an elevated platform. Hinged platform sections open to allow the STC to enter the platform area. All equipment and workstations are provided on the work platform.

The crew will attach a hose to the shield plug siphon port. The other side of the hose will lead to the pool; there will also be a pump connected to the hose to create a vacuum. Once the hose is connected, the crewmember will turn on the pump and watch the water level in STC – when it reaches just below the TAD canister lid, the crewmember will stop the pump and disconnect the hose.

Move TAD Canister Welding Machine to the TAD Canister and Position the TAD Canister Welding Machine on the TAD Canister Lid

The jib crane is used to lift the TAD canister welding machine and move it to the TAD canister. This operation is done from the platform. Crewmembers set up the TAD canister welding machine. The welding machine weight is sufficient to maintain the machine in place, and the machine does not need to be bolted down.

The crane operator lowers the jib crane, with the hook, into position over the TAD canister welding machine in the staging area, engages the hook and lifts the TAD canister welding machine to proper height for movement.

The crane operator will move the jib crane over the TAD canister in the welding area. The crane operator can align the TAD canister welding machine over the TAD canister roughly on his/her own, but final alignment is directed by another crewmember in close visual contact with the machine.

When properly positioned over the TAD canister, the crewmember will signal the crane operator that it is okay to lower the TAD canister welding machine into place. The crane operator will then proceed to lower the TAD canister welding machine. After the TAD canister welding machine is securely in place, the crewmember will disengage the hook, and the crane will lift to its maximum height in preparation for the next operation.

Weld TAD Inner Lid

The TAD canister inner lid is welded in place using the TAD canister welding machine. The weld machine is semi-automatic and, once set up, will make automatic weld passes around the periphery of the lid while being operated from a remote location.

Remove TAD Canister Welding Machine from the TAD Canister

The Jib Crane is used to remove the TAD canister welding machine from the TAD canister and stage it on the welding machine stand.

The crane operator lowers the jib crane into position over the welding machine and engages the hook. Once engaged properly, the crane operator lifts the welding machine and clears the cask, then lowers the machine to the proper height for movement.

The crane operator will move the jib crane to the welding machine stand. The crane operator will place the welding machine on the stand and disengage the hook.

Inspect Weld

The inner lid weld is inspected using an ultrasonic testing hand tool as well as a visual inspection. The weld is verified by the appropriate level of American Society for Nondestructive Testing practices and by certified personnel.

Drain TAD Canister Fully, Vacuum Dry, Helium Fill, and Leak Test TAD Canister Weld

The crew will install a drying and inerting system to the vent and siphon ports in the inner lid to drain and dry the interior of the TAD canister using pressurized Helium and backfill it with Helium gas. There is a moisture indicator associated with the Helium drying system. Once the TAD canister is dry and inerted, the weld is leak tested and the drying/inerting system/hose is disconnected. Details are provided in *Wet Handling Facility TAD/STC Drying and TAD Inerting Piping & Instrument. Diagram* (Ref. 2.2.81).

Move TAD Canister Welding Machine to the TAD Canister and Position the TAD Canister Welding Machine on the TAD Inner Lid

The jib crane is used to lift the TAD canister welding machine and move it to the TAD canister. This operation is done from the platform. The TAD canister welding machine is set-up by crewmembers. The welder's weight is sufficient to maintain the welding machine in place, and the machine does not need to be bolted down.

The crane operator lowers the jib crane, with the hook, into position over the TAD canister welding machine in the staging area, engages the hook and lifts the TAD canister welding machine to the proper height for movement.

The crane operator will move the jib crane with the TAD canister welding machine over the TAD canister in the welding area. When properly positioned over the TAD canister, other crewmembers will signal the crane operator that it is okay to lower the TAD canister welding machine into place. The crane operator will then proceed to lower the TAD canister welding machine. Once the TAD canister welding machine is securely in place, the crewmember will disengage the hook, and the crane will lift away in preparation for the next operation.

Weld TAD Canister Drainport Covers

The TAD canister drainport covers are welded to the TAD inner lid using the TAD canister welding machine. All TAD canister welds are stainless steel.

The weld machine is semi-automatic and, once set up, will make automatic weld passes around the periphery of the port while being operated from a remote location.

Remove TAD Canister Welding Machine from the TAD Canister

The jib crane is used to remove the TAD canister welding machine from the TAD canister and stage it on the welding machine stand.

The crane operator lowers the jib crane into position over the welding machine and engages the hook. Once engaged properly, the crane operator lifts the welding machine and clears the cask, then lowers the machine to the proper height for movement. The crane operator will then move the jib crane to the welding machine stand. The crane operator will place the welding machine on the stand and disengage the hook.

Inspect Welds

The inner lid weld is inspected using an ultrasonic testing hand tool as well as a visual inspection. The weld is verified by the appropriate level of American Society for Nondestructive Testing practices and by certified personnel.

Place Outer Lid on TAD

The jib crane is used to lift the TAD canister outer lid and move it to the TAD canister. This operation is done from the platform.

The crane operator lowers the jib crane, with the hook, into position over the outer lid in the staging area, engages the hook and lifts the outer lid to proper height for movement. The crane operator will then move the jib crane over the TAD canister in the welding area. When properly positioned over the TAD canister, another crewmember will signal the crane operator that it is okay to lower the outer lid into place. The crane operator will then proceed to lower the outer lid. Once the outer lid is securely in place, the crewmember will disengage the hook, and the crane will lift away in preparation for the next operation.

Move the TAD Canister Welding Machine to the TAD Canister and Position on the TAD outer Lid

The jib crane is used to place the TAD canister welding machine on the TAD canister lid. The TAD canister welding machine is set-up by personnel standing on a platform. The outer lid has a flat lifting feature on its top with which the weld machine must interface. The TAD canister welding machine will then be positioned on top of the outer lid’s 6-in. high lifting feature to perform the closure weld on the outer lid. The welder will have at least three pawls that will engage the inside of the lifting feature to anchor the welder to the TAD canister lid.

Once the TAD canister welding machine is securely in place on the lifting feature of the outer lid, the crewmember will engage the pawls that connect the welding machine to the outer lid’s lifting feature. He/she will then disengage the crane hook, and the crane operator will lift the crane away in preparation for the next operation.

Weld TAD Canister Outer Lid

The TAD canister outer lid is welded in place using the TAD canister welding machine. All TAD canister welds are stainless steel.

The weld machine is semi-automatic and, once set up, will make automatic weld passes around the periphery of the lid while being operated from a remote location.

Remove TAD Canister Welding Machine from the TAD Canister

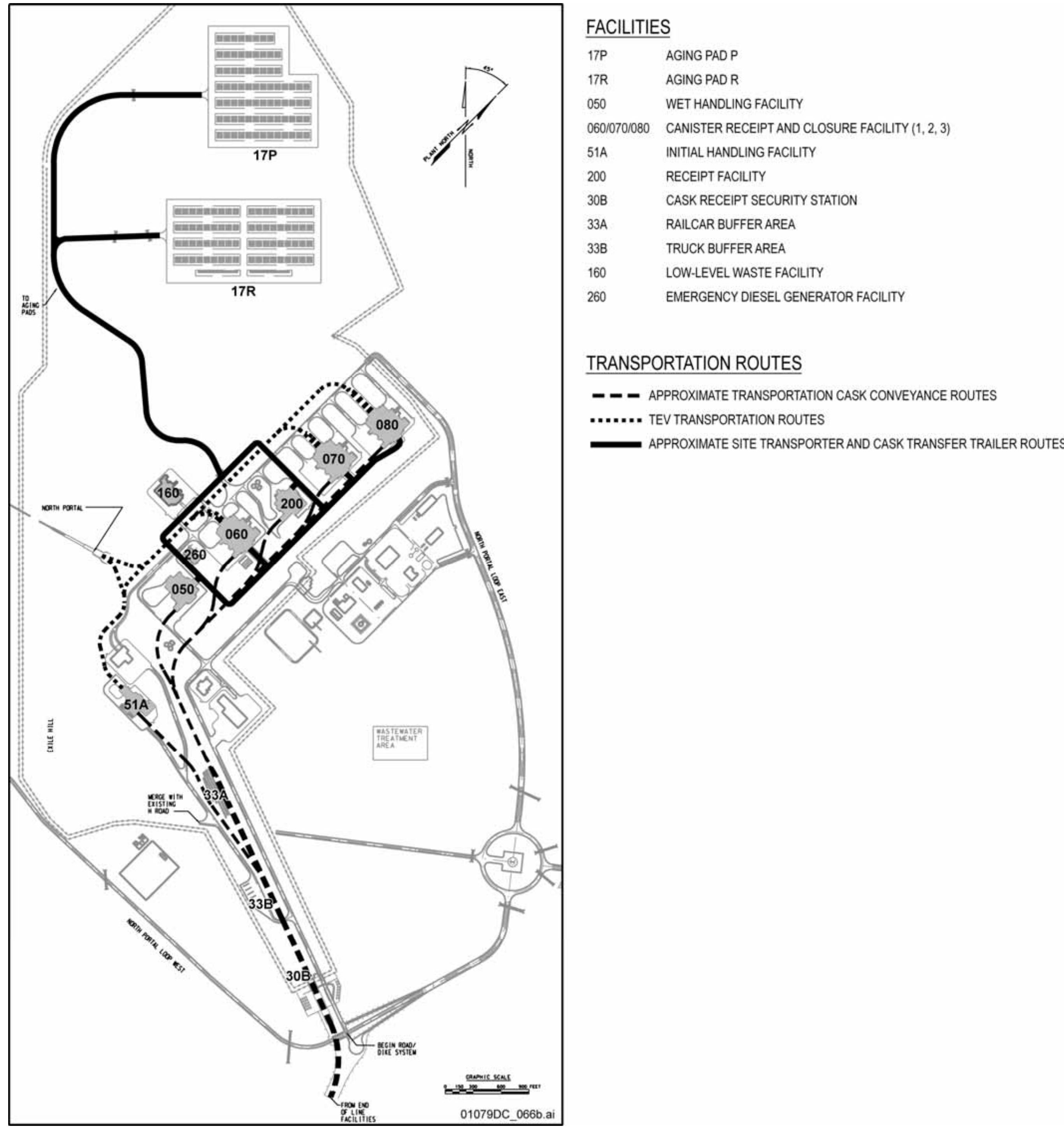
The jib crane is used to remove the TAD canister welding machine from the TAD canister and stage it on the welding machine stand in a process that is the reverse of welding machine placement on the TAD lid.

Inspect Weld

The inner lid weld is inspected using an ultrasonic testing hand tool as well as a visual inspection. The weld is verified by the appropriate level of American Society for Nondestructive Testing practices and certified personnel.

ATTACHMENT C
WET HANDLING FACILITY LOCATION WITHIN THE GROA

The WHF is one of four waste-handling building types (Ref. 2.2.88). Figure C-1 displays the location of the WHF and other major facilities within the GROA. The WHF provides the space, a pool, radiological confinement, structures, and internal systems that support receipt, wet and dry handling, transfer, and packaging of commercial spent nuclear fuel (CSNF). The WHF receives truck and rail-based transportation casks containing bare CSNF, and rail-based transportation casks containing dual-purpose canisters (DPCs). The WHF also receives shielded transfer casks (STCs) or aging overpacks containing DPCs. The CSNF from the transportation casks and DPCs is repackaged into transport, aging and disposal (TAD) canisters, and the sealed TAD canisters are transported to either the Aging Facility or to the Canister Receipt and Closure Facility (CRCF).



NOTE: TEV = transport and emplacement vehicle.

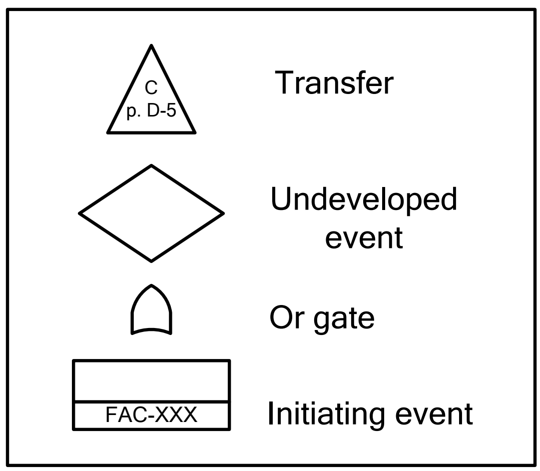
Source: Modified from (Ref. 2.2.88) and *Geologic Repository Operations Area Overall Site Plan* (Ref. 2.2.89).

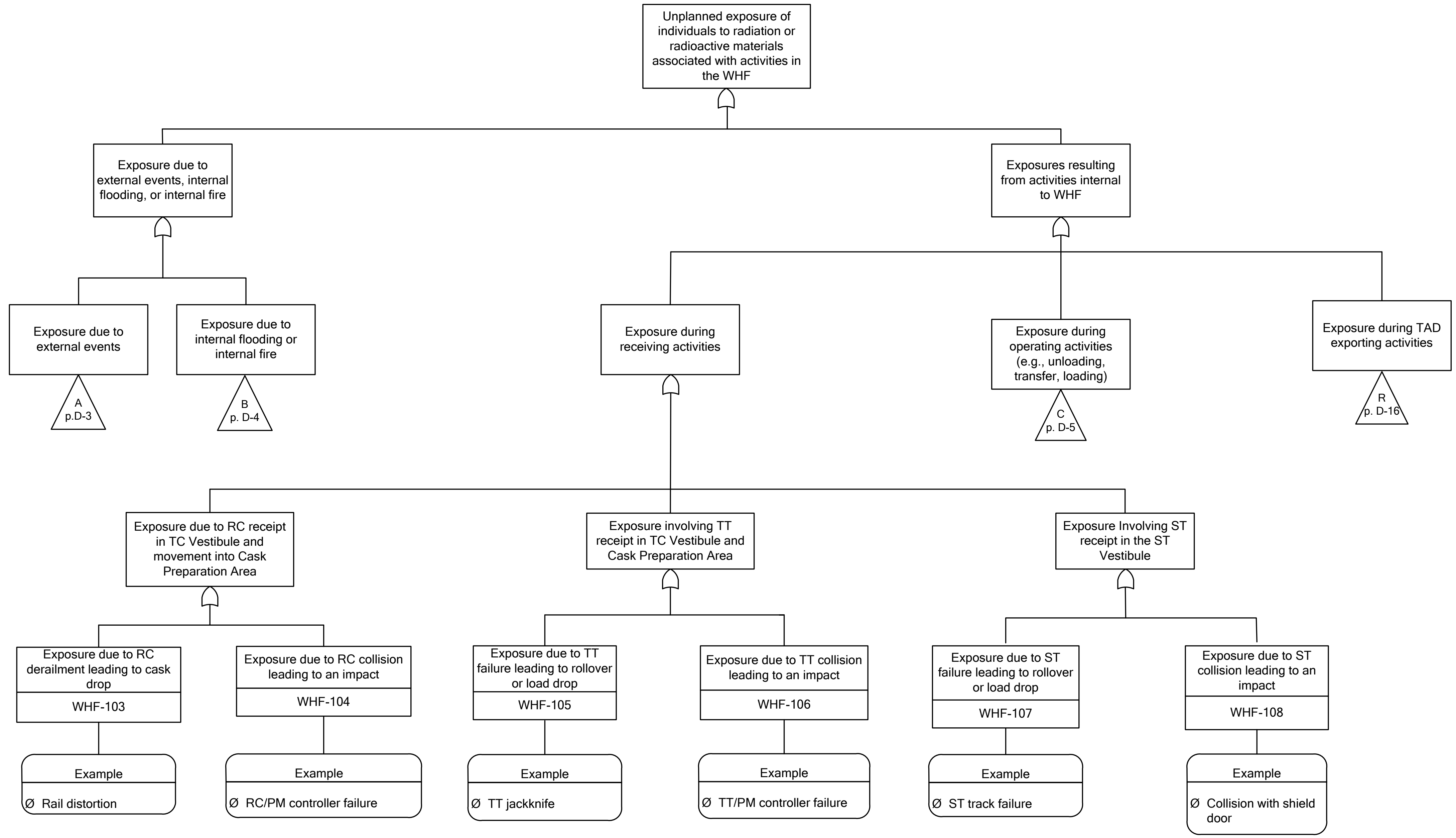
Figure C-1. Geologic Repository Operations Area Overall

ATTACHMENT D
WET HANDLING FACILITY MASTER LOGIC DIAGRAM

This section presents MLD for WHF. The portions of the MLD describing internal and external events (except seismic events) are shown in Figures D-1 to D-21.

Legend

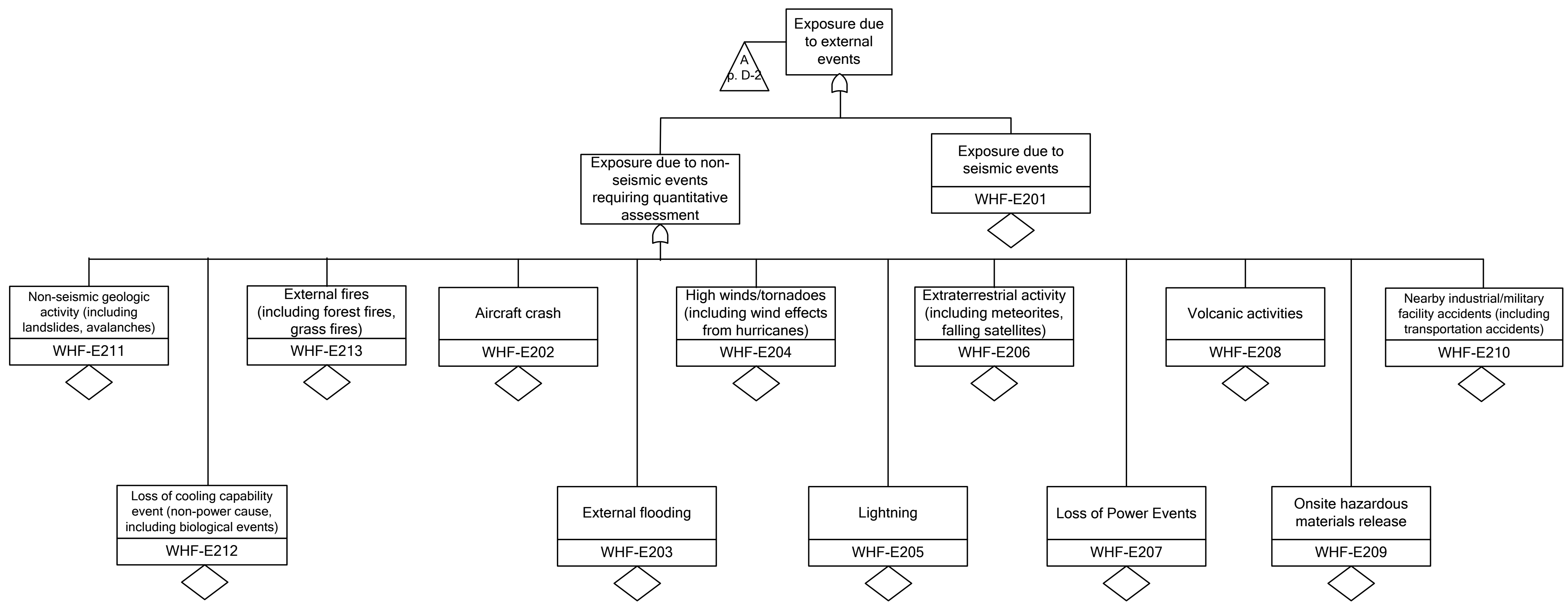




NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
AO = aging overpack; PM = prime mover; RC = railcar; ST = site transporter; TAD = transportation, aging, and disposal; TC = transportation cask; TT = truck trailer; WHF = Wet Handling Facility.

Source: Original

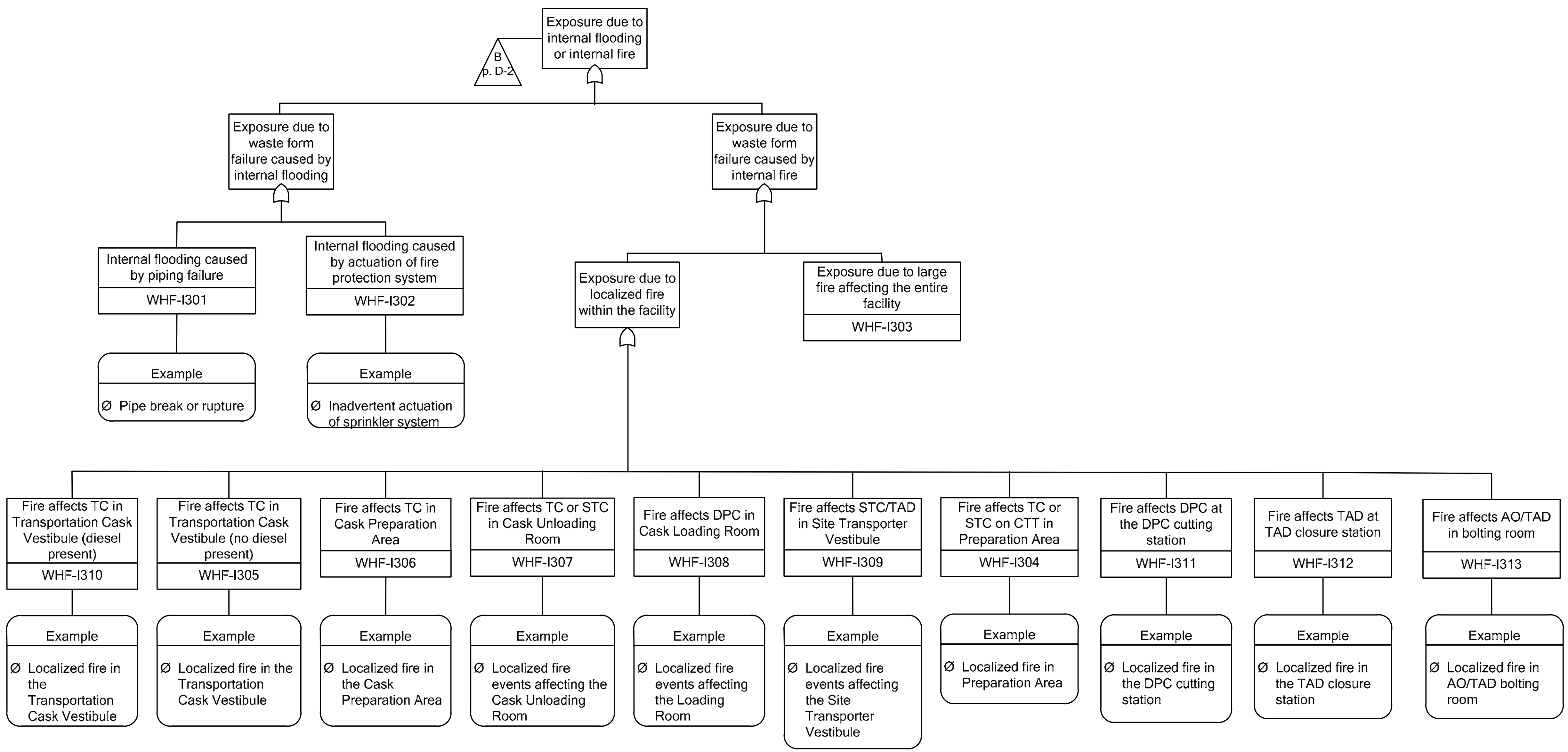
Figure D-1. Unplanned Exposure of Individuals to Radiation or Radioactive Materials associated with WHF Activities



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
These external events are analyzed in the (Ref. 2.2.23),
WHF = Wet Handling Facility.

Source: Original

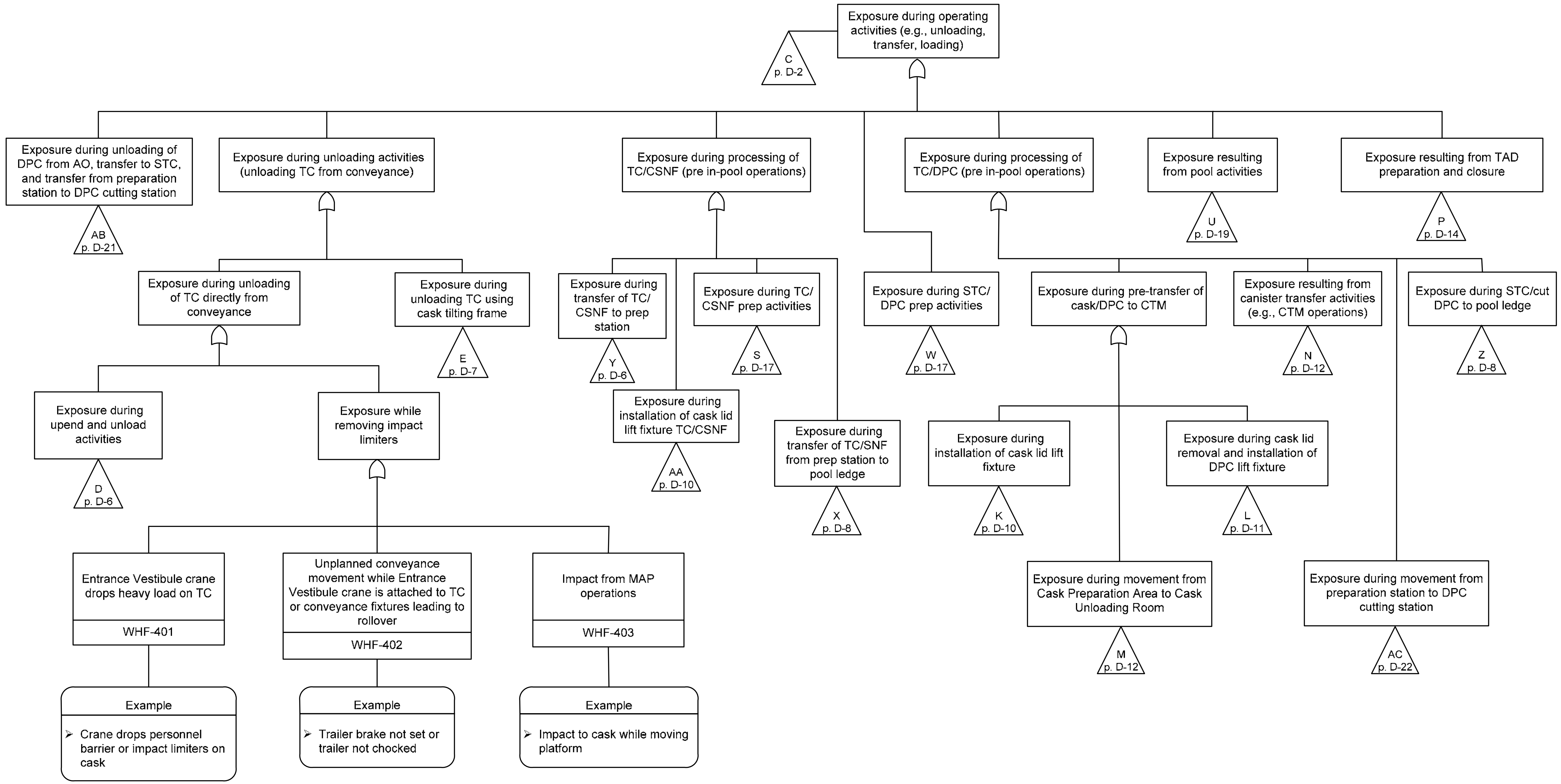
Figure D-2. Exposure Due to External Events



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
CTT = cask transfer trolley; DPC dual-purpose canister; ST = site transporter; STC = shielded transfer cask; TAD = transportation, aging, and disposal; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

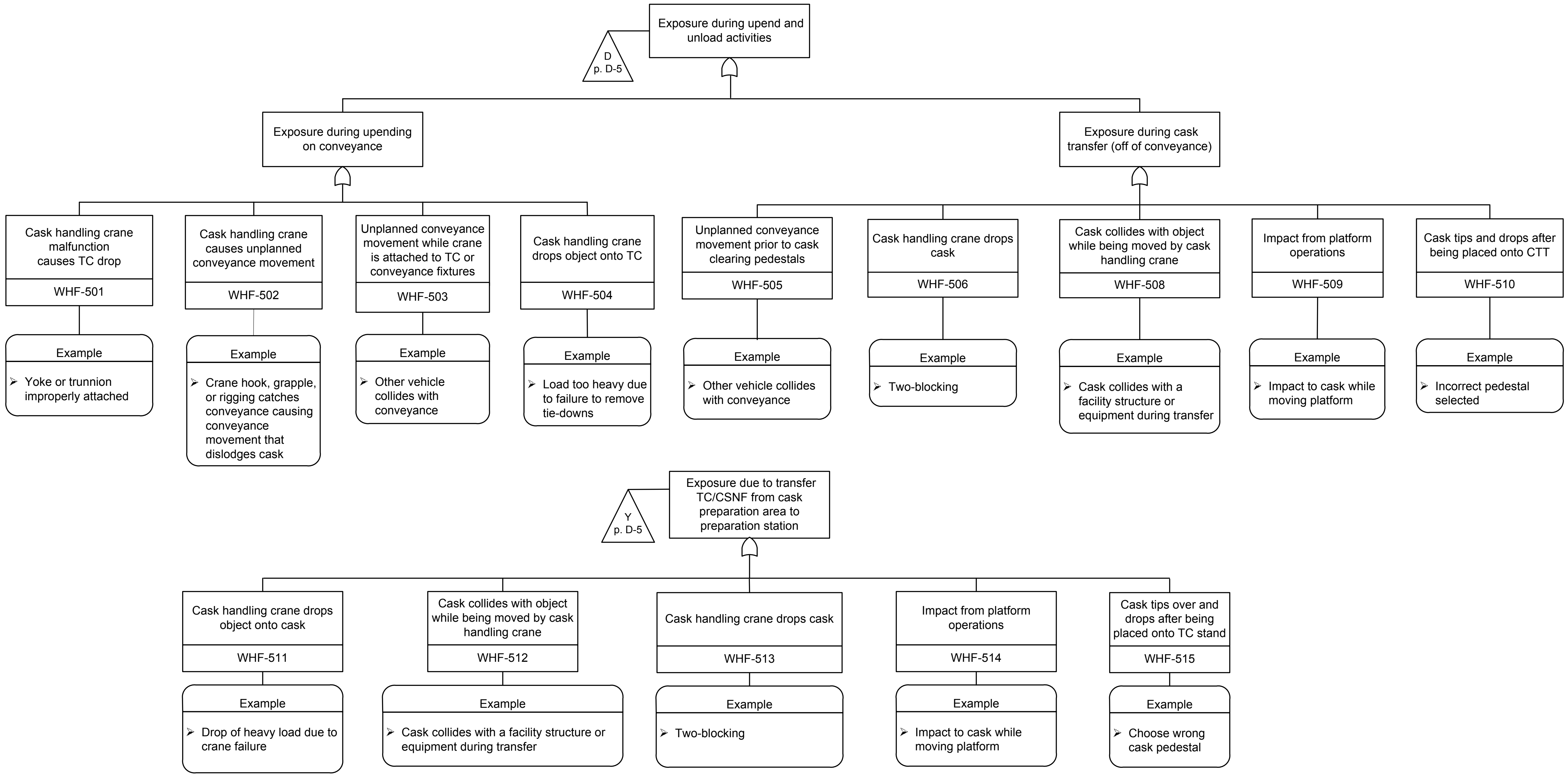
Figure D-3. Exposure Due to Internal Flooding or Fire



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
AO = aging overpack; CSNF = commercial spent nuclear fuel; CTM = cask transfer machine; DPC = dual-purpose canister; MAP = mobile access platform; SNF = spent nuclear fuel; SPM = site prime mover; STC = shielded transfer cask; TAD = transportation, aging, and disposal; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

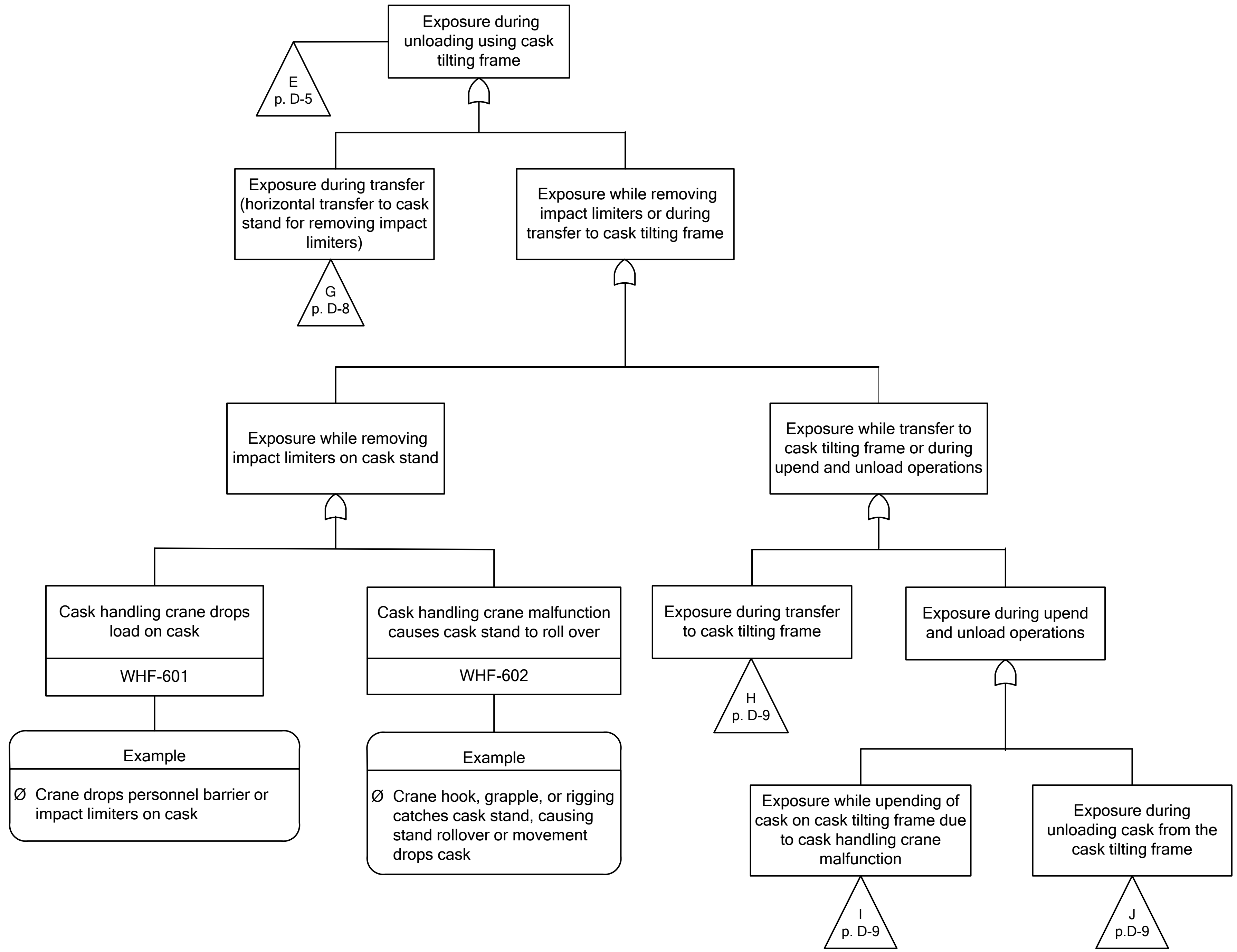
Figure D-4. Exposure During Operating and Processing Activities



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
CTT = cask transfer trolley; CSNF = commercial spent nuclear fuel; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

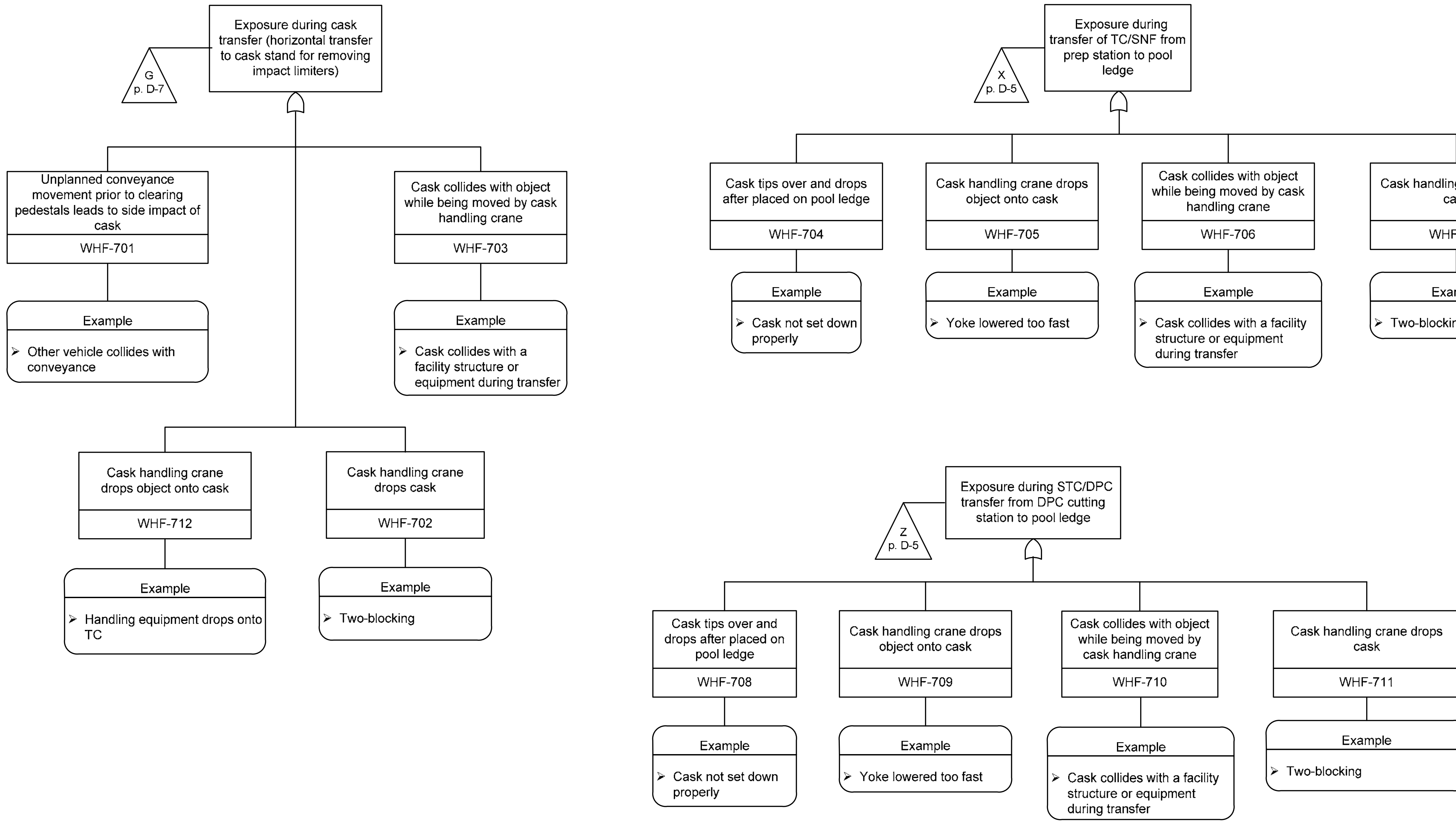
Figure D-5. Exposure During Upend and Unload Activities



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

Source: Original

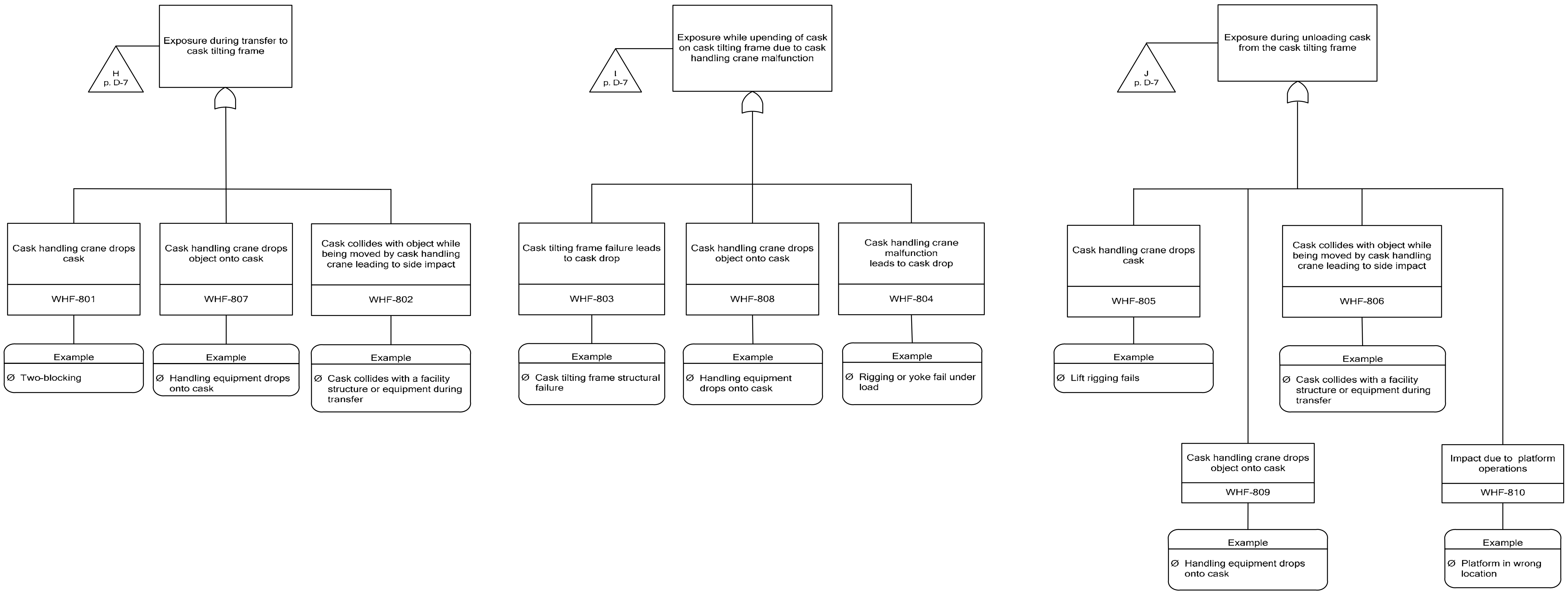
Figure D-6. Exposure During Unloading Cask Using Cask Tilting Frame and Exposure during CTT Movement to Preparation Station



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
DPC = dual-purpose canister; SNF = spent nuclear fuel; STC = shielded transfer cask; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

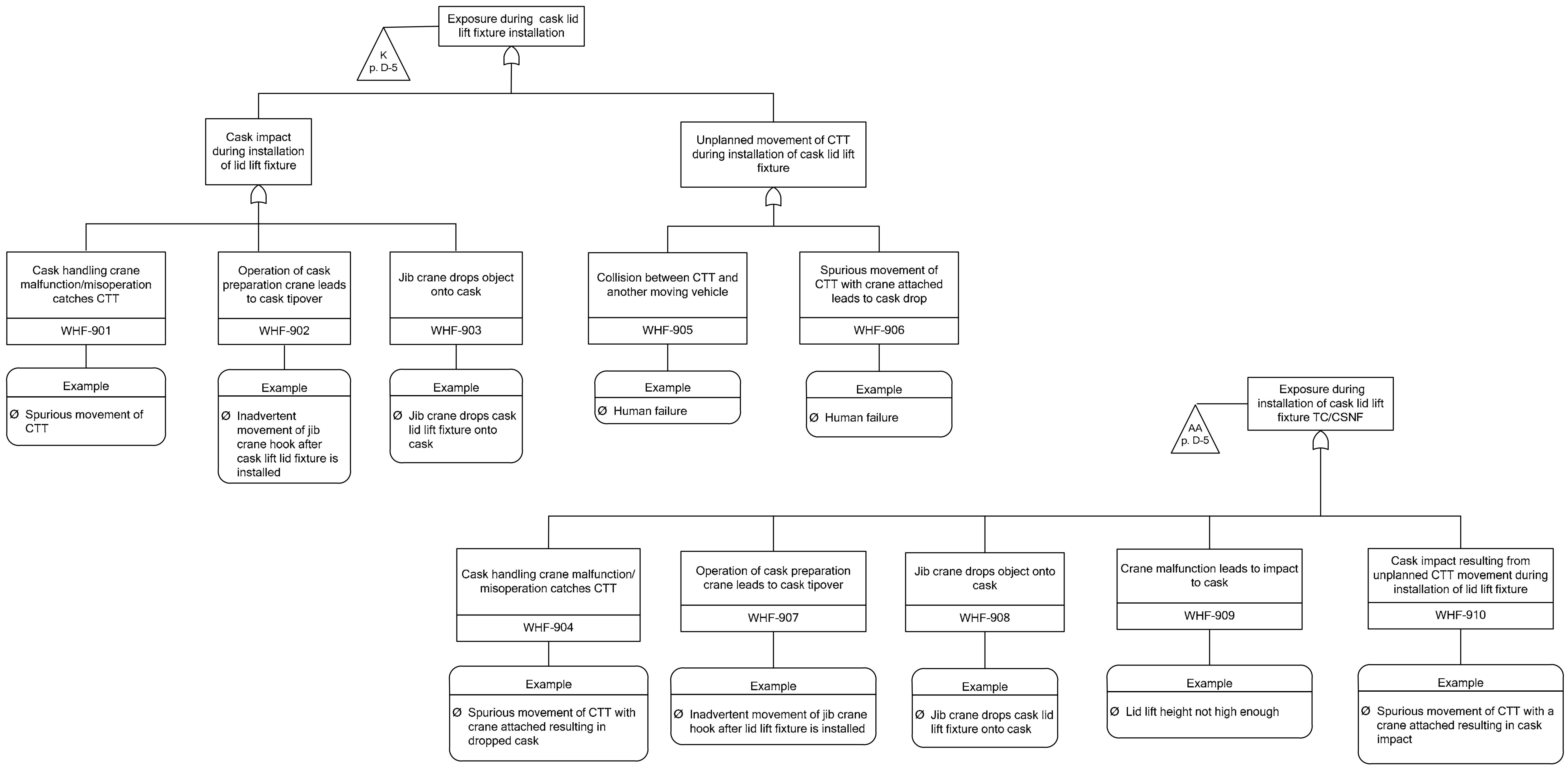
Figure D-7. Exposure during Cask Transfer (Horizontal Transfer to Stand for Removing Impact Limiters) and Exposure during Transfer to TC/SNF from Prep Station to Pool Ledge



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as “exposure.”
WHF = Wet Handling Facility.

Source: Original

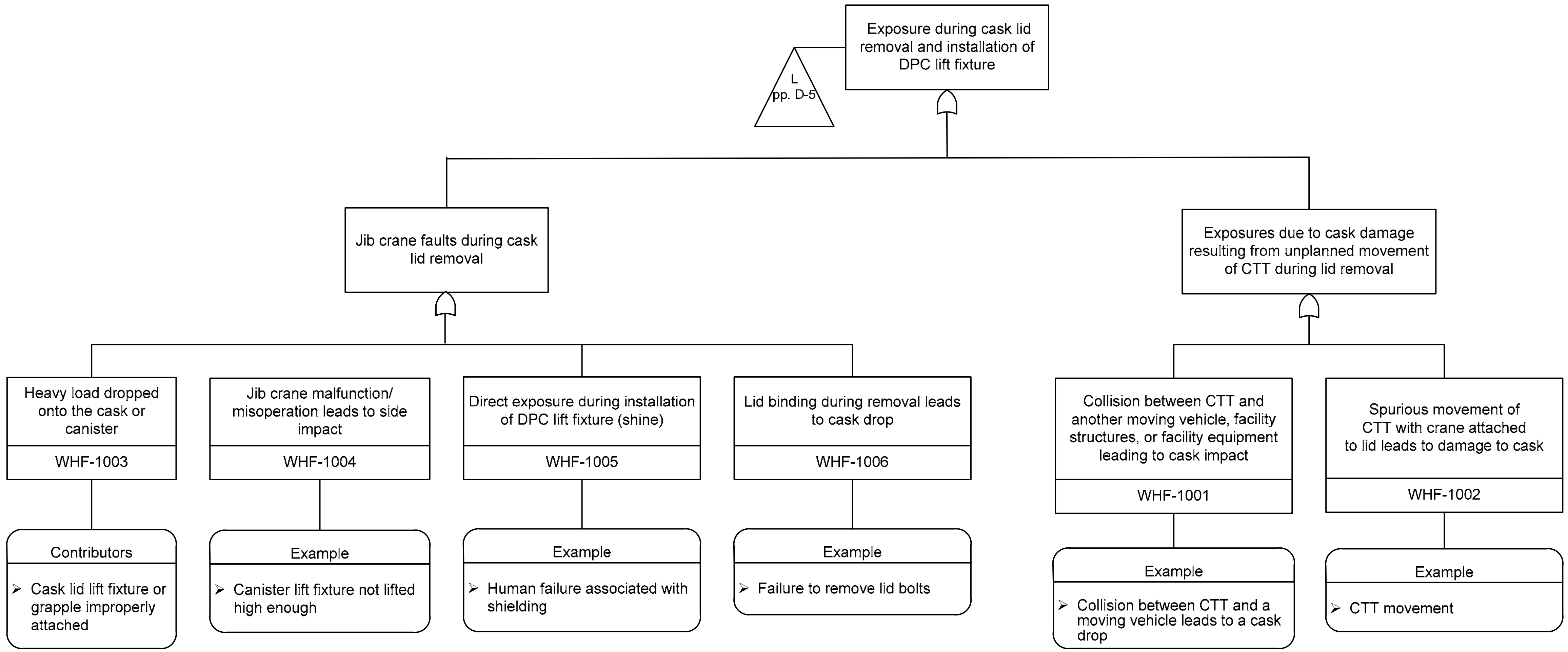
Figure D-8. Exposure during Transfer to Cask Tilting Frame and Exposure while Upending of Cask due to Cask Handling Crane Malfunction and Exposure during Unloading Cask from the Cask Tilting Frame



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
CSNF = commercial spent nuclear fuel; CTT = cask transfer trolley; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

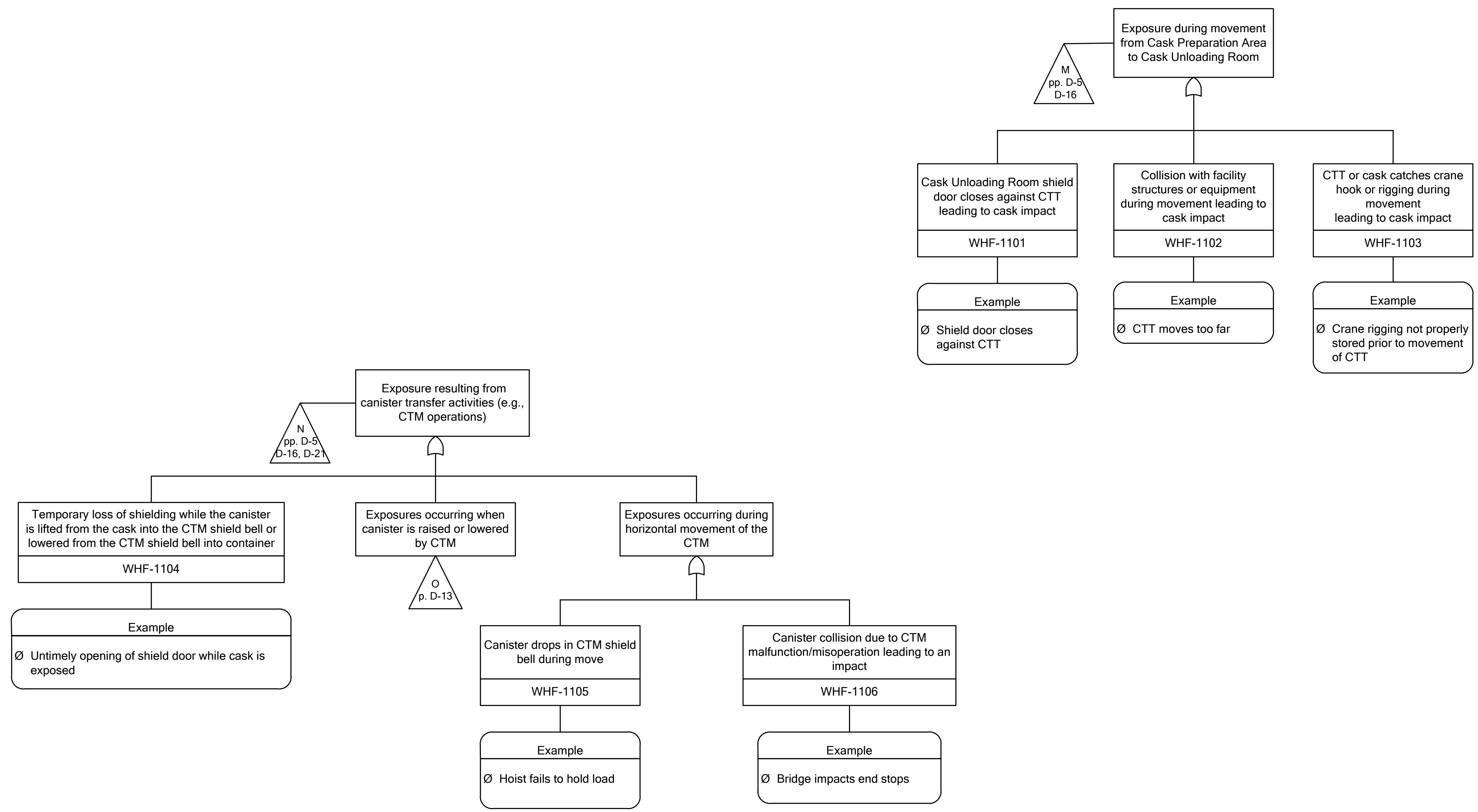
Figure D-9. Exposure during Installation of Cask Lid Lift Fixture and Exposure during Installation of Cask Lid Lift fixture TC/CSNF



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

Source: Original

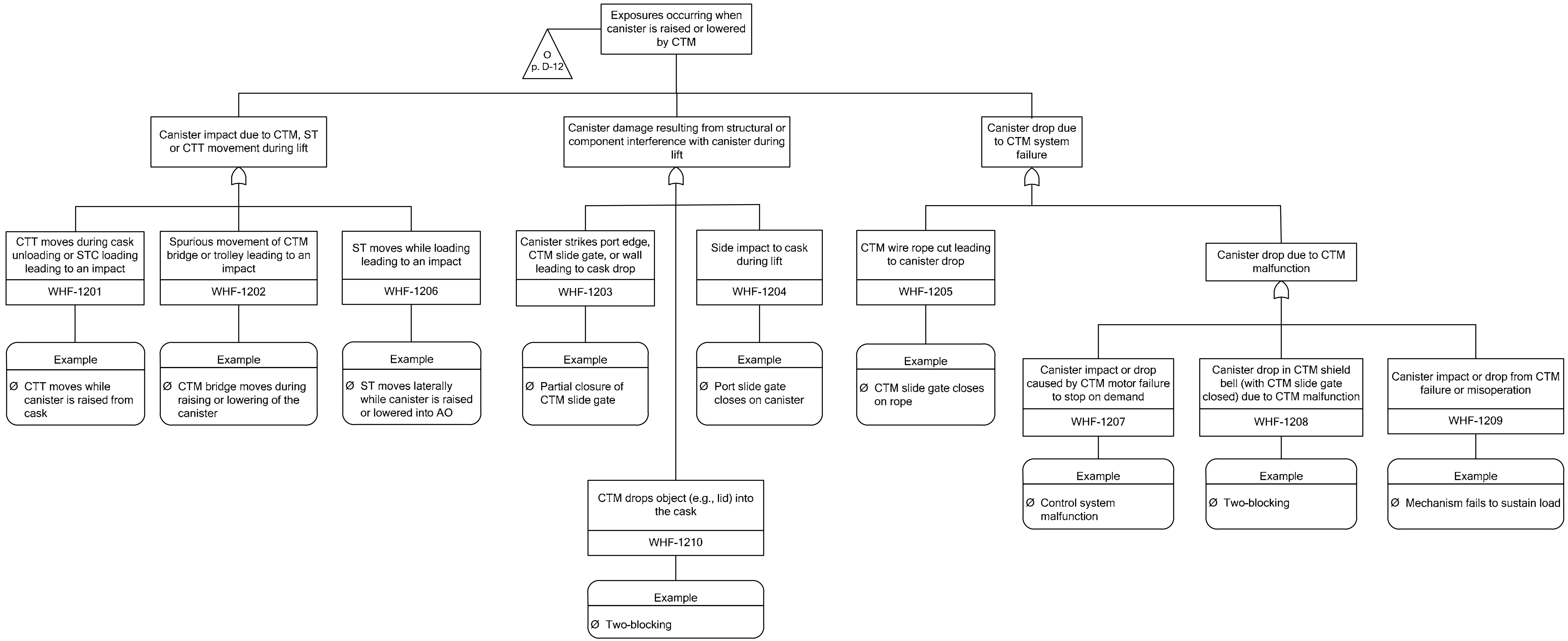
Figure D-10. Exposure During Cask Lid Removal and Installation of DPC Lift Fixture in Site Transporter Vestibule



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
CTM = canister transfer machine; CTT = cask transfer trolley; WHF = Wet Handling Facility.

Source: Original

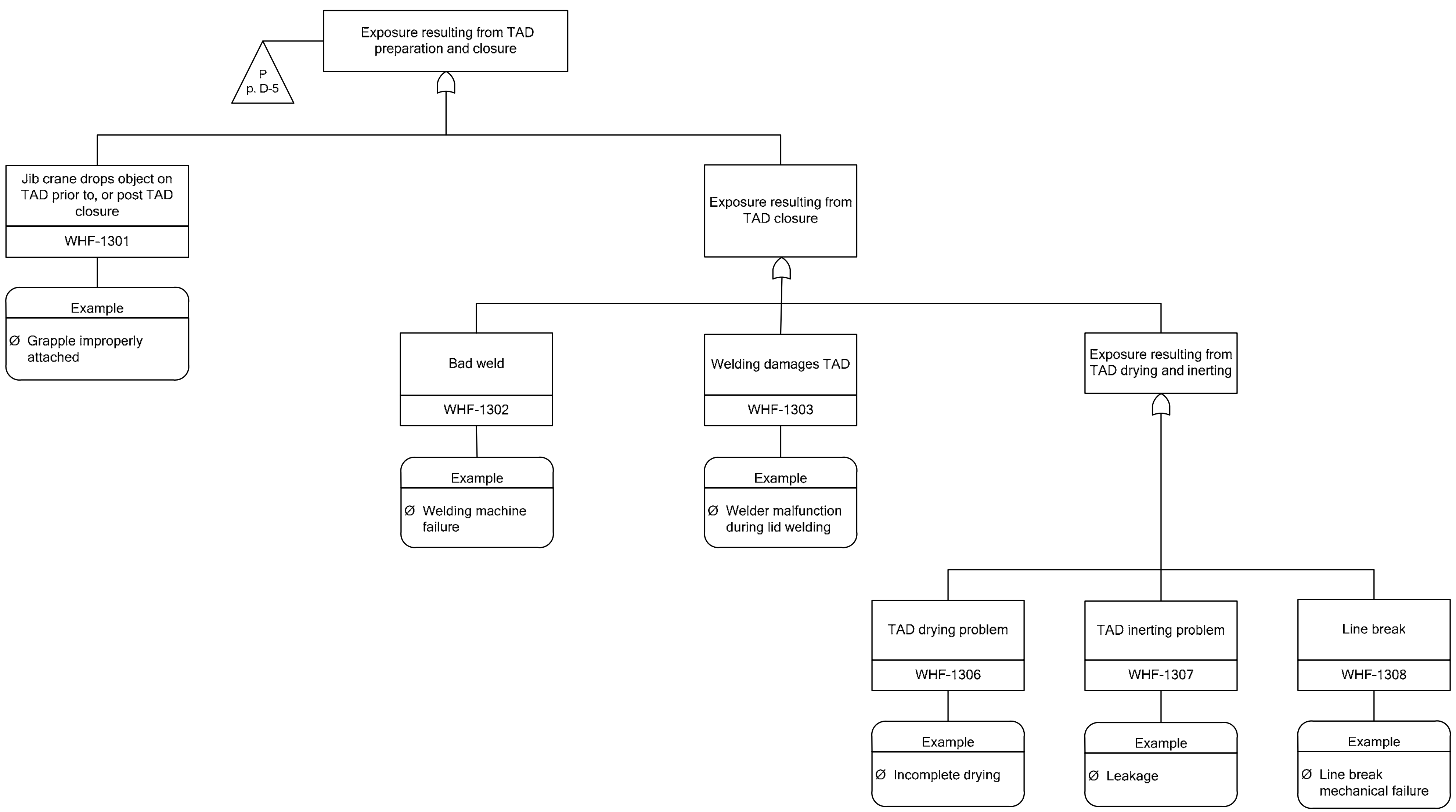
Figure D-11. Exposure during Movement from Cask Preparation Area to Cask Unloading Room and Exposure Resulting from Canister Transfer Activities (e.g., CTM Operations)



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as “exposure.”
CTM = canister transfer machine; CTT = cask transfer trolley; ST = site transporter; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

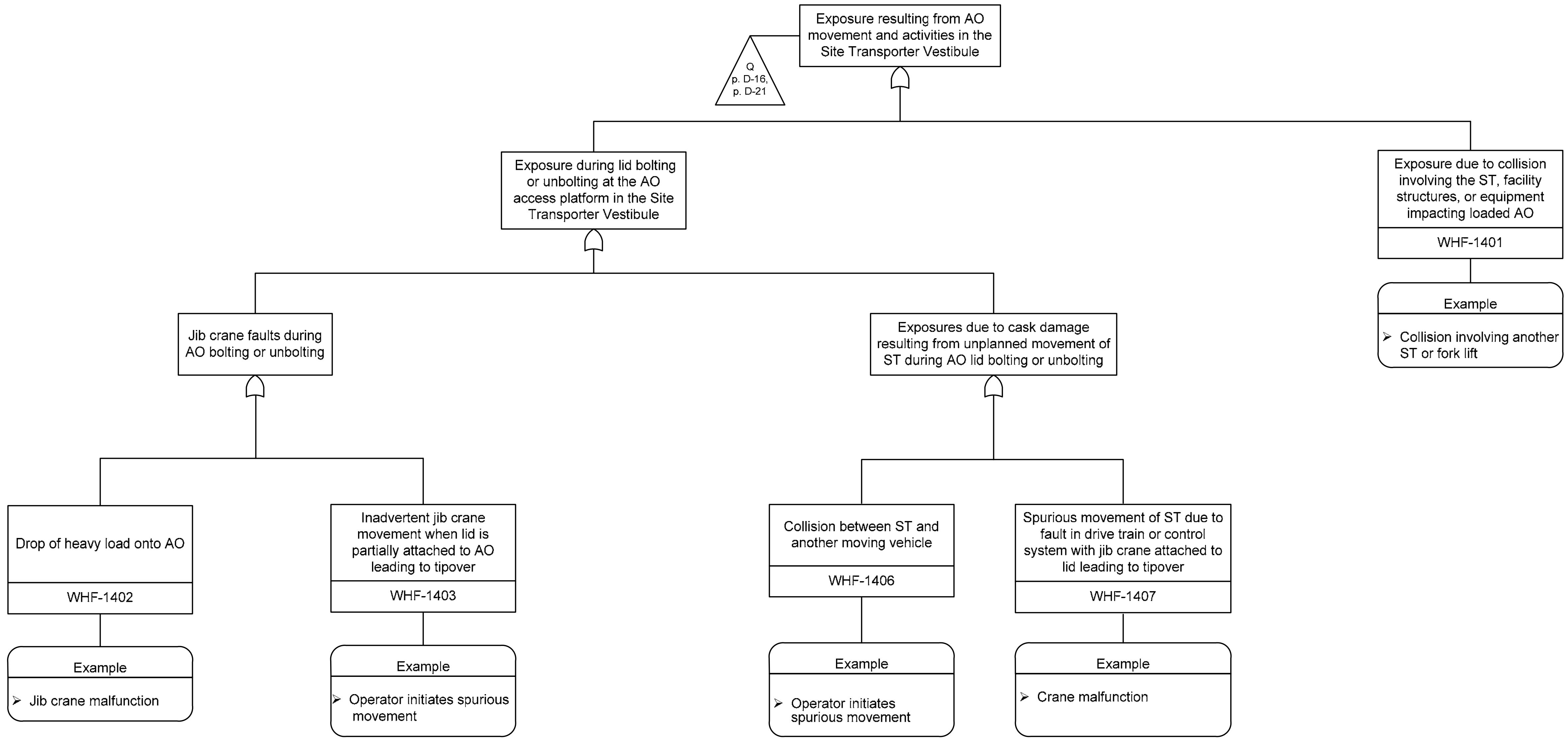
Figure D-12. Exposures Occurring when Canister is Raised or Lowered by CTM



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as “exposure.” TAD = transportation, aging, and disposal; WHF = Wet Handling Facility.

Source: Original

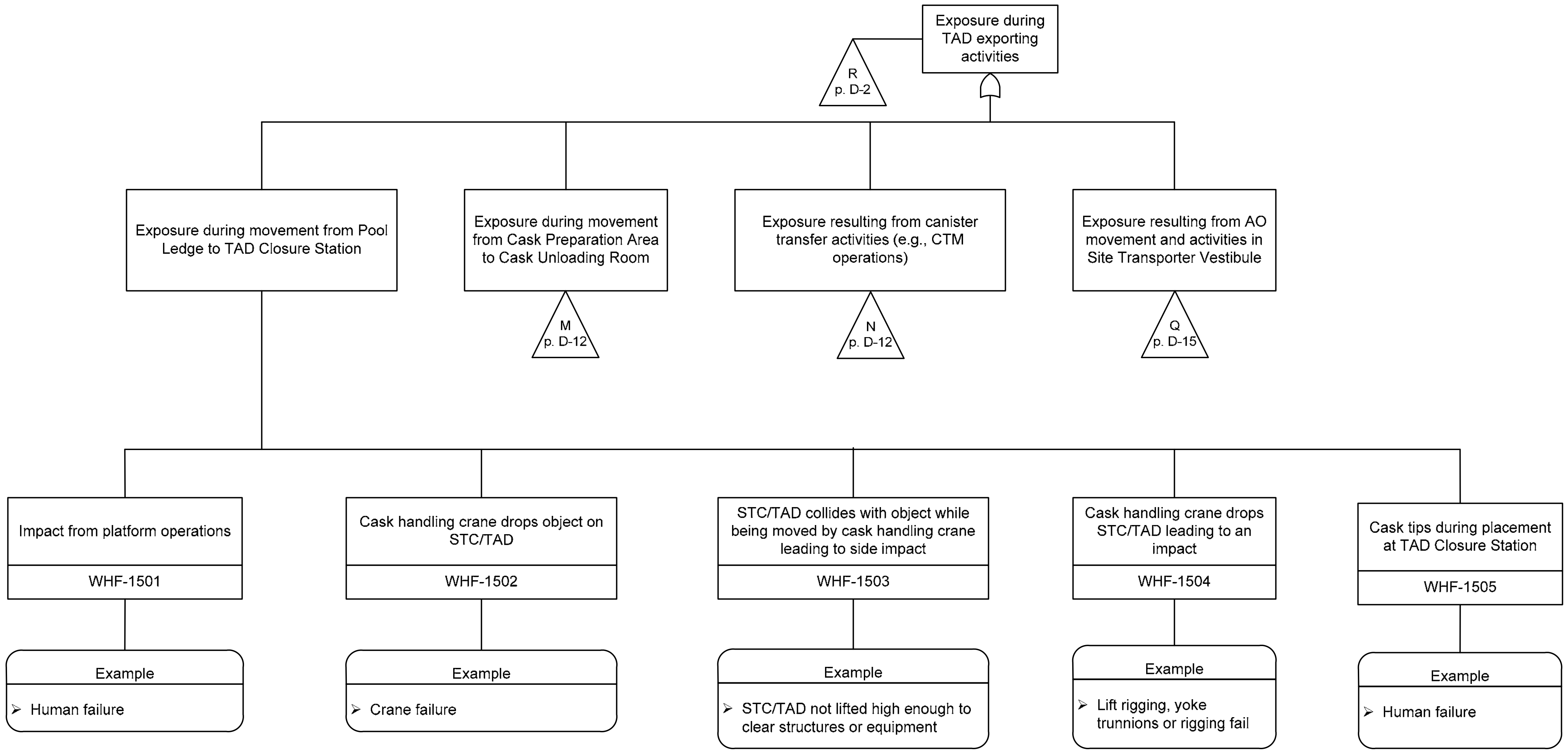
Figure D-13. Exposure Resulting from Preparation Activities of TAD and Closure



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as “exposure.”
AO = aging overpack; ST = site transporter; WHF = Wet Handling Facility.

Source: Original

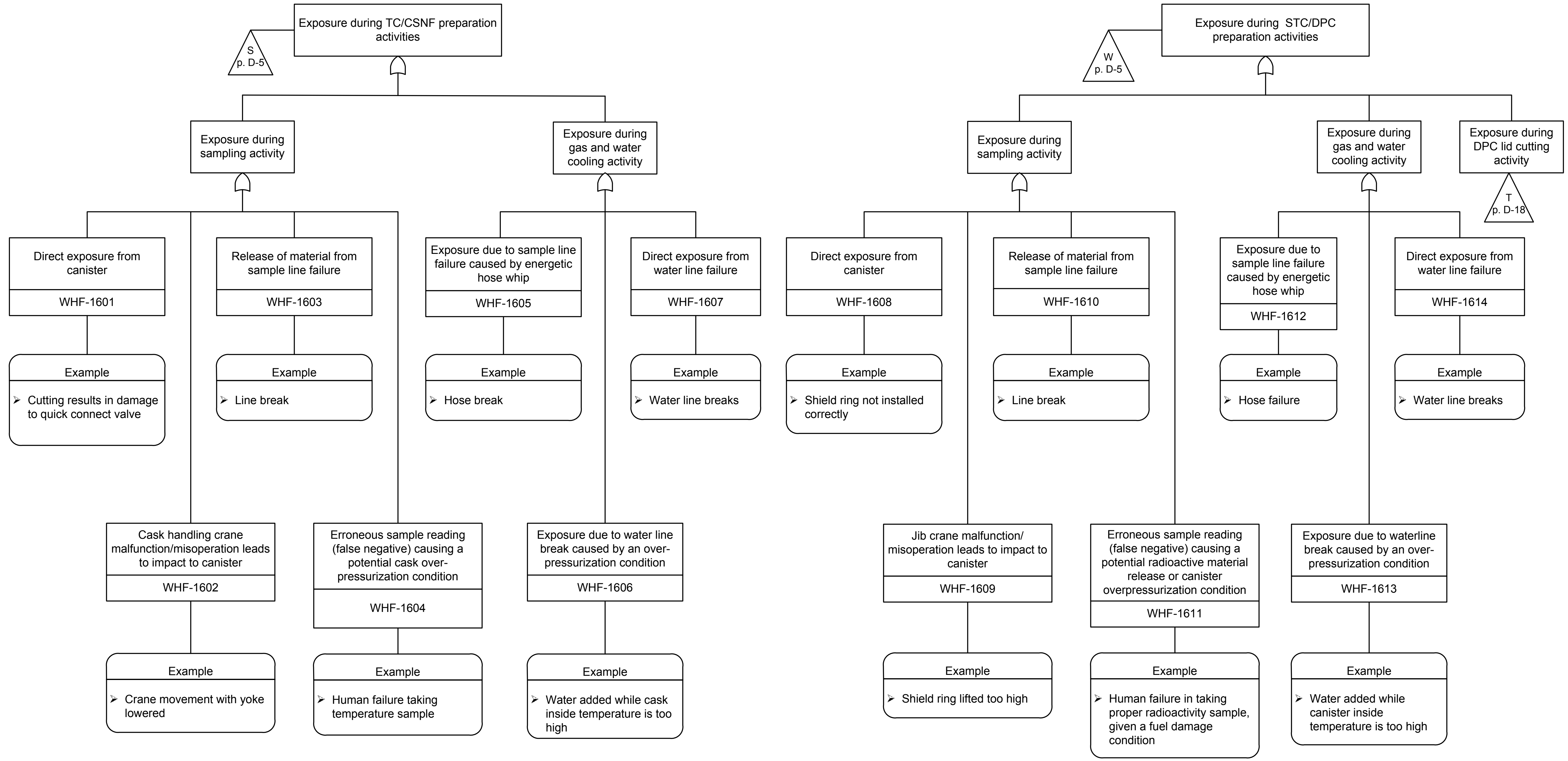
Figure D-14. Exposure Resulting from Preparing TAD/AO for Export



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
AO = aging overpack; CTM = canister transfer machine; CTT = cask transfer trolley; STC = shielded transfer cask; TAD = transportation, aging, and disposal; WHF = Wet Handling Facility.

Source: Original

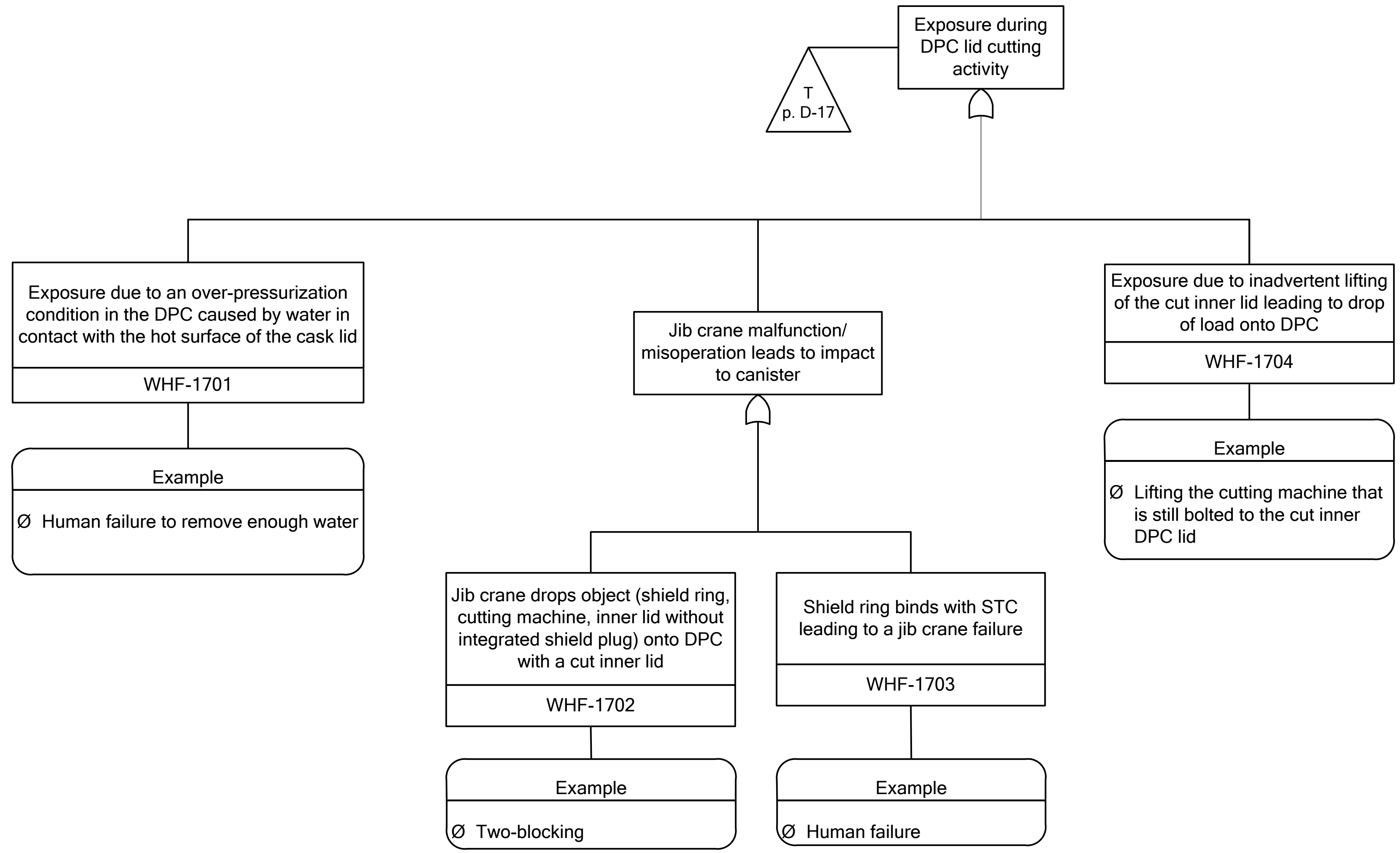
Figure D-15. Exposure during Exporting Activities



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
CSNF = commercial spent nuclear fuel; DPC = dual-purpose canisters; STC = shielded transfer cask; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

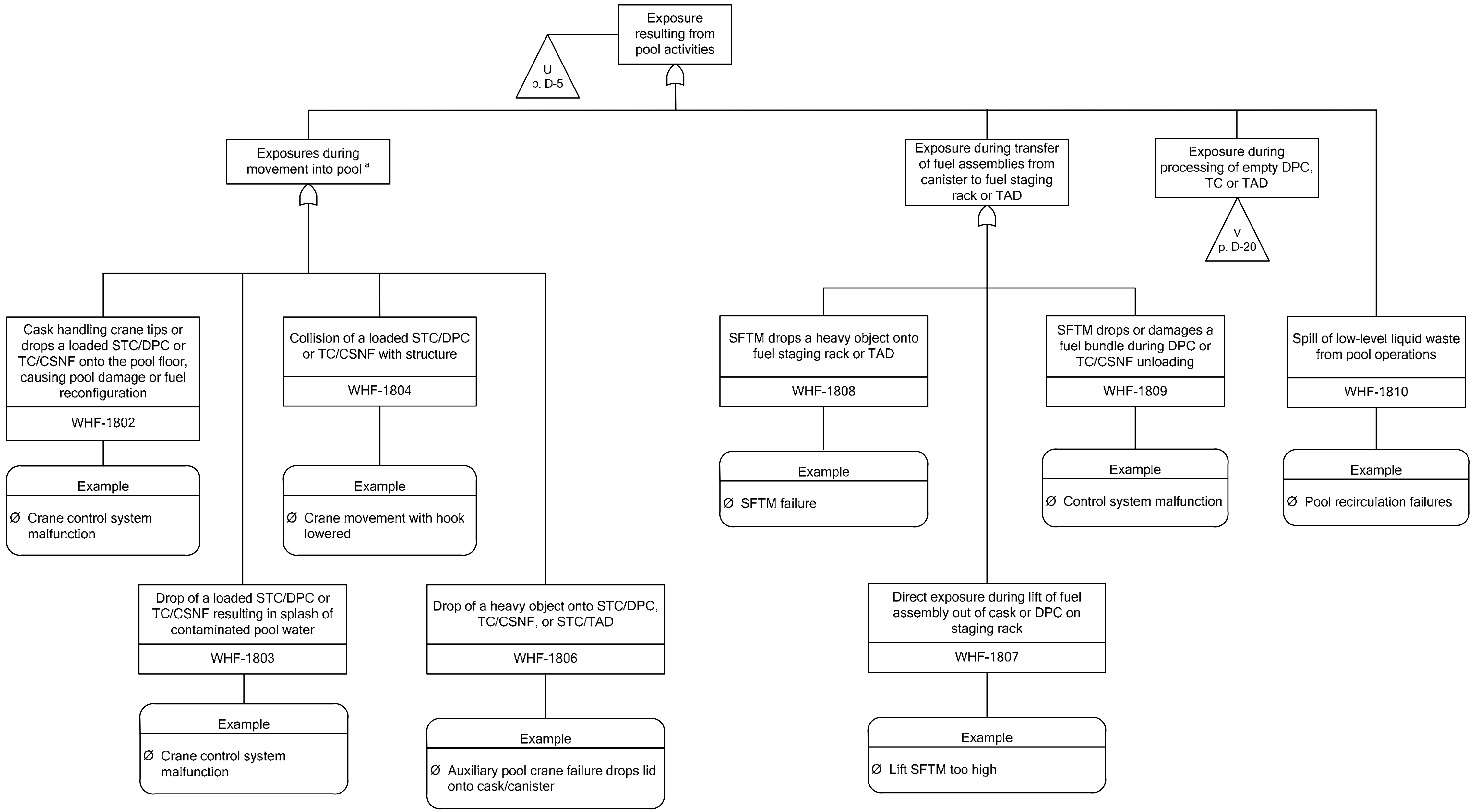
Figure D-16. Exposure during TC/CSNF Preparation Activities and Exposure during STC/DPC Preparation Activities



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
DPC = dual-purpose canisters; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

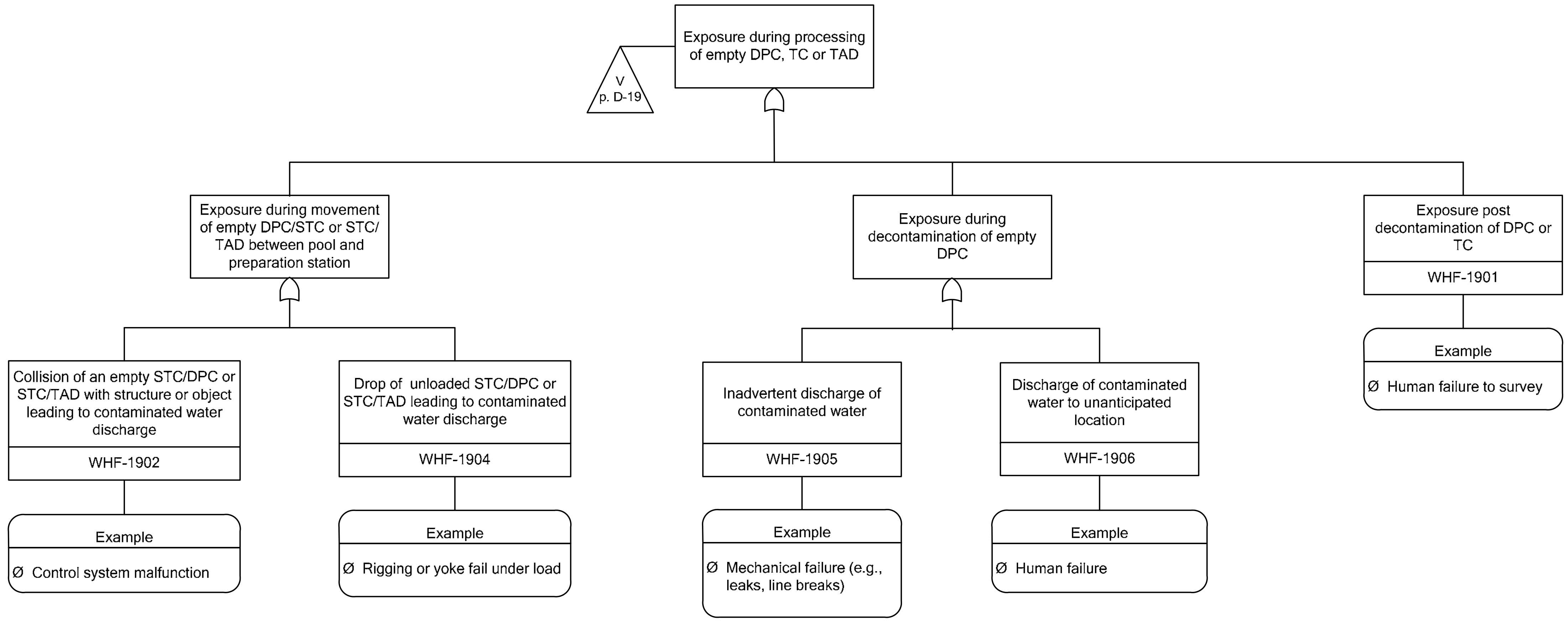
Figure D-17. Exposure during DPC Lid Cutting Activity



NOTE: a Drop into the pool or a misload in the pool concurrent with an insufficient concentration of boration could result in a condition favorable to criticality. Loss of boration will be evaluated in the ESD. Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
CSNF = commercial spent nuclear fuel; DPC = dual-purpose canisters; ESD = Event Sequence Diagram; SFTM = spent fuel transfer machine; STC = shielded transfer cask; TAD = transportation, aging, and disposal; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

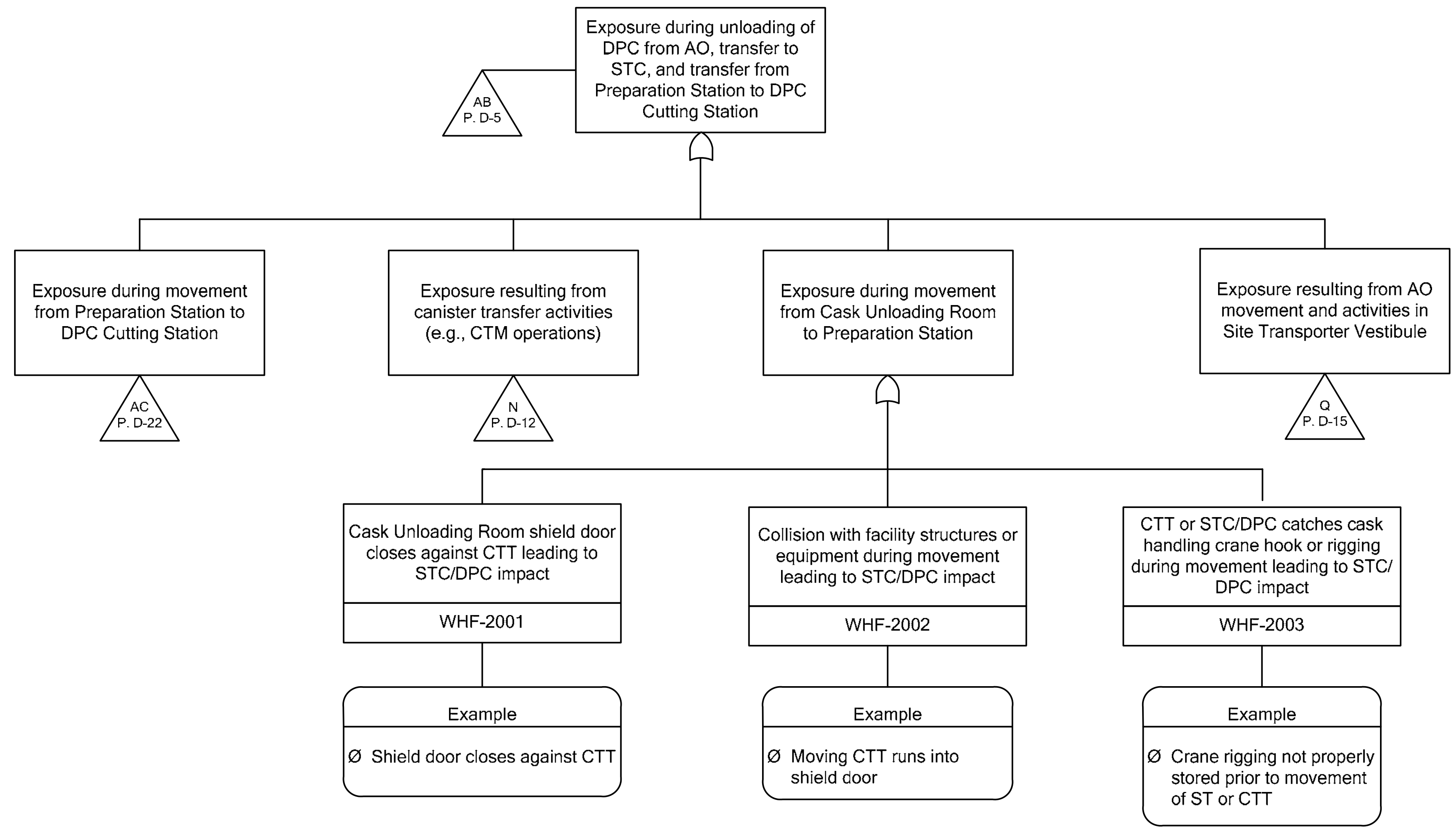
Figure D-18. Exposure Resulting from Pool Activities



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
DPC = dual-purpose canister; STC = shielded transfer canister; TAD = transportation, aging, and disposal; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

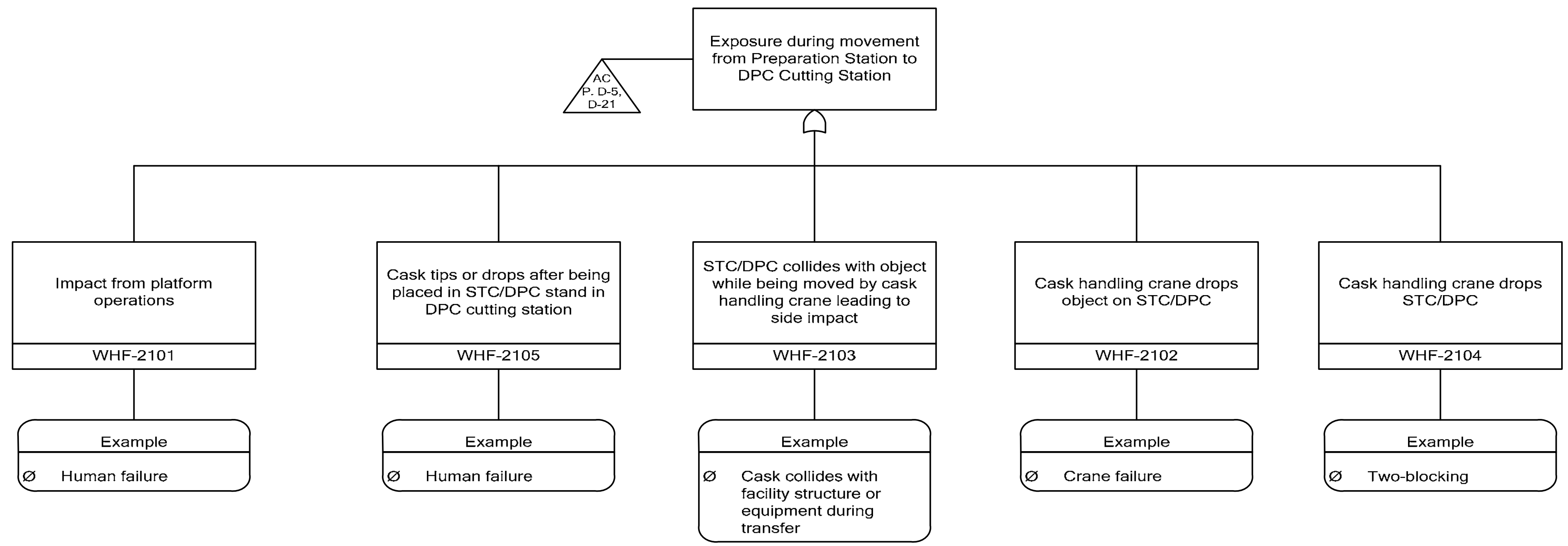
Figure D-19. Exposure during Processing of Empty DPC or TC



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
AO = aging overpack; CTT = cask transport trolley; CTM = canister transfer machine; DPC = dual-purpose canister; ST = site transporter; STC = shielded transfer canister; TAD = transportation, aging, and disposal; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Figure D-20. Exposure During Unloading of DPC from AO, Transfer to STC, and Transfer from Preparation Station to DPC Cutting Station



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is referred to as "exposure."
DPC = dual-purpose canister; STC = shielded transfer canister; WHF = Wet Handling Facility.

Source: Original

Figure D-21 Exposure During Movement from Preparation Station to DPC Cutting Station

ATTACHMENT E
WET HANDLING FACILITY HAZARD AND OPERABILITY

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

HAZOP MEETINGS

LIST OF SUBJECT MATTER EXPERT (SME) ATTENDEES AND BIOGRAPHIES

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

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

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

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

HAZOP Meetings		
Name	**Telephone Number**	**Organization**
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 Meeting Dates and List of Attendees (Continued)

HAZOP Meetings		
Name	**Telephone Number**	**Organization**
Meeting Date: April 3, 2007		
Paul Amico	702-821-7911	SAIC
Erin Collins	702-821-7913	SAIC
Robert Garrett	702-821-8239	B&A
Norm Graves	702-821-7012	BSC
Daryl Keppler	505-272-7102	ARES
Phuoc Le	702-821-7468	SAIC
Kelvin Montague	702-821-7847	B&A
Doug Orvis	702-821-7914	BSC
Mary Presley	505-272-7102	ARES
Guy Ragan	702-821-7637	BSC
Clarence Smith	702-821-7126	BSC
Meeting Date: April 4, 2007		
Paul Amico	702-821-7911	SAIC
Erin Collins	702-821-7913	SAIC
Norm Graves	702-821-7012	BSC
Daryl Keppler	505-272-7102	ARES
Phuoc Le	702-821-7468	SAIC
Kelvin Montague	702-821-7847	B&A
Doug Orvis	702-821-7914	BSC
Mary Presley	505-272-7102	ARES
Guy Ragan	702-821-7637	BSC
Clarence Smith	702-821-7126	BSC
Meeting Date: April 6, 2007		
Paul Amico	702-821-7911	SAIC
Norm Graves	702-821-7012	BSC
Daryl Keppler	505-272-7102	ARES
Phuoc Le	702-821-7468	SAIC
Dale Pendry	702-821-8380	BSC
Mary Presley	505-272-7102	ARES

Source: Original

Biographies of SMEs Attending the HAZOP Meetings:

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

Erin P. Collins: Ms. Collins is a risk analyst with over 20 years of experience in safety, reliability and risk analysis for the Army chemical weapons destruction program, National Aeronautics and Space Administration, Federal Aviation Administration, nuclear power plants, and the chemical process industry. Her specialties are equipment reliability database development and human reliability analysis. She has participated in two prior HAZOPs as part of the 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 study, Mr. Garrett served as a representative in the Intra-Site Operations areas for the HAZOP sessions.

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

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

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

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 study, Ms. Loyd served as a participant for subsurface-related HAZOP sessions.

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

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

Douglas D. Orvis, Ph.D. (Nuclear): Dr. Orvis is a registered professional engineer (California, Nuclear No. 0925) with over 35 years of experience in nuclear engineering, regulation, and risk analysis of nuclear power plants, alternative concepts for interim storage of spent nuclear fuel, and aerospace applications. He has performed numerous qualitative and quantitative safety assessments, to include participation in HAZOP sessions. He 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. He has performed event tree and fault tree analyses of hazardous systems for both internal events and seismic initiators. Dr. Orvis is a former Supervisor of the BSC Preclosure Safety Analysis group.

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

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

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

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

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

Table E-2. HAZOP Analysis Worksheet

Facility/Operation: WHF | **Process**: TC Receipt and Transfer into Preparation Area

Node 1: Receive and Move TC on Rail Car into Preparation Area for Unloading | **Process/Equipment**: SPM, Rail Car

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

Node Item Number	Parameter	Deviation Considered	Postulated Cause	Consequence(s)	Potential Prevention/Mitigation Design of Operational Feature	Notes	MLD Index Number
1.1	Speed	(More) SPM moves too fast	Driver drives too fast	Potential loss of control or collision leading to radioactive release	1–TC remains in 10 CFR 71 configuration 2–Procedures and training	Creeping speed	WHF-104 WHF-106
1.2	Speed	(More) SPM moves too fast	Mechanical failure of SPM	Potential loss of control or collision leading to radioactive release	1–TC remains in 10 CFR 71 configuration 2–Procedures and training	Creeping speed	WHF-104 WHF-106
1.3	Speed	(Less) SPM moves too slow	Mechanical failure of SPM	No safety consequences			
1.4	Speed	(No) SPM does not move	1–Human failure 2–Mechanical failure	No safety consequences		Always at least one-door boundary for HVAC if conveyance is stuck in doorway – Does not apply to WHF	
1.5	Direction	(Reverse) Backs up instead of going forward	1–Human failure 2–Mechanical failure	Potential loss of control or collision leading to radioactive release	1–TC remains in 10 CFR 71 configuration 2–Procedures and training	Potential loss of HVAC boundary if collision with door	WHF-104 WHF-106
1.6	Direction	(Other Than) SPM derailment	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–TC remains in 10 CFR 71 configuration 2–Procedures and training		WHF-103 WHF-105
1.7	Direction	(Other Than) SPM derailment	Rail distortion due to structural failure	Potential drop leading to radioactive release	1–TC remains in 10 CFR 71 configuration 2–Procedures and training 3–Rail design		WHF-103 WHF-105
1.8	Direction	(Other Than) Not following designated route	1–Human failure 2–Mechanical failure	Potential loss of control or collision leading to radioactive release	1–TC remains in 10 CFR 71 configuration 2–Procedures and training	Steering failure – Applies only to truck in WHF	WHF-104 WHF-106
1.9	Direction	(Other Than) Not following designated route and going to wrong location or problem area	1–Human failure 2–Mechanical failure	Potential loss of control or collision leading to radioactive release	1–TC remains in 10 CFR 71 configuration 2–Procedures and training	Faulty track or switch indicator	WHF-104 WHF-106
1.10	Parking	(Other Than) Improper positioning and constraint of cask conveyance	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–TC remains in 10 CFR 71 configuration 2–Procedures and training 3–Brakes, chocks, and rail stops	Collision caused by unconstrained cask conveyance	WHF-104 WHF-106
1.11	Temperature	(More) Exceeds 10 CFR 71 temperature design basis	Fire	1–Radioactive release 2–Potential criticality	1–TC remains in 10 CFR 71 configuration 2–Procedures and training 3–Combustible materials control	1–10 CFR 71 temperature design basis 2–WHF truck a source of fire during subsequent operations 3–Removal of SPM prior to cask handling operations as part of combustible materials control	WHF-I305 WHF-I309 WHF-I310
1.12	Temperature	(Less) Below 10 CFR 71 temperature design basis	Normal condition	No safety consequences			
1.13	Shielding	(Less) Displacement of TC shielding	Impact or fire	Direct exposure	1–TC remains in 10 CFR 71 configuration 2–Procedures and training 3–Combustible materials control	Includes reduction or complete loss of shielding	WHF-I305 WHF-I309 WHF-I310

NOTE: Guidewords not used in this node: As Well As and Part Of.
HVAC = heating, ventilation, and air conditioning; IHF = Initial Handling Facility; SPM = site prime mover; TC = transportation cask; WHF = Wet Handling Facility.
10 CFR 71 = see Ref. 2.3.3

Source: Original

Table E-3. HAZOP Analysis Worksheet

Facility/Operation: WHF							**Process**: TC Unloading
Node 2: Remove Impact Limiters from TC on Rail Car							**Process/Equipment**: Rail Car, Cask Handling Crane (Auxiliary Hook), Cask Access Platform
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							**Consequence Categories**: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
2.1	Load	(More) Load lifted too heavy for crane	Failure to remove restraining bolt on impact limiters	Drop of load leading to radioactive release	1–TC design 2–Procedures and training 3–Crane design and below-the-hook devices	20-ton hoist	WHF-401
2.2	Load	(Less) Load lifted too light		No safety consequences			
2.3	Speed (Crane)	(More) Hook lowers too fast	1–Human failure 2–Mechanical failure	Potential drop of load leading to radioactive release	1–TC design 2–Procedures and training 3–Crane design		WHF-401
2.4	Speed (Crane)	(Less) Hook lowers too slow		No safety consequences			
2.5	Travel (Crane)	(Other Than) Crane movement with hook lowered	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–TC design 2–Procedures and training 3–Crane design		WHF-403
2.6	Travel (Crane)	(More) Crane moves past desired position for activity	1–Human failure 2–Mechanical failure	No safety consequences			
2.7	Travel (Crane)	(Less) Crane does not move into desired position for activity	1–Human failure 2–Mechanical failure	No safety consequences			
2.8	Travel (Crane)	(Reverse) Travels in wrong direction	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–TC design 2–Procedures and training 3–Crane design		WHF-403
2.9	Motor	(More) Motor temperature too high	1–Human failure 2–Mechanical malfunction	No safety consequences		Potential fire scenario	
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)				PLC faults are considered in event sequence development (event tree/FTA/HRA)	
2.12	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment		1–Crane operator training program 2–Human factor evaluation 3–Industrial hygiene standards	Considered in HRA	
2.13	Alignment	(Other Than)	See 2.5 through 2.8 above				
2.14	Mobile Access Platform Operations	(Other Than) Impact from operational activities	1–Human failure 2–Mechanical failure	Potential impact leading to radioactive release	1–TC design 2–Procedures and training 3–Platform and tool design		WHF-401 WHF-402 WHF-403 WHF-509

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

Source: Original

Table E-4. HAZOP Analysis Worksheet

Facility/Operation: WHF							**Process**: TC Unloading
Node 3: Attach Lift Yoke to TC on Rail Car							**Process/Equipment**: Rail Car, 200-Ton Crane, Lift Yoke, Trunnions (as required)
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							**Consequence Categories**: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
3.1	Speed (Crane)	(More) Yoke lowers too fast	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–Procedures and training 2–Crane design	TC design may mitigate event, depending on passive equipment failure analysis	WHF-504
3.2	Speed (Crane)	(Less) Yoke lowers too slow		No safety consequences			
3.3	Travel (Crane)	(Other Than) Crane movement with yoke lowered	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–Procedures and training 2–Crane design	TC design may mitigate event, depending on passive equipment failure analysis	WHF-503
3.4	Motor	(More) Motor temperature too high	1–Human failure 2–Mechanical malfunction	No safety consequences		Potential fire scenario	
3.5	Maintenance	(No) Improper maintenance of crane	Human failure		Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	
3.6	Controls (PLC)	(Other Than)				PLC faults are considered in event sequence development (event tree/FTA/HRA)	
3.7	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment		1–Crane operator training program 2–Human factor evaluation 3–Industrial hygiene standards	Considered in HRA – Precursor to handling mishap	
3.8	Mobile Access Platform Operations	(Other Than) Impact from operational activities	1–Human failure 2–Mechanical failure	Potential impact leading to radioactive release	1–TC design 2–Procedures and training 3–Platform and tool design		WHF-401 WHF-402 WHF-403 WHF-509
3.9	Engagement (Yoke)	(More) Over-travel on yoke arm positioning	1–Human failure 2–Mechanical failure	Potential drop of TC leading to radioactive release	1–Positioning interlocks 2–Yoke adjustment motor design 3–Pin alignment 4–Procedures and training		WHF-501
3.10	Engagement (Yoke)	(Less) Under-travel on yoke arm positioning	1–Human failure 2–Mechanical failure	Potential drop of TC leading to radioactive release	1–Positioning interlocks 2–Yoke adjustment motor design 3–Pin alignment 4–Procedures and training	Potential partial yoke engagement	WHF-501
3.11	Engagement (Yoke)	(No) Fails to engage		No safety consequences			
3.12	Engagement (Yoke)	(Other Than) Wrong yoke used				Only one yoke used, except in WHF	
3.13	Yoke	(Other Than) Trunnion installed incorrectly	1–Human failure 2–Mechanical failure	Potential drop of TC leading to radioactive release	1–Procedures and training 2–Trunnion design	As required for certain casks	WHF-501

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

Source: Original

Table E-5. HAZOP Analysis Worksheet

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

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

Source: Original

Table E-6. HAZOP Analysis Worksheet

Facility/Operation: WHF				**Process**: TC Unloading			
Node 5: Transfer TC from Rail Car to CTT (Air Pallet)				**Process/Equipment**: Rail Car, 200-Ton Crane, CTT			
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of				**Consequence Categories**: Radioactive Release, Lack of Shielding, Criticality			
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
5.1	Lift	(More) Two-blocking	1–Human failure 2–Mechanical malfunction	Potential drop leading to radioactive release	1–Crane design 2–Procedures and training	1–TC may mitigate event, depending on passive equipment failure analysis 2–20 ft or greater drop considered	WHF-513
5.2	Lift	(Less) Not lifted high enough to clear other structures or equipment	1–Human failure 2–Mechanical malfunction	Potential drop or collision leading to radioactive release	Procedures and training		WHF-512
5.3	Lift	(No)		No safety consequences			
5.4	Lift	(Reverse) Rapid rundown	1–Human failure 2–Mechanical malfunction	Potential drop leading to radioactive release	1–Crane design 2–Procedures and training	TC may mitigate event, depending on passive equipment failure analysis	WHF-513
5.5	Speed (Crane)	(More) Crane moves faster than allowed by procedures	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–Crane design 2–Procedures and training	TC design may mitigate event, depending on passive equipment failure analysis	WHF-513
5.6	Speed (Crane)	(Less) Crane moves too slow	1–Human failure 2–Mechanical failure	Potential drop leading to radioactive release	Procedures and training	Prolonged exposure time for sequence initiation	WHF-513
5.7	Speed (Crane)	(Other Than) Abrupt stop	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–Crane design 2–Procedures and training	TC design may mitigate event, depending on passive equipment failure analysis	WHF-512
5.8	Alignment (Trolley)	(No) Improper alignment	Human failure			Check for self-aligning features or electronic-aligning features	
5.9	Miscellaneous					Check door design on CTT–hinged or need to fetch with crane	
5.10	Miscellaneous					Verify mechanisms for securing cask to CTT	

NOTE: Guidewords not used in this node: As Well As and Part Of.
CTT = cask transfer trolley; ft = feet; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Table E-7. HAZOP Analysis Worksheet

Facility/Operation: WHF							**Process**: TC Unloading
Node 6: Attach Slings to TC on Rail Car							**Process/Equipment**: Rail Car, 200-Ton Crane, Lift Slings
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							**Consequence Categories**: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
6.1	Speed (Crane)	(More) Slings lower too fast	1–Human failure 2–Mechanical failure	Potential drop leading to radioactive release	1–Procedures and training 2–Crane design	TC design may mitigate event, depending on passive equipment failure analysis	WHF-507
6.2	Speed (Crane)	(Less) Slings lower too slow		No safety consequences			
6.3	Travel (Crane)	(Other Than) Crane movement with slings lowered	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–Procedures and training 2–Crane design	TC design may mitigate event, depending on passive equipment failure analysis	WHF--508
6.4	Motor	(More) Motor temperature too high	1–Human failure 2–Mechanical malfunction	No safety consequences		Potential fire scenario	
6.5	Maintenance	(No) Improper maintenance of crane	Human failure		Maintenance program	Considered in event sequence development (event tree/FTA/HRA)–Potential cause for latent failure	
6.6	Controls (PLC)	(Other Than)				PLC faults are considered in event sequence development (event tree/FTA/HRA)	
6.7	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment		1–Crane operator training program 2–Human factor evaluation 3–Industrial hygiene standards	Considered in HRA–Precursor to handling mishap	
6.8	Mobile Access Platform Operations	(Other Than) Impact from operational activities	1–Human failure 2–Mechanical failure	Potential impact leading to radioactive release	1–TC design 2–Procedures and training 3–Platform and tool design		WHF-509
6.9	Engagement (Slings)	(More) Over-travel on sling arm positioning	1–Human failure 2–Mechanical failure	Potential drop of TC leading to radioactive release	1–Positioning interlocks 2–Sling adjustment motor design 3–Pin alignment 4–Procedures and training		WHF-506
6.10	Engagement (Slings)	(Less) Under-travel on sling arm positioning	1–Human failure 2–Mechanical failure	Potential drop of TC leading to radioactive release	1–Positioning interlocks 2–Sling adjustment motor design 3–Pin alignment 4–Procedures and training	Potential partial sling engagement	WHF-506
6.11	Engagement (Slings)	(No) Fails to engage		No safety consequences			
6.12	Engagement (Slings)	(Other Than) Wrong slings used				Only one sling used, except in WHF	
6.13	Slings	(Other Than) Trunnion installed incorrectly	1–Human failure 2–Mechanical failure	Potential drop of TC leading to radioactive release	1–Procedures and training 2–Trunnion design	As required for certain casks	WHF-506

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

Source: Original

Table E-8. HAZOP Analysis Worksheet

Facility/Operation: WHF							**Process**: TC Unloading
Node 7: Transfer Horizontal TC from Rail Car to Cask Stand for Removal of Impact Limiters							**Process/Equipment**: Rail Car, 200-Ton Crane, Cask Stand
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							**Consequence Categories**: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
7.1	Speed (Crane)	(More) Slings lower too fast	1–Human failure 2–Mechanical failure	Potential drop leading to radioactive release	1–Procedures and training 2–Crane design	TC design may mitigate event, depending on passive equipment failure analysis	WHF-702
7.2	Speed (Crane)	(Less) Slings lower too slow		No safety consequences			
7.3	Travel (Crane)	(Other Than) Crane movement with slings lowered	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–Procedures and training 2–Crane design	TC design may mitigate event, depending on passive equipment failure analysis	WHF-703
7.4	Motor	(More) Motor temperature too high	1–Human failure 2–Mechanical malfunction	No safety consequences		Potential fire scenario	
7.5	Maintenance	(No) Improper maintenance of crane	Human failure		Maintenance program	Considered in event sequence development (event tree/FTA/HRA) – Potential cause for latent failure	
7.6	Controls (PLC)	(Other Than)				PLC faults are considered in event sequence development (event tree/FTA/HRA)	
7.7	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment		1–Crane operator training program 2–Human factor evaluation 3–Industrial hygiene standards	Considered in HRA	
7.8	Lift	(More) Two-blocking	1–Human failure 2–Mechanical malfunction	Potential drop leading to radioactive release	1–Crane design 2–Procedures and training	1–TC may mitigate event, depending on passive equipment failure analysis 2–20 ft or greater drop considered	WHF-702
7.9	Lift	(Less) Not lifted high enough to clear other structures or equipment	1–Human failure 2–Mechanical malfunction	Potential drop or collision leading to radioactive release	Procedures and training		WHF-703
7.10	Lift	(No)		No safety consequences			
7.11	Lift	(Reverse) Rapid rundown	1–Human failure 2–Mechanical malfunction	Potential drop leading to radioactive release	1–Crane design 2–Procedures and training	TC may mitigate event, depending on passive equipment failure analysis	WHF-702
7.12	Speed (Crane)	(More) Crane moves faster than allowed by procedures	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–Crane design 2–Procedures and training	TC design may mitigate event, depending on passive equipment failure analysis	WHF-703
7.13	Speed (Crane)	(Less) Crane moves too slow	1–Human failure 2–Mechanical failure	Potential drop leading to radioactive release	Procedures and training	Prolonged exposure time for sequence initiation	WHF-702
7.14	Speed (Crane)	(Other Than) Abrupt stop	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–Crane design 2–Procedures and training	TC design may mitigate event, depending on passive equipment failure analysis	WHF-703

NOTE: Guidewords not used in this node: As Well As and Part Of.
ft = feet; FTA = fault-tree analysis; HRA = human-reliability analysis; PLC = programmable logic controller; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Table E-9. HAZOP Analysis Worksheet

Facility/Operation: WHF							**Process**: TC Unloading
Node 8: Upright Horizontal TC from Saddle onto Cask Tilting Frame							**Process/Equipment**: 200-Ton Crane, Cask Tilting Frame
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							**Consequence Categories**: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
8.1	Load	(More) Load lifted too heavy for crane	Failure to remove tie-downs	Drop of load leading to radioactive release	1–Procedures and training 2–Crane design	1–200-ton hoist 2–TC may mitigate event, depending on passive equipment failure analysis	WHF-801
8.2	Load	(Less) Load lifted too light		No safety consequences			
8.3	Speed (Crane and Hook)	(More or Less) Hook and crane speed not matched during lifting motion	1–Human failure 2–Mechanical failure	Potential drop leading to radioactive release	1–Procedures and training 2–Crane design and below-the-hook design	TC may mitigate event, depending on passive equipment failure analysis	WHF-801
8.4	Travel (Crane)	(Reverse) Travels in wrong direction	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–Procedures and training 2–Crane design and below-the-hook design	1–TC may mitigate event, depending on passive equipment failure analysis 2–Crane feature to prevent rapid rundown needs to be subjected to FTA	WHF-802
8.5	Motor	(More) Motor temperature too high	1–Human failure 2–Mechanical malfunction	No safety consequences		Potential precursor to fire scenario	
8.6	Motor Motive Force	(Less or No) Loss of motive force allows rapid rundown	1–Human failure 2–Mechanical malfunction	Potential drop leading to radioactive release		1–TC may mitigate event, depending on passive equipment failure analysis 2–Crane feature to prevent rapid rundown needs to be subjected to FTA	WHF-801
8.7	Maintenance	(No) Improper maintenance of crane	Human failure		Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	
8.8	Controls (PLC)	(Other Than)			Maintenance program	PLC faults are considered in event sequence development (event tree/FTA/HRA)	
8.9	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment		1–Crane operator training program 2–Human factor evaluation 3–Industrial hygiene standards	Considered in HRA – Precursor to handling mishap	
8.10	Alignment	(Other Than)	See 8.3 above				
8.11	Pivot Point	(Other Than)		Potential load slap-down leading to radioactive release	1–Transportation skid pedestal design 2–Procedures and training	Cask tilting frame set upright without anchored pivot point	WHF-803

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

Source: Original

Table E-10. HAZOP Analysis Worksheet

Facility/Operation: WHF				**Process**: Step-by-Step TC Receipt			
Node 9: Receive TC on Rail Car and Transfer to CTT				**Process/Equipment**: NONE			
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of				**Consequence Categories**: Radioactive Release, Lack of Shielding, Criticality			
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
9.1		(Other Than) Chooses wrong cask pedestal	Human failure	Cask tip-over leading to resulting in a release	1–Procedures and training 2–Pedestal design	1–Human factors 2–Scheduling by campaigns may minimize occurrence	WHF-510
9.2		(Other Than) 200-ton crane used instead of 20-ton entrance vestibule crane to remove impact limiters	Human failure	Drop of cask leading to resulting in a release	1–Procedures and training 2–Hook design		WHF-805
9.3		(No) Improper installation of pivot adapter, if required	Human failure	Potential drop	Procedures and training	Bolt installation	WHF-804
9.4		(No) Improper installation of lifting plate	Human failure	Potential drop	Procedures and training	Bolt installation	WHF-805
9.5		(No) Cask not secured to cask tilting frame prior to bringing upright	1–Human failure 2–Mechanical failure	Potential drop or impact	1–Procedures and training 2–L-frame design		WHF-804
9.6		(No) Failure to release cask from cask tilting frame after bringing upright	Human failure	Potential drop or impact	Procedures and training		WHF-805

NOTE: No guidewords are used in this node.
CTT = cask transfer trolley; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Table E-11. HAZOP Analysis Worksheet

Facility/Operation: WHF	**Process**: TC Preparation
Node 10: Preparation Operations for TC/DPC	**Process/Equipment**: Preparation Station, Common Tools, Cask Shield Ring, Standard Rigging, Cask Handling Crane, Jib Crane
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of	**Consequence Categories**: Radioactive Release, Lack of Shielding, Criticality

Node Item Number	Parameter	Deviation Considered	Postulated Cause	Consequence(s)	Potential Prevention/Mitigation Design of Operational Feature	Notes	MLD Index Number
10.1	Jib Crane Load	(More) Too much load for crane	1–Human failure 2–Equipment failure	Potential release of materials from cask canister annulus into environment	1–Procedures and training 2–TC design	1–Verify jib crane use and load design 2–TC may mitigate event, depending on passive equipment failure analysis	WHF-1003
10.2	Jib Crane Load	(Less) Too light		No safety consequences			
10.3	Jib Crane Travel					Verify jib crane design and operation	
10.4	Loosen/Remove Lid Bolts	(Other Than) Failure to remove	Human failure	No safety consequences		1–Sequence of bolt removal and installation of lift fixture may impact human failure probability associated with failure to remove bolts 2–Precursor to cask drop if remaining bolts are overloaded	
10.5	Loosen/Remove Bolts	(Reverse) Bolts tightened instead of loosened	1–Human failure 2–Equipment failure	No safety consequences		Potential precursor to cask drop if remaining bolts are overloaded	
10.6	Attach TC Lid Lift Fixture	(Other Than) Improper attachment	1–Human failure 2–Equipment failure	No safety consequences	1–Procedures and training 2–Potentially precluded by design	Potential precursor to cask lid drop	
10.7	Remove TC Lid	(More) Attempting to lift more than lid alone (see 10.4 and 10.5 above)	Human failure	Potential drop of cask leading to radioactive release	1–Procedures and training 2–Crane design features	Model crane overload protection features and failure modes	WHF-1004
10.8	Remove TC Lid	(More) Attempting to lift lid too high (i.e., two-blocking)	Human failure	Potential impact leading to radioactive release	1–Procedures and training 2–Crane design features	Potential impact caused by lid dropping onto canister	WHF-1003 WHF-1006
10.9	Remove TC Lid	(Less) Not lifting lid high enough to clear cask	Human failure	Potential drop of cask leading to radioactive release	Procedures and training	Catching lid on cask causing cask to tip over or drop	WHF-1005
10.10	Remove TC Lid	(Other Than) Lift with fixture improperly attached (see 10.6 above)	Human failure	Potential impact leading to radioactive release	Procedures and training	Potential impact caused by lid dropping onto canister	WHF-1003
10.11	Install Shield Ring	(More) Lifts too high	1–Human failure 2–Equipment failure	Potential impact leading to radioactive release	Procedures and training	1–Shield ring installation includes attaching ring to jib crane and moving it to cask stand 2–Impact caused by dropping ring onto canister	WHF-1003
10.12	Install Shield Ring	(Less) Does not lift high enough to clear cask	Human failure	Potential impact leading to radioactive release	Procedures and training	Impact to side of cask, leading to potential of dropping cask and canister which then leads to radioactive release	WHF-1005 WHF-1006
10.13	Install Shield Ring	(No) No installation	Human failure	Direct exposure	Procedures and training		WHF-1007
10.14	Install Shield Ring	(Other Than) Improperly installed	Human failure	Direct exposure	Procedures and training	Improper installation includes lopsided installation or misalignment	WHF-1007
10.15	Install Canister Lift Fixture	(More) Lift too high	1–Human failure 2–Equipment failure	Potential impact leading to radioactive release	Procedures and training	1–Potential impact caused by dropping fixture onto canister 2–Lifted by jib crane	WHF-1003
10.16	Install Canister Lift Fixture	(Less) Lift not high enough to clear cask	Human failure	Potential impact leading to radioactive release	Procedures and training	Impact to side of cask, leading to potential cask and canister drop which then leads to radioactive release	WHF-1006
10.17	Install Canister Lift Fixture	(Other Than) Improperly installed for movement to installation position	Human failure	Potential impact leading to radioactive release	Procedures and training	Potential impact caused by dropping fixture onto canister	WHF-1003

Table E-11. HAZOP Analysis Worksheet (Continued)

Facility/Operation: WHF				**Process**: TC Preparation			
Node 10: Preparation Operations for TC/DPC				**Process/Equipment**: Preparation Station, Common Tools, Cask Shield Ring, Standard Rigging, Cask Handling Crane, Jib Crane			
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of				**Consequence Categories**: Radioactive Release, Lack of Shielding, Criticality			
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
10.18	Install Canister Lift Fixture	(Other Than) Improperly installed	Human failure	No safety consequences	Procedures and training	Precursor to dropping canister during lift	
10.19	Remove and Store Shield Ring	(More) Lift too high	1–Human failure 2–Equipment failure	Potential drop leading to radioactive release	Procedures and training	Dropping ring onto canister leading to radioactive release	WHF-1003
10.20	Remove and Store Shield Ring	(Less) Lift not high enough to clear cask	Human failure	Potential impact leading to radioactive release	Procedures and training	Impact to side of cask leading to potential cask and canister drop which then leads to radioactive release	WHF-1006
10.21	Remove and Store Shield Ring	(No) No removal	Human failure	No safety consequences	Procedures and training	Precursor to drop of or impact to canister during CTM lift	

NOTE: Guidewords not used in this node: As Well As and Part Of.
CTM = canister transfer machine; DPC = dual-purpose canister; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Table E-12. HAZOP Analysis Worksheet

Facility/Operation: WHF							**Process**: TC/DPC Preparation
Node 11: Move to CTM Unloading Cell/Bay/Room							**Process/Equipment**: CTT
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							**Consequence Categories**: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
11.1	CTT Lift	(More) Too much lift	No cause identified			Unable to lift more than 5/16-inch over longest dimension	
11.2	CTT Lift	(Less) Not enough lift	1–Lack of air pressure 2–Cone malfunction	No safety consequences			
11.3	CTT Lift	(Other Than) Uneven lift	Cone malfunction	No safety consequences		Unable to lift more than 5/16-inch over longest dimension	
11.4	CTT Lift	(Other Than) Drops	Loss of air	No safety consequences			
11.5	CTT Movement	(More) Moves too far	1–Human failure 2–Mechanical malfunction	Potential collision leading to radioactive release	1–Procedures and training 2–CTT design 3–TC design	Shield door open, collision with facility structure	WHF-1106
11.6	CTT Movement	(More) Moves too far	1–Human failure 2–Mechanical malfunction	Potential collision leading to radioactive release	1–Procedures and training 2–CTT design 3–TC design	Shield door closed, collision with shield door	WHF-1106
11.7	CTT Movement	(Less) Does not move enough	1–Human failure 2–Mechanical malfunction	No safety consequences			
11.8	CTT Movement	(Reverse) Moves in opposite direction	1–Human failure 2–Mechanical malfunction	Potential collision leading to radioactive release	1–Procedures and training 2–CTT design 3–TC design		WHF-1106
11.9	CTT Movement	(Other Than) Sideways movement	1–Human failure 2–Mechanical malfunction	Potential collision leading to radioactive release	1–Procedures and training 2–CTT design 3–TC design		WHF-1106
11.10	Shield Door Movement	(Other Than) Spurious closure of shield door	1–Human failure 2–Mechanical malfunction	Potential collision leading to radioactive release	1–Procedures and training 2–Design of shield-door controls 3–TC design		WHF-1101
11.11	Preparation Platform Position	(Other Than) Out of position leading to platform collision with CTT frame	1–Human failure 2–Mechanical malfunction	Potential collision leading to radioactive release	1–Procedures and training 2–CTT design 3–TC design		WHF-1102

NOTE: Guidewords not used in this node: No, As Well As, and Part Of.
CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Table E-13. HAZOP Analysis Worksheet

Facility/Operation: WHF				**Process**: CTM Operation			
Node 12: Remove Canister from Cask using CTM (Vertical Movement)				**Process/Equipment**: CTM, CTM Bay/Cell			
Guide Words: 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	Shield Door Movement	(Other Than) Failure to close shield door	1–Human failure 2–Mechanical malfunction	Direct exposure	1–Procedures and training 2–Design of shield-door controls	Must be concurrent with removal of canister	WHF-1104
12.2	Shield Door Movement	(Other Than) Spurious opening of shield door	1–Human failure 2–Mechanical malfunction	Direct exposure	1–Procedures and training 2–Design of shield-door controls	Must be concurrent with removal of canister	WHF-1104
12.3	Shield Door Movement	(Other Than) Failure to evacuate personnel prior to door closure	1–Human failure 2–Mechanical malfunction	Direct exposure	1–Procedures and training 2–Design of shield-door controls	Must be concurrent with removal of canister	WHF-1104
12.4	Port Slide Gate	(Other Than) Failure to open slide gate	1–Human failure 2–Mechanical malfunction	No safety consequences	1–Procedures and training 2–Design of slide-gate controls		
12.5	Port Slide Gate	(Other Than) Failure to close port slide gate	1–Human failure 2–Mechanical malfunction	Direct exposure	1–Procedures and training 2–Design of slide-gate controls	Potential direct exposure to personnel on second floor when CTM moves	WHF-1104
12.6	Port Slide Gate	(Other Than) Opening of port slide gate	1–Human failure 2–Mechanical malfunction	Direct exposure	1–Procedures and training 2–Design of slide-gate controls	Potential direct exposure to personnel on second floor when CTM moves	WHF-1104
12.7	Port Slide Gate	(Other Than) Closure while lifting canister	1–Human failure 2–Mechanical malfunction	Potential drop or impact leading to radioactive release	1–Procedures and training 2–Design of slide-gate controls	1–Examine closures on rope as well as canister 2–Closure of slide gate while canister is lifted up could lead to canister impact or hoist cable shearing which leads to canister drop	WHF-1205
12.8	CTM Slide Gate	(Other Than) Failure to open slide gate	1–Human failure 2–Mechanical malfunction	No safety consequences	1–Procedures and training 2–Design of slide-gate controls		
12.9	CTM Slide Gate	(Other Than) Failure to close slide gate	1–Human failure 2–Mechanical malfunction	Direct exposure	1–Procedures and training 2–Design of slide-gate controls	Potential direct exposure to personnel on second floor when skirt lifts	WHF-1104
12.10	CTM Slide Gate	(Other Than) Opening of CTM slide gate	1–Human failure 2–Mechanical malfunction	Direct exposure	1–Procedures and training 2–Design of slide-gate controls	Potential direct exposure to personnel on second floor when skirt lifts	WHF-1104
12.11	CTM Slide Gate	(Other Than) Closure while lifting canister	1–Human failure 2–Mechanical malfunction	Potential drop or impact leading to radioactive release	1–Procedures and training 2–Design of slide-gate controls	1–Examine closures on rope as well as canister 2–Closure of slide gate while canister is lifted up could lead to canister impact or hoist cable shearing which leads to canister drop	WHF-1204
12.12	Canister Grapple Engagement	(Other Than) Improper attachment	1–Human failure 2–Equipment failure	No safety consequences	1–Procedures and training 2–Potentially precluded by design	Potential precursor to canister drop	
12.13	Lift Canister	(More) Attempting to lift more than canister	Human failure	Potential drop leading to radioactive release	1–Procedures and training 2–CTM design features	FTA model of CTM would cover overload protection features and failure modes	WHF-1206
12.14	Lift Canister	(More) Attempting to lift canister too high (i.e., two-blocking)	Human failure	1–Potential drop of canister leading to radioactive release 2–Direct exposure if lifted above top of shield bell	1–Procedures and training 2–CTM design features		WHF-1206

Table E-13. HAZOP Analysis Worksheet (Continued)

Facility/Operation: WHF				**Process**: CTM Operation			
Node 12: Remove Canister from Cask using CTM (Vertical Movement)				**Process/Equipment**: CTM, CTM Bay/Cell			
Guide Words: 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**
12.15	Lift Canister	(Less) Not lifting canister high enough to clear floor	Human failure	Potential drop or impact leading to radioactive release	Procedures and training	Potential shear of canister or cable when CTM moved, leading to radioactive release	WHF-1206
12.16	Lift Canister	(Other Than) Movement of carrier during lift of canister	Human failure	Potential drop or impact leading to radioactive release	1–Procedures and training 2–CTT and ST design features	Potential shear of canister or cable if carrier moves during lift, leading to radioactive release	WHF-1206
12.17	Lift Canister	(Other Than) Miscellaneous mechanical failures	Mechanical malfunction	Potential drop leading to radioactive release	CTM design features	Maintenance program	WHF-1207
12.18	Lift Canister	(Other Than) Lift with grapple improperly attached (see 12.12 above)	1–Human failure 2–Mechanical malfunction	Potential drop leading to radioactive release	Procedures and training		WHF-1206 WHF-1207

NOTE: Guidewords not used in this node: No, Reverse, As Well As, and Part Of.
CTM = canister transfer machine; CTT = cask transfer trolley; FTA = fault-tree analysis; ST = site transporter; WHF = Wet Handling Facility.

Source: Original

Table E-14. HAZOP Analysis Worksheet

Facility/Operation: WHF							**Process**: CTM Operation
Node 13: Move CTM Laterally							**Process/Equipment**: CTM
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of							**Consequence Categories**: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
13.1	Speed (CTM)	(More) CTM moves faster than allowed by procedures	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–CTM design 2–Procedures and training	Collision with structures	WHF-1106
13.2	Speed (CTM)	(No) CTM stuck in middle of room during move	1–Human failure 2–Mechanical failure	Potential heat-up, etc., leading to radioactive release		Verify cooling requirements	WHF-1106
13.3	Speed (CTM)	(Less) CTM moves too slow	1–Human failure 2–Mechanical failure	No safety consequences			
13.4	Speed (CTM)	(Other Than) Abrupt stop	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–CTM design 2–Procedures and training	Potential radioactive release resulting from collision between canister and CTM	WHF-1106
13.5	Direction (CTM)	(More) CTM moves too far	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–CTM design 2–Procedures and training	Collision with structures	WHF-1106
13.6	Direction (CTM)	(Less) CTM does not move enough	1–Human failure 2–Mechanical failure	No safety consequences			
13.7	Direction (CTM)	(Reverse) Moves in wrong direction	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–CTM design 2–Procedures and training	Collision with structures	WHF-1106
13.8	Miscellaneous (CTM)	(Other Than) Moves over lid not properly stored	Human failure	Potential collision leading to radioactive release	1–Facility design 2–Procedures and training	Collision with structures	WHF-1106

NOTE: Guidewords not used in this node: As Well As and Part Of.
CTM = canister transfer machine; WHF = Wet Handling Facility.

Source: Original

Table E-15. HAZOP Analysis Worksheet

Facility/Operation: WHF				**Process**: CTM Operation			
Node 14: Lower Canister from CTM to Receptacle				**Process/Equipment**: CTM, STC, AO			
Guide Words: 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	Shield Door Movement	(Other Than) Failure to close shield door	1–Human failure 2–Mechanical malfunction	Direct exposure	1–Procedures and training 2–Design of shield-door controls	Must be concurrent with lowering of canister	WHF-1104
14.2	Shield Door Movement	(Other Than) Spurious opening of shield door	1–Human failure 2–Mechanical malfunction	Direct exposure	1–Procedures and training 2–Design of shield-door controls	Must be concurrent with lowering of canister	WHF-1104
14.3	Shield Door Movement	(Other Than) Failure to evacuate personnel prior to door closure	1–Human failure 2–Mechanical malfunction	Direct exposure	1–Procedures and training 2–Design of shield-door controls	Must be concurrent with lowering of canister	WHF-1104
14.4	Port Slide Gate	(Other Than) Failure to open port slide gate	1–Human failure 2–Mechanical malfunction	No safety consequences	1–Procedures and training 2–Design of slide-gate controls	Verify with passive equipment failure analysis	
14.5	Port Slide Gate	(Other Than) Failure to close port slide gate	1–Human failure 2–Mechanical malfunction	Direct exposure	1–Procedures and training 2–Design of slide-gate controls	Potential direct exposure to personnel on second floor when CTM moves	WHF-1104
14.6	Port Slide Gate	(Other Than) Inadvertent opening of port slide gate	1–Human failure 2–Mechanical malfunction	Direct exposure	1–Procedures and training 2–Design of slide-gate controls	Potential direct exposure to personnel on second floor when CTM moves	WHF-1104
14.7	Port Slide Gate	(Other Than) Closure while lowering canister	1–Human failure 2–Mechanical malfunction	Potential drop of canister or impact leading to radioactive release	1–Procedures and training 2–Design of slide-gate controls	1–Examine closures on rope as well as canister 2–Slide gate closure while canister is lifted up could lead to canister impact or hoist cable shearing and result in canister drop	WHF-1205
14.8	CTM Slide Gate	(Other Than) Failure to open slide gate	1–Human failure 2–Mechanical malfunction	No safety consequences	1–Procedures and training 2–Design of slide-gate controls		
14.9	CTM Slide Gate	(Other Than) Failure to close slide gate	1–Human failure 2–Mechanical malfunction	No safety consequences			
14.10	CTM Slide Gate	(Other Than) Opening of CTM slide gate	1–Human failure 2–Mechanical malfunction	Direct exposure	1–Procedures and training 2–Design of slide-gate controls	Potential direct exposure to personnel on second floor when skirt lifts	WHF-1104
14.11	CTM Slide Gate	(Other Than) Closure while lowering canister	1–Human failure 2–Mechanical malfunction	Potential drop or impact leading to radioactive release	1–Procedures and training 2–Design of slide-gate controls	1–Examine closures on rope as well as canister 2–Closure of slide gate while canister is lifted up could lead to canister impact or hoist cable shearing which leads to canister drop	WHF-1204
14.12	Lowering of Canister	(Less) Does not lower canister enough to clear bottom of second floor	Human failure	Potential drop or impact leading to radioactive release	Procedures and training	Potential shear of canister or cable when CTM or receiver moved, leading to radioactive release	WHF-1206
14.13	Lowering of Canister	(Other Than) Movement of carrier (CTT, ST) during lowering of canister	Human failure	Potential drop or impact leading to radioactive release	1–Procedures and training 2–CTT design features	Potential shear of canister or cable when CTM or receiver moved, leading to radioactive release	WHF-1206
14.14	Lowering of Canister	(Other Than) Miscellaneous mechanical failures	Mechanical malfunction	Potential drop leading to radioactive release	CTM design features	Maintenance program	WHF-1207
14.15	Lowering of Canister	(Other Than) Lowers canister without a receptacle below	1–Human failure 2–Mechanical malfunction	Direct exposure	Procedures and training	Potential worker direct exposure if working inside CTM bay or when shield door opens	WHF-1104
14.16	Lowering of Canister	(Other Than) Misalignment of CTM and port	1–Human failure 2–Mechanical malfunction	Potential impact or drop leading to radioactive release	Procedures and training	Potential of catching ledge and dropping into hole	WHF-1206

NOTE: Guidewords not used in this node: No, More, Reverse, As Well As, and Part Of.
AO = aging overpack; CTM = canister transfer machine; CTT = cask transfer trolley; ST = site transporter; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

Table E-16. HAZOP Analysis Worksheet

Facility/Operation: WHF					**Process**: ST Operations		
Node 15: Move Loaded Receptacle/Carrier on ST into or out of WHF					**Process/Equipment**: ST, AO, STC		
Guide Words: 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**
15.1	ST Movement	(More) Moves too far	1–Human failure 2–Mechanical malfunction	Potential collision leading to radioactive release	1–Procedures and training 2–ST design 3–Receptacle/carrier design	Receptacle/carrier may mitigate event, depending on passive equipment failure analysis	WHF-108
15.2	ST Movement	(Less) Does not move enough	1–Human failure 2–Mechanical malfunction	No safety consequences			
15.3	ST Movement	(Less) ST loses track or has other breakdown	1–Human failure 2–Mechanical malfunction	Potential collision leading to radioactive release	1–Procedures and training 2–ST design 3–Receptacle/carrier design		WHF-108
15.4	ST Movement	(Reverse) Moves in opposite direction	1–Human failure 2–Mechanical malfunction	Potential collision leading to radioactive release	1–Procedures and training 2–ST design 3–Receptacle/carrier design		WHF-108
15.5	ST Movement	(Other Than) Steers off designated path	1–Human failure 2–Mechanical malfunction	Potential collision leading to radioactive release	1–Procedures and training 2–ST design 3–Receptacle/carrier design		WHF-108
15.6	ST	(Other Than) Fire	1–Human failure 2–Mechanical malfunction	Potential heat-up, etc., leading to release of radioactivity	1–Procedures and training 2–ST design	For PCSA fire analysis	WHF-I309
15.7	Lift	(More) ST lifts load higher than 1 ft	1–Human failure 2–Mechanical failure	Potential drop leading to radioactive release	1–ST design limits lift height to 1 ft 2–Procedures and training	Procurement requirement	WHF-107
15.8	Lift	(Less) ST does not lift to required transport height	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–ST design 2–Procedures and training		WHF-107
15.9	Lift	(No) ST does not lift load	1–Human failure 2–Mechanical failure	No safety consequences		1–No loss of shielding or radioactive release 2–Expected damage to bottom plate only	

NOTE: Guidewords not used in this node: No, As Well As, and Part Of.
AO = aging overpack; ft = foot; PCSA = preclosure safety analysis; ST = site transporter; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

Table E-17. HAZOP Analysis Worksheet

Facility/Operation: WHF					**Process**: DPC Cutting		
Node 16: Remove STC Lid					**Process/Equipment**: STC, Jib Crane, Common Tools, DPC		
Guide Words: No, More, Less, Reverse, Other Than, As Well As, Part Of					**Consequence Categories**: Radioactive Release, Lack of Shielding, Criticality		
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
16.1	Loosen/Remove Bolts	(Other Than) Failure to remove	Human failure	No safety consequences		1–Verify how and where bolts are removed 2–Potential precursor to overloading jib crane	
16.2	Loosen/Remove Bolts	(Reverse) Tighten bolts instead of loosen	1–Human failure 2–Equipment failure	No safety consequences		Potential precursor to overloading jib crane	
16.3	Jib Crane Load	(More) Too much load for crane	1–Human failure 2–Equipment failure	Potential drop leading to radioactive release	1–Procedures and training 2–STC design	1–Verify jib crane use and design 2–STC may mitigate event, depending on passive equipment failure analysis	WHF-1103
16.4	Jib Crane Load	(Less) Too light		No safety consequences			
16.5	Attach STC Lid Lift Fixture	(Other Than) Improper attachment	1–Human failure 2–Equipment failure	No safety consequences	1–Procedures and training 2–Potentially precluded by design	1–Check STC lid design 2–Precursor to dropping STC lid back onto canister	
16.6	Lid Grapple Engagement	(Other Than) Improper attachment	1–Human failure 2–Equipment failure	No safety consequences	1–Procedures and training 2–Potentially precluded by design	Potential precursor to dropping STC lid	
16.7	Remove STC Lid	(More) Attempting to lift more than lid alone (see 16.1 and 16.2 above)	Human failure	Potential drop leading to radioactive release	1–Procedures and training 2–Crane design features	1–Jib crane collapses onto STC 2–Check passive equipment failure analysis	WHF-1003
16.8	Remove STC Lid	(More) Attempting to lift lid too high (i.e., two-blocking)	Human failure	Potential release of radioactive materials	1–Procedures and training 2–Crane design features	1–STC lid drops onto STC 2–Check passive equipment failure analysis	WHF-1003
16.9	Remove STC Lid	(Other Than) Lift with grapple improperly attached (see 16.6 above)	Human failure	Potential impact leading to radioactive release	Procedures and training	STC lid drops onto canister	WHF-1003

NOTE: Guidewords not used in this node: No, As Well As, and Part Of.
DPC = dual-purpose canister; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

Table E-18. HAZOP Analysis Worksheet

Facility/Operation: WHF				**Process**: TC Unloading			
Node 17: Sample DPC				**Process/Equipment**: Common Tools, Cutting Tools, Sampling Line, Sample Detectors, Temperature Monitor, DPC			
Guide Words: 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**
17.1	Install Shield Ring	(More) Lifts too high	1–Human failure 2–Equipment failure	Potential drop leading to radioactive release	Procedures and training	1–Dropping ring onto canister 2–Shield ring installation includes attaching ring to jib crane and moving it to DPC cutting station	WHF-1608
17.2	Install Shield Ring	(Less) Does not lift high enough to clear STC	Human failure	No safety consequences	Procedures and training	Impact to side of STC	
17.3	Install Shield Ring	(No) No installation	Human failure	Direct exposure	Procedures and training		WHF-1608
17.4	Install Shield Ring	(Other Than) Improperly installed	Human failure	Direct exposure	Procedures and training	Improper installation includes lopsided installation or misalignment	WHF-1608
17.5	Remove Cover to Access Port	(More) Cuts too much and damages quick connect valve	Human failure	Direct exposure	Procedures and training	Cutting too deep or dropping cover back into access port	WHF-1608
17.6	Sample Line Hookup	(Other Than) Improper hookup	Human failure	Potential loss of confinement boundary leading to radioactive release	1–Procedures and training 2–Connection design	Verify connection design	WHF-1610
17.7	Sample Line Hookup	(Other Than) Line breaks	1–Human failure 2–Equipment failure	Potential loss of confinement boundary leading to radioactive release	1–Procedures and training 2–Sample system design		WHF-1610
17.8	Taking Sample (Radioactivity)	(Other Than) Incorrect or inadequate sample or false negative	1–Human failure 2–Equipment failure	No safety consequences	1–Procedures and training 2–Sample system design	Faulty sampling could lead to undesired or untimely break of confinement–Precursor to radioactive release	
17.9	Taking Sample (Temperature)	(Other Than) Incorrect temperature reading	1–Human failure 2–Equipment failure	No safety consequences	1–Procedures and training 2–Sample system design	Precursor to potential steam explosion and fuel cladding damage when adding water during cooling phase	

NOTE: Guidewords not used in this node: Reverse, As Well As, and Part Of.
DPC = dual-purpose canister; STC = shielded transfer cask; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Table E-19. HAZOP Analysis Worksheet

Facility/Operation: WHF							**Process**: DPC Cutting
Node 18: Cooling							**Process/Equipment**: Helium Line, Pool Water Line (Borated), Valve and Connections, Temperature Gauge, DPC
Guide Words: 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**
18.1						Helium and water lines cannot be cross-connected	
18.2	Helium Cooling Pressure	(More) Too much pressure	1–Failure of regulator 2–Helium bottle not isolated	Potential loss of confinement boundary leading to radioactive release	Relief valve	Helium line breaks from overpressurization	WHF-1612
18.3	Helium Cooling Pressure	(Other Than) Failure to have positive seal on connections	1–Human failure 2–Mechanical failure	Potential loss of confinement boundary leading to radioactive release	Procedures and training		WHF-1612
18.4	Helium Cooling Temperature	(Less) Insufficient cooling	1–Human failure 2–Mechanical failure	No safety consequences		1–Open bypass path, temperature gauge failure, or miscalibration leads operator to believe temperature is okay–Precursor to steam explosion 2–Verify temperature reading location	
18.5	Helium Cooling Temperature	(Less) Insufficient cooling	Mechanical failure of helium cooling system or pump	No safety consequences		Precursor to steam explosion if operator misreads temperature gauge	
18.6	Water Cooling	(Other Than) Waste form temperature too high (see 18.4 and 18.5 above)	Human failure	Potential loss of confinement boundary leading to radioactive release	1–Procedures and training 2–Temperature gauge	Steam explosion causes loss of confinement	WHF-1613
18.7	Water Cooling Flow	(No) Flow does not start	1–Human failure 2–Mechanical failure	No safety consequences		1–If waste form reheats and water flow starts – Precursor to steam explosion 2–Temperature gauge may not show proper reading due to system configuration	
18.8	Water Cooling Flow	(Less or No) Low or no flow given flow was started	1–Human failure 2–Mechanical failure	No safety consequences		Verify natural circulation will prevent flash steam explosion	
18.9	Water Cooling	(Less) Premature cooling termination	1–Human failure 2–Mechanical failure of temperature gauge	No safety consequences		Precursor to release during lid cutting	
18.10	Water Line	(Other Than) Water line breaks	Mechanical failure	Direct exposure	1–System design 2–PPE for operators		WHF-1614

NOTE: Guidewords not used in this node: Reverse, As Well As, and Part Of.
DPC = dual-purpose canister; PPE = personal protective equipment; WHF = Wet Handling Facility.

Source: Original

Table E-20. HAZOP Analysis Worksheet

Facility/Operation: WHF				**Process**: DPC Cutting			
Node 19: Cut DPC				**Process/Equipment**: DPC, Cutting Machine, Jib Crane, Water Line			
Guide Words: 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**
19.1	Lower Water Level	(Less or No) Not enough water removed	1–Human failure 2–Mechanical failure	1–Potential loss of confinement leading to radioactive release 2–Direct exposure due to water line blown off	Procedures and training	1–Loss of confinement could be caused by canister cracking due to thermal effect 2–Thermal expansion during cutting process will spew contaminated water – Precursor to direct exposure 3–Verify if indicator is associated with amount of water extracted 4–Verify if pressure relief mode exists 5–Verify magnitude of temperature increase	WHF-1701
19.2	Lower Water Level	(More) All or too much water removed	1–Human failure 2–Mechanical failure	No safety consequences	Procedures and training	1 –If uncover fuel, potential oxygen infiltration 2–Verify if indicator is associated with amount of water extracted	
19.3	Jib Crane Load	(More) Too much load for crane	1–Human failure 2–Equipment failure	Potential drop leading to radioactive release	1–Procedures and training 2–Canister design	1–Verify jib crane use and design 2–Verify passive equipment failure analysis for canister	WHF-1702
19.4	Jib Crane Load	(Less) Too light		No safety consequences			
19.5	Attach Cutting Machine to Jib Crane	(Other Than) Improper attachment	1–Human failure 2–Equipment failure	Potential drop leading to radioactive release	1–Procedures and training 2–Canister design	1–Verify jib crane use and design 2–Verify passive equipment failure analysis for canister	WHF-1702
19.6	Attach Cutting Machine to Canister Lid	(Other Than) Improper attachment	1–Human failure 2–Mechanical failure	No safety consequences		Verify cutting machine/cooling line interference – Precursor to cut in an undesired location	
19.7	Cutting	(Other Than) (see 19.1 and 19.2 above and 18.6 through 18.9 in previous node)		1–Direct exposure 2–Potential loss of confinement leading to radioactive release	See 18.6 through 18.9, 19.1 and 19.2		WHF-1701 WHF-1702 WHF-1613
19.8	Cutting	(More) Cuts too deep	1–Human failure (wrong bit or wrong bit setting) 2–Mechanical failure	No safety consequences	1–Procedures and training 2–Bit length		
19.9	Cutting	(Less) Cuts too shallow or not all the way around	1–Human failure 2–Mechanical failure	No safety consequences	Procedures and training		
19.10	Cutting	(Other Than) Breaking or sticking bit	Mechanical failure	No consequence of concern			
19.11	Cutting	(More or Less) Too much or too little lubricating fluid during cutting	Mechanical failure	No safety consequences		Bit may fail with too little lubrication	
19.12	Bolt Removal	(Other Than) Bolts not fully removed	Human failure	No safety consequences	Procedures and training	Precursor to premature lid removal	
19.13	Remove Cutting Machine	(More) Attempting to lift more than cutting machine alone (see 19.12 above)	Human failure	Direct exposure	Procedures and training	Lid comes off with cutting machine	WHF-1702
19.14	Remove Cutting Machine	(More) Attempting to lift more than cutting machine alone (see 19.12 above)	Human failure	Potential drop leading to radioactive release	Procedures and training	Lid comes off with cutting machine but then drops	WHF-1702
19.15	Remove Cutting Machine	(More) Attempting to lift cutting machine too high (i.e., two-blocking)	Human failure	Potential drop leading to radioactive release	1–Procedures and training 2–Crane design features	1–Cutting machine drops back onto canister 2–Verify with passive equipment failure analysis	WHF-1702

Table E-20. HAZOP Analysis Worksheet (Continued)

Facility/Operation: WHF							**Process**: DPC Cutting
Node 19: Cut DPC							**Process/Equipment**: DPC, Cutting Machine, Jib Crane, Water Line
Guide Words: 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**
19.16	Remove Cutting Machine	(Other Than) Lift with rigging improperly attached or failure of rigging	1–Human failure 2–Mechanical failure	Potential drop leading to radioactive release	Procedures and training	1–Cutting machine drops back onto canister 2–Verify with passive equipment failure analysis	WHF-1702
19.17	Attach DPC Lid Lift Fixture	(Other Than) Improper attachment	1–Human failure 2–Equipment failure	No safety consequences	Procedures and training	Precursor to dropping lid back onto canister	
19.18	Shield Ring Removal	(No) Not removed	Human failure	No safety consequences	Procedures and training	Verify STC lid will not fit on STC if shield ring not removed	
19.19	Shield Ring Removal	(Other Than) Drops onto DPC canister during removal	1–Human failure 2–Mechanical malfunction	Potential drop leading to radioactive release	1–Procedures and training 2–Crane design	Improper attachment of rigging	WHF-1702
19.20	Shield Ring Removal	(Other Than) Shield ring binds with STC during shield removal	1–Human failure 2–Mechanical malfunction	Potential impact or drop leading to radioactive release	1–Procedures and training 2–Crane design	1–Crane breaks and falls on lid 2–Verify with passive equipment failure analysis	WHF-1702
19.21	Shield Ring Removal	(Less) Shield ring fails to clear STC	1–Human failure 2–Mechanical malfunction	No safety consequences	1–Procedures and training 2–Crane design	Jib crane cannot tip over STC	
19.22	STC Lid Grapple Engagement	(Other Than) Improper attachment	1–Human failure 2–Equipment failure	No safety consequences	Procedures and training	Potential precursor to STC lid drop	
19.23	Install Lid	(More) Attempting to lift lid too high (i.e., two-blocking)	Human failure	Potential impact or drop leading to radioactive release	1–Procedures and training 2–Crane design features	Dropping lid onto canister	WHF-1702
19.24	Install Lid	(Other Than) Lift with grapple improperly attached (see 19.22 above)	Human failure	Potential impact or drop leading to radioactive release	Procedures and training	Dropping cask lid onto canister	WHF-1702
19.25	Bolt Installation	(Less or No) No bolts installed	Human failure	No safety consequences	Procedures and training	1–Potential precursor to release from loss of lid 2–Fuel ejection if dropped	

NOTE: Guidewords not used in this node: Reverse, As Well As, and Part Of.
DPC = dual-purpose canister; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

Table E-21. HAZOP Analysis Worksheet

Facility/Operation: WHF	**Process**: DPC Transfer to Pool
Node 20: Transfer STC to Pool	**Process/Equipment**: Crane, Yoke, STC, Pool
Guide Words: 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
20.1	Attach Yoke to Crane	(Other Than) Improper attachment of yoke to crane	Human failure	No safety consequences	Procedures and training	Precursor to drop of STC or on STC	
20.2	Movement (Yoke/Crane)	(Other Than) Drop yoke (see 20.1 above)		Potential drop leading to radioactive release	See 20.1 above		WHF-711
20.3	Speed (Crane)	(More) Yoke lowers too fast and too far	1–Human failure 2–Mechanical failure	Potential drop leading to radioactive release	1–Procedures and training 2–Crane design	STC design may mitigate event, depending on passive equipment failure analysis	WHF-709
20.4	Speed (Crane)	(Less) Yoke lowers too slow		No safety consequences			
20.5	Travel (Crane)	(Other Than) Crane movement with yoke lowered	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–Procedures and training 2–Crane design	STC design may mitigate event, depending on passive equipment failure analysis	WHF-710
20.6	Motor	(More) Motor temperature too high	1–Human failure 2–Mechanical malfunction	No safety consequences		Potential fire scenario	
20.7	Maintenance	(No) Improper maintenance of crane	Human failure		Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	
20.8	Controls (PLC)	(Other Than)				PLC faults are considered in event sequence development (event tree/FTA/HRA)	
20.9	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment		1–Crane operator training program 2–Human factor evaluation 3–Industrial hygiene standards	Considered in HRA - Precursor to handling mishaps	
20.10	Engagement (Yoke)	(More) Over-travel on yoke arm positioning	1–Human failure 2–Mechanical failure	Potential drop leading to radioactive release	1–Positioning interlocks 2–Yoke adjustment motor design 3–Pin alignment 4–Procedures and training		WHF-711
20.11	Engagement (Yoke)	(Less) Under-travel on yoke arm positioning	1–Human failure 2–Mechanical failure	Potential drop leading to radioactive release	1–Positioning interlocks 2–Yoke adjustment motor design 3–Pin alignment 4–Procedures and training	Potential partial yoke engagement	WHF-711
20.12	Engagement (Yoke)	(No) Fails to engage		No safety consequences			
20.13	Travel	(More) Crane moves past desired position on pool edge for activity	1–Human failure 2–Mechanical failure	No safety consequences	1–Procedures and training 2–Crane design 3–Impact pad 4–Borated water	1–Travel includes lowering crane, including potentially lowering while moving into position 2–Verify that drop in pool is inconsequential to radioactive release 3–Verify criticality 4–Verify requirements for limiting heavy load movement above fuel 5–Verify if use mechanical stops for crane	

Table E-21. HAZOP Analysis Worksheet (Continued)

Facility/Operation: WHF				**Process**: DPC Transfer to Pool			
Node 20: Transfer STC to Pool				**Process/Equipment**: Crane, Yoke, STC, Pool			
Guide Words: 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**
20.14	Travel (Crane to Pool Ledge)	(Less) Crane does not move into desired position for activity (hits pool edge and drops into pool)	1–Human failure 2–Mechanical failure	No safety consequences	1–Procedures and training 2–Impact pad 3–Borated water	1–Travel includes lowering crane, including potentially lowering while moving into position 2–Verify that drop in pool is inconsequential to radioactive release 3–Verify criticality 4–Verify requirements for limiting heavy load movement above fuel	
20.15	Travel (Crane to Pool Ledge)	(Less) Crane does not move into desired position for activity (hits floor and remains outside of pool)	1–Human failure 2–Mechanical failure	Potential drop or collision leading to radioactive release	Procedures and training	Travel includes lowering crane, including potentially lowering while moving into position	WHF-710 WHF-711
20.16	Travel (Crane to Pool Ledge)	(Reverse) Travels in wrong direction	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	Procedures and training	Hit other SSCs	WHF-710

NOTE: Guidewords not used in this node: As Well As and Part Of.
DPC= dual-purpose canister; FTA = fault-tree analysis; HRA = human-reliability analysis; PLC = programmable logic controller; SSCs = structures, systems, and components; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

Table E-22. HAZOP Analysis Worksheet

Facility/Operation: WHF				**Process**: TC/CSNF Preparation and Movement into Pool			
Node 21: Prepare TC/CSNF and Move into Pool				**Process/Equipment**: Similar to DPC Cutting)			
Guide Words: 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**
NOTE: This node is similar to the DPC Cutting nodes, starting with removing the access port covers, sampling inside the canister, helium cooling, then water cooling. However, the similarity ends there. The process jumps forward to attaching the yoke to the TC/CSNF and moving it to the pool. Once it is placed on the pool ledge, the cask lid bolts are removed, the extended yoke attached, and the TC/CSNF lowered to the bottom of the pool. There, the TC/CSNF lid is lifted, and fuel removal is performed. The HAZOP completed for the similar DPC Cutting nodes above were reproduced for the appropriate steps in the TC/CSNF Preparation and Movement to Pool process. The scope of this node starts with the TC/CSNF located in the preparation station and ends when it is lowered and set on the pool ledge. Moving the TC/CSNF from the conveyance to the preparation station is covered in Node 5. Removal of the fuel assembly is covered in the In-Pool Operations node.							
21.1	Remove Cover to Access Port	(More) Cuts too much and damages quick connect valve	Human failure	Direct exposure	Procedures and training		WHF-1601
21.2	Sample Line Hookup	(Other Than) Improper hookup	Human failure	Potential loss of confinement boundary leading to radioactive release	1–Procedures and training 2–Connection design	Verify connection design	WHF-1603
21.3	Sample Line Hookup	(Other Than) Line breaks	1–Human failure 2–Equipment failure	Potential loss of confinement boundary leading to radioactive release	1–Procedures and training 2–Sample system design		WHF-1603
21.4	Taking Sample (Radioactivity)	(Other Than) Incorrect or inadequate sample or false negative	1–Human failure 2–Equipment failure	No safety consequences	1–Procedures and training 2–Sample system design	Faulty sampling could lead to undesired or untimely break of confinement – Precursor to radioactive release	
21.5	Taking Sample (Temperature)	(Other Than) Incorrect temperature reading	1–Human failure 2–Equipment failure	No safety consequences	1–Procedures and training 2–Sample system design	Adding water during cooling phase – Precursor to potential steam explosion and fuel cladding damage	
21.6						Helium and water lines cannot be cross-connected	
21.7	Helium Cooling Pressure	(More) Too much pressure	1–Failure of regulator 2–Helium bottle not isolated	Potential loss of confinement boundary leading to radioactive release	Relief valve	Helium line breaks from overpressurization	WHF-1605
21.8	Helium Cooling Pressure	(Other Than) Failure to have positive seal on connections	1–Human failure 2–Mechanical failure	Potential loss of confinement boundary leading to radioactive release	Procedures and training		WHF-1605
21.9	Helium Cooling Temperature	(Less) Insufficient cooling	1–Human failure 2–Mechanical failure	No safety consequences		1–Open bypass path, temperature gauge failure, or miscalibration leads operator to believe temperature is okay – Precursor to steam explosion 2–Verify temperature reading location	
21.10	Helium Cooling Temperature	(Less) Insufficient cooling	Mechanical failure of helium cooling system or pump	No safety consequences		Precursor to steam explosion if operator misreads temperature gauge	
21.11	Water Cooling	(Other Than) Waste temperature too high (see 21.9 and 21.10 above)	Human failure	Potential loss of confinement boundary leading to radioactive release	1–Procedures and training 2–Temperature gauge	Steam explosion causes loss of confinement	WHF-1606
21.12	Water Cooling Flow	(No) Flow does not start	1–Human failure 2–Mechanical failure	No safety consequences		1–If waste form reheats and water flow starts – Precursor to steam explosion 2–Temperature gauge may not show proper reading due to system configuration	

Table E-22. HAZOP Analysis Worksheet (Continued)

Facility/Operation: WHF				**Process**: TC/CSNF Preparation and Movement into Pool			
Node 21: Prepare TC/CSNF and Move into Pool				**Process/Equipment**: Similar to DPC Cutting)			
Guide Words: 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**
21.13	Water Cooling Flow	(Less or No) Low or no flow given flow was started	1–Human failure 2–Mechanical failure	No safety consequences		Verify natural circulation will prevent flash steam explosion	
21.14	Water Cooling	(Less) Premature cooling termination	1–Human failure 2–Mechanical failure of temperature gauge	No safety consequences		Precursor to release during lid cutting	
21.15	Water Line	(Other Than) Water line breaks	Mechanical failure	Direct exposure	1–System design 2–PPE for operators		WHF-1607
21.16	Attach Yoke to Crane	(Other Than) Improper attachment of yoke to crane	Human failure	No safety consequences	Procedures and training	Precursor to drop of STC or on STC	
21.17	Movement (Yoke/Crane)	(Other Than) Drop yoke (see 21.16 above)		Potential drop leading to radioactive release	See 21.16 above?		WHF-1602
21.18	Speed (Crane)	(More) Yoke lowers too fast and too far	1–Human failure 2–Mechanical failure	Potential drop leading to radioactive release	1–Procedures and training 2–Crane design	STC design may mitigate event, depending on passive equipment failure analysis	WHF-1602
21.19	Speed (Crane)	(Less) Yoke lowers too slow		No safety consequences			
21.20	Travel (Crane)	(Other Than) Crane movement with yoke lowered	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	1–Procedures and training 2–Crane design	STC design may mitigate event, depending on passive equipment failure analysis	WHF-1602
21.21	Motor	(More) Motor temperature too high	1–Human failure 2–Mechanical malfunction	No safety consequences		Potential fire scenario	
21.22	Maintenance	(No) Improper maintenance of crane	Human failure		Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	
21.23	Controls (PLC)	(Other Than)				Considered in event sequence development (event tree/FTA/HRA)	
21.24	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment		1–Crane operator training program 2–Human factor evaluation 3–Industrial hygiene standards	Considered in HRA	
21.25	Engagement (Yoke)	(More) Over-travel on yoke arm positioning	1–Human failure 2–Mechanical failure	Potential drop of STC leading to radioactive release	1–Positioning interlocks 2–Yoke adjustment motor design 3–Pin alignment 4–Procedures and training		WHF-1602
21.26	Engagement	(Less) Under-travel on yoke arm positioning	1–Human failure 2–Mechanical failure	Potential drop of STC leading to radioactive release	1–Positioning interlocks 2–Yoke adjustment motor design 3–Pin alignment 4–Procedures and training	Potential partial yoke engagement	WHF-1602
21.27	Engagement	(No) Yoke fails to engage		No safety consequences			

Table E-22. HAZOP Analysis Worksheet (Continued)

Facility/Operation: WHF				**Process**: TC/CSNF Preparation and Movement into Pool			
Node 21: Prepare TC/CSNF and Move into Pool				**Process/Equipment**: Similar to DPC Cutting)			
Guide Words: 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**
21.28	Travel (Crane to Pool Ledge)	(More) Crane moves past desired position for activity	1–Human failure 2–Mechanical failure	No safety consequences	1–Procedures and training 2–Crane design 3–Impact pad 4–Borated water	1–Travel includes lowering crane, including potentially lowering while moving into position 2–Verify that drop in pool is inconsequential to radioactive release 3–Verify criticality 4–Verify requirements for limiting heavy load movement above fuel 5–Verify if use mechanical stops for crane	
21.29	Travel (Crane to Pool Ledge)	(Less) Crane does not move into desired position for activity (hits pool edge and drops into pool)	1–Human failure 2–Mechanical failure	No safety consequences	1–Procedures and training 2–Impact pad 3–Borated water	1–Travel includes lowering crane, including potentially lowering while moving into position 2–Verify that drop in pool is inconsequential to radioactive release 3–Verify criticality 4–Verify requirements for limiting heavy load movement above fuel	
21.30	Travel (Crane to Pool Ledge)	(Less) Crane does not move into desired position for activity (hits floor and remains outside of pool)	1–Human failure 2–Mechanical failure	Potential impact or drop leading to radioactive release	Procedures and training	Travel includes lowering crane, including potentially lowering while moving into position	WHF-1602
21.31	Travel (Crane to Pool Ledge)	(Reverse) Travels in wrong direction	1–Human failure 2–Mechanical failure	Potential collision leading to radioactive release	Procedures and training	Hit other SSCs	WHF-1602

NOTE: Guidewords not used in this node: As Well As and Part Of.
CSNF = commercial spent nuclear fuel; DPC = dual-purpose canister; FTA = fault-tree analysis; HRA = human-reliability analysis; PLC = programmable logic controller; PPE = personal protective equipment; SSCs = structures, systems, and components; STC = shielded transfer cask; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Table E-23. HAZOP Analysis Worksheet

Facility/Operation: WHF	**Process**: In-Pool Operations
Node 22: In-Pool Operations	**Process/Equipment**: Yoke, Yoke Extension, Crane, STC, TC, Common Tools
Guide Words: 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
22.1	Disengage Yoke	(Less or No) Yoke not disengaged	Human failure	No safety consequences	Procedures and training	Precursor to drop into pool	
22.2	Move Yoke	(Other Than) (see 22.1 above)		No safety consequences	1–Impact pad 2–Procedures and training	1–Verify that drop in pool is inconsequential to radioactive release 2–Verify criticality	
22.3	Bolt Removal	(Other Than) Bolts not fully removed	Human failure	No safety consequences	Procedures and training	Precursor to drop cask or pull down crane	
22.4	Add Extension to Yoke	(Other Than) Improper attachment of assembly or any part thereof	Human failure	No safety consequences	Procedures and training	Precursor to drop cask and extension	
22.5	Movement (Yoke/Crane)	(Other Than) Drops yoke (see 21.16 in previous node?)		Potential drop leading to radioactive release	See 21.16 in previous node	1–Verify that drop in pool is inconsequential to radioactive release 2–Verify criticality	WHF-1802
22.6	Engagement (Yoke)	(More) Over-travel on yoke arm positioning	1–Human failure 2–Mechanical failure	No safety consequences	1–Positioning interlocks 2–Yoke adjustment motor design 3–Pin alignment 4–Procedures and training	1–Verify that drop in pool is inconsequential to radioactive release 2–Verify criticality 3–Verify yoke type used in pool	
22.7	Engagement (Yoke)	(Less) Under-travel on yoke arm positioning	1–Human failure 2–Mechanical failure	No safety consequences	1–Positioning interlocks 2–Yoke adjustment motor design 3–Pin alignment 4–Procedures and training	1–Potential partial yoke engagement 2–Verify yoke type used in pool	
22.8	Engagement (Yoke)	(No) Fails to engage		No safety consequences			
22.9	Speed (Crane)	(More) Yoke lowers too fast and too far	1–Human failure 2–Mechanical failure	No safety consequences	1–Procedures and training 2–Crane design 3–Impact pad 4–Borated water	1–Verify that drop in pool is inconsequential to radioactive release 2–Verify criticality	
22.10	Speed (Crane)	(Less) Yoke lowers too slow		No safety consequences			
22.11	Travel (Crane)	(Other Than) Crane movement with yoke lowered	1–Human failure 2–Mechanical failure	No safety consequences	1–Procedures and training 2–Crane design 3–Impact pad 4–Borated water	1–Verify that drop in pool is inconsequential to radioactive release 2–Verify criticality	
22.12	Maintenance	(No) Improper maintenance of crane	Human failure		Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	
22.13	Controls (PLC)	(Other Than)				Considered in event sequence development (event tree/FTA/HRA)	
22.14	Vision/ Communicatio n	(Other Than) Unclear communication	Poor operating environment		1–Crane operator training program 2–Human factor evaluation 3–Industrial hygiene standards	Considered in HRA	

Table E-23. HAZOP Analysis Worksheet (Continued)

Facility/Operation: WHF				**Process**: In-Pool Operations			
Node 22: In-Pool Operations				**Process/Equipment**: Yoke, Yoke Extension, Crane, STC, TC, Common Tools			
Guide Words: 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**
22.15	Travel (Crane to Bottom of Pool)	(More) Crane moves past desired position for activity	1–Human failure 2–Mechanical failure	No safety consequences	1–Procedures and training 2–Crane design 3–Impact pad 4–Borated water	1–Travel includes lowering crane, including potentially lowering while moving into position 2–Verify that drop in pool is inconsequential to radioactive release 3–Verify criticality 4–Verify requirements for limiting heavy load movement above fuel 5–Verify if use mechanical stops for crane 6–Potential to drop heavy load onto fuel staging rack	
22.16	Travel (Crane to Bottom of Pool)	(Less) Crane does not move into desired position for activity (hits pool edge and drops into pool)	1–Human failure 2–Mechanical failure	No safety consequences	1–Procedures and training 2–Impact pad 3–Borated water	1–Travel includes lowering crane, including potentially lowering while moving into position 2–Verify that drop in pool is inconsequential to radioactive release 3–Verify criticality 4–Verify requirements for limiting heavy load movement above fuel	
22.17	Travel (Crane to Bottom of Pool)	(Less) Crane does not move into desired position for activity (hits floor and remains outside of pool)	1–Human failure 2–Mechanical failure	No safety consequences	1–Procedures and training 2–Impact pad 3–Borated water	Travel includes lowering crane, including potentially lowering while moving into position	
22.18	Travel (Crane to Bottom of Pool)	(Reverse) Travels in wrong direction	1–Human failure 2–Mechanical failure	No safety consequences	1–Procedures and training 2–Impact pad 3–Borated water	Hits side of pool	
22.19	Lid Grapple Engagement	(Other Than) Improper attachment	1–Human failure 2–Equipment failure	No safety consequences	1–Procedures and training 2–Potentially precluded by design	Potential precursor to cask lid drop	
22.20	Remove STC Lid	(More) Attempting to lift more than lid alone (see 22.3 above)	Human failure	No safety consequences	1–Procedures and training 2–Impact pad 3–Borated water	Event in pool	
22.21	Remove STC Lid	(More) Attempting to lift lid too high (i.e., two-blocking)	Human failure	No safety consequences	1–Procedures and training 2–Impact pad 3–Borated water	Event in pool	
22.22	Remove STC Lid	(Other Than) Lift with grapple improperly attached (see 22.19 above)	Human failure	No safety consequences	1–Procedures and training 2–Impact pad 3–Borated water	Event in pool	
22.23	Remove Canister Lid	(More) Attempting to lift more than lid alone (see 22.3 above)	Human failure	No safety consequences	1–Procedures and training 2–Impact pad 3–Borated water	Event in pool	
22.24	Remove Canister Lid	(More) Attempting to lift canister lid higher than needed (i.e., two-blocking)	Human failure	No safety consequences	1–Procedures and training 2–Impact pad 3–Borated water	Event in pool	

Table E-23. HAZOP Analysis Worksheet (Continued)

Facility/Operation: WHF				**Process**: In-Pool Operations			
Node 22: In-Pool Operations				**Process/Equipment**: Yoke, Yoke Extension, Crane, STC, TC, Common Tools			
Guide Words: 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**
22.25	Remove Canister Lid	(Other Than) Canister lid lifted with grapple improperly attached (see 22.19 above)	Human failure	No safety consequences	1–Procedures and training 2–Impact pad 3–Borated water	Event in pool	
22.26	Engagement	(Other Than) Improper attachment of SFTM grapple	1–Human failure 2–Equipment failure	No safety consequences	Procedures and training	Potential precursor to dropping fuel assembly	
22.27	SFTM Lift	(More) Attempting to lift too high	Human failure	Direct exposure	1–Procedures and training 2–Crane design	Reduce shielding provided by pool water	WHF-1807
22.28	SFTM Lift	(Less or No) Attempting to move SFTM while fuel assembly is still in DPC	Human failure	No safety consequences	Procedures and training	1–Bent fuel assembly 2–Event in pool	WHF-1809
22.29	Boron Concentration	(Less or No) Not enough boron concentration	Human failure	Potential criticality	1–Procedures and training 2–Boron concentration monitoring		
22.30	Boron Concentration	(Less or No) Not enough boron concentration	Temperature low	Potential criticality	1–Procedures and training 2–Boron concentration monitoring	1–Boron precipitation on low temperature 2–Pool temperature cooling/heating maintained by heat exchangers	
22.31	Fuel Assembly	(Less or Other Than) Loss of fuel assembly integrity	Aged fuel	Potential criticality	Borated water		
22.32	Pool Water	(Less) Loss of pool water	1–Hole in pool bottom 2–Evaporation (massive) 3–Pool circulation loop failure	Direct exposure	1–Water makeup system 2–Crush pad 3–Pool leak detection system 4–Procedures and training		WHF-1807

NOTE: Guidewords not used in this node: As Well As and Part Of.
DPC = dual-purpose canister; FTA = fault-tree analysis; HRA = human-reliability analysis; PLC = programmable logic controller; SFTM = spent fuel transfer machine; STC = shielded transfer cask; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Table E-24. HAZOP Analysis Worksheet

Facility/Operation: WHF				**Process**: TAD Canister Loading and Closure			
Node 23: Load TAD Canister in Pool, Remove from Pool and Process in Closure Station				**Process/Equipment**: Welding Equipment			
Guide Words: 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**
23.1	Welding Process Temperature	(More) Greater than expected temperature	1–Human failure 2–Mechanical malfunction	No safety consequences	Weld machine design	Verify if high-temperature welding can cut through TAD canister lid	
23.2	Welding Process Temperature	(Less) Less than expected temperature	1–Human failure 2–Mechanical malfunction	No safety consequences	Weld machine design	1–Improper weld 2–Potential weakening of TAD canister boundary	
23.3	Welding Process Material	(Other Than) Wrong welding material	Human failure	No safety consequences	Procedures and training	1–Improper weld 2–Potential weakening of TAD canister boundary	
23.4	Welding Process Material	(More) More than expected amount	1–Human failure 2–Mechanical malfunction	No safety consequences	Procedures and training	1–Improper weld 2–Potential weakening of TAD canister boundary	
23.5	Welding Process Material	(Less) Less than expected amount	1–Human failure 2–Mechanical malfunction	No safety consequences	Procedures and training	1–Improper weld 2–Potential weakening of TAD canister boundary	
23.6	Welding Process Debris				Procedures and training	No debris from weld process utilized for TAD canister closure	
23.7	Welding Process Inerting Blanket	(Less or No) Loss of inerting blanket	1–Human failure 2–Mechanical malfunction	No safety consequences	Procedures and training	1–Improper weld 2–Potential weakening of TAD canister boundary	
23.8	Welding Process Inerting Blanket	(Other Than) Flammable gas substituted for inerting gas	Human failure	No safety consequences	Procedures and training	Improper weld – Potential fire initiator	
23.9	Weld Cooling	(More) Too much cooling	1–Human failure 2–Mechanical malfunction	No safety consequences	Procedures and training	Check water supply for ultrasonic testing	
23.10	Weld Cooling	(Less) Localized temperature exceeds limits	1–Human failure 2–Mechanical malfunction	No safety consequences	Procedures and training		
23.11	Loading TAD Canister	(Other Than) Misloading TAD canister with fuel assembly too hot	Human failure		Procedures and training	Verify thermal effects on TAD canister integrity	
23.12	Drying TAD Canister	(Less or No) Not dry enough	1–Human failure 2–Mechanical failure	No safety consequences in PCSA	Procedures and training	Verify potential radiohydrolysis and corrosion	
23.13	Inerting TAD Canister	(Less or No) Not inerting TAD canister	1–Human failure 2–Mechanical failure	No safety consequences in PCSA	Procedures and training	Verify potential oxidation of fuel	
23.14	Inerting TAD Canister	(Other Than) Uses wrong type of gas	Human failure	Potential loss of confinement leading to radioactive release	Procedures and training		WHF-1307

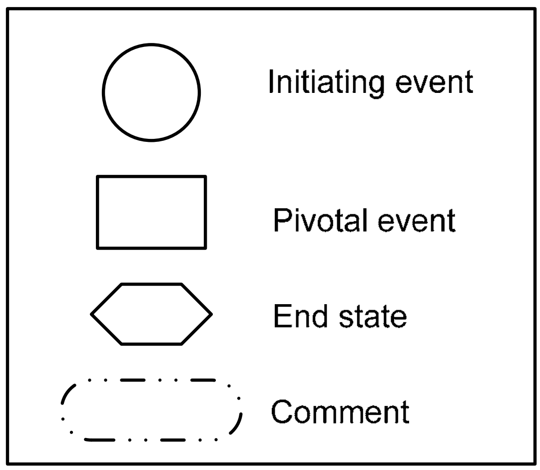
NOTE: Guidewords not used in this node: Reverse, As Well As, and Part Of.
PCSA = preclosure safety analysis; TAD = transportation, aging, and disposal; WHF = Wet Handling Facility.

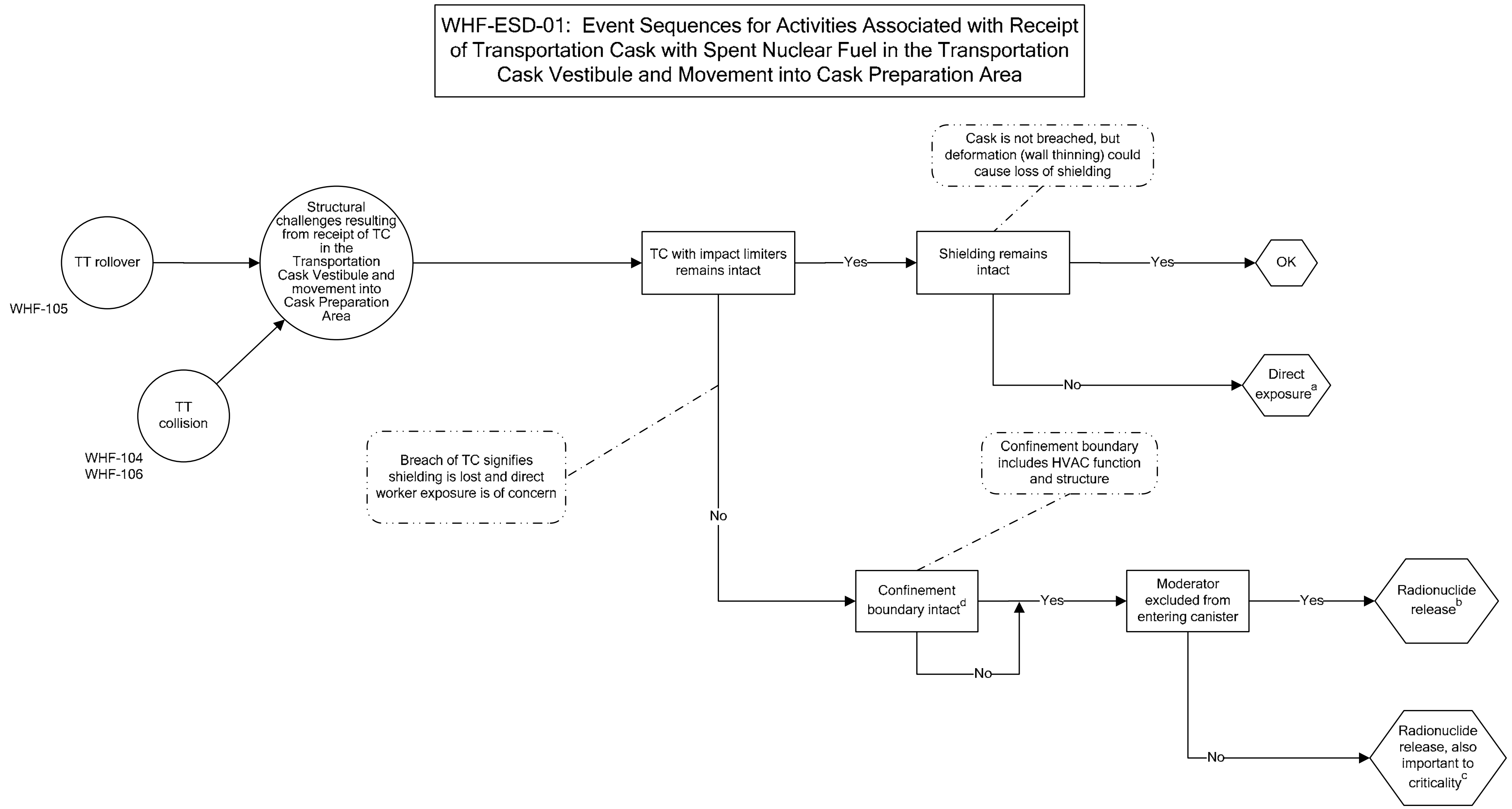
Source: Original

ATTACHMENT F
WET HANDLING FACILITY EVENT SEQUENCE DIAGRAMS

ESDs for WHF are presented in Figures F-1 to F-31. Internal event sequences (excluding seismic events) are shown in Figures F-1 to F-30, and event sequence related to internal fires in Figure F-31. A key to these diagrams is presented in legend shown below.

Legend





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 which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.

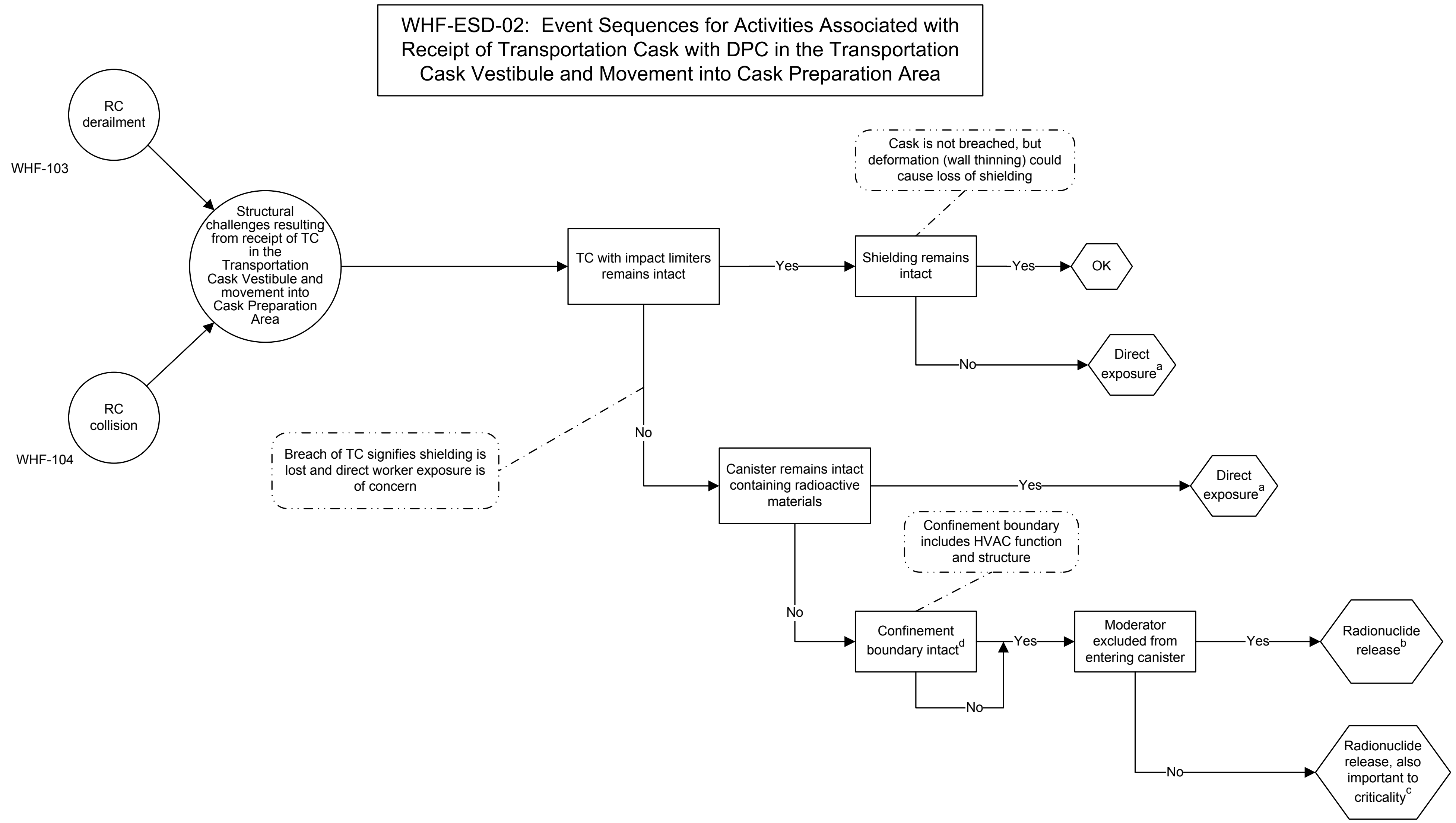
[c] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

[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.

Assume that TC/CSNF only comes on truck trailer.
Potential for fire analyzed in fire ESDs. Upright cask is assumed to be dislodged from conveyance.
CSNF = commercial spent nuclear fuel; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; TC = transportation cask; TT = truck trailer; WHF = Wet Handling Facility.

Source: Original

Figure F-1. WHF-ESD-01 Event Sequences for Activities Associated with Receipt of Transportation Cask with Spent Nuclear Fuel in the Transportation Cask Vestibule and Movement into Cask Preparation Area



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 which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.

[c] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

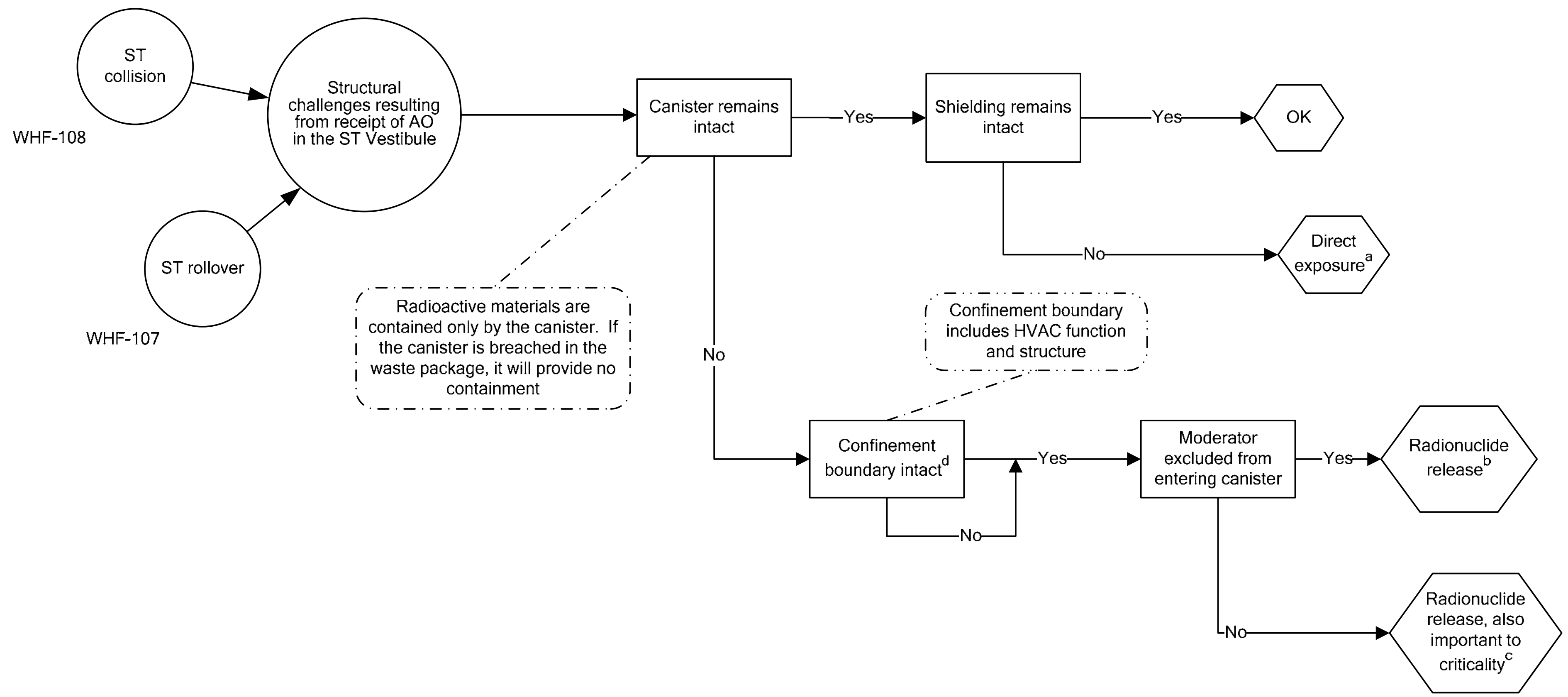
[d] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

Assume that TC/DPC only comes on railcar.
Potential for fire analyzed in fire ESDs. Upright cask is assumed to be dislodged from conveyance.
DPC = dual-purpose canister; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; RC = railcar; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Figure F-2. WHF-ESD-02 Event Sequences for Activities Associated with Receipt of Transportation Cask with DPC in the Transportation Cask Vestibule and Movement into Cask Preparation Area

WHF-ESD-03: Event Sequences for Activities Associated with Receipt of Aging Overpack in the Site Transporter Vestibule



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 which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.

[c] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

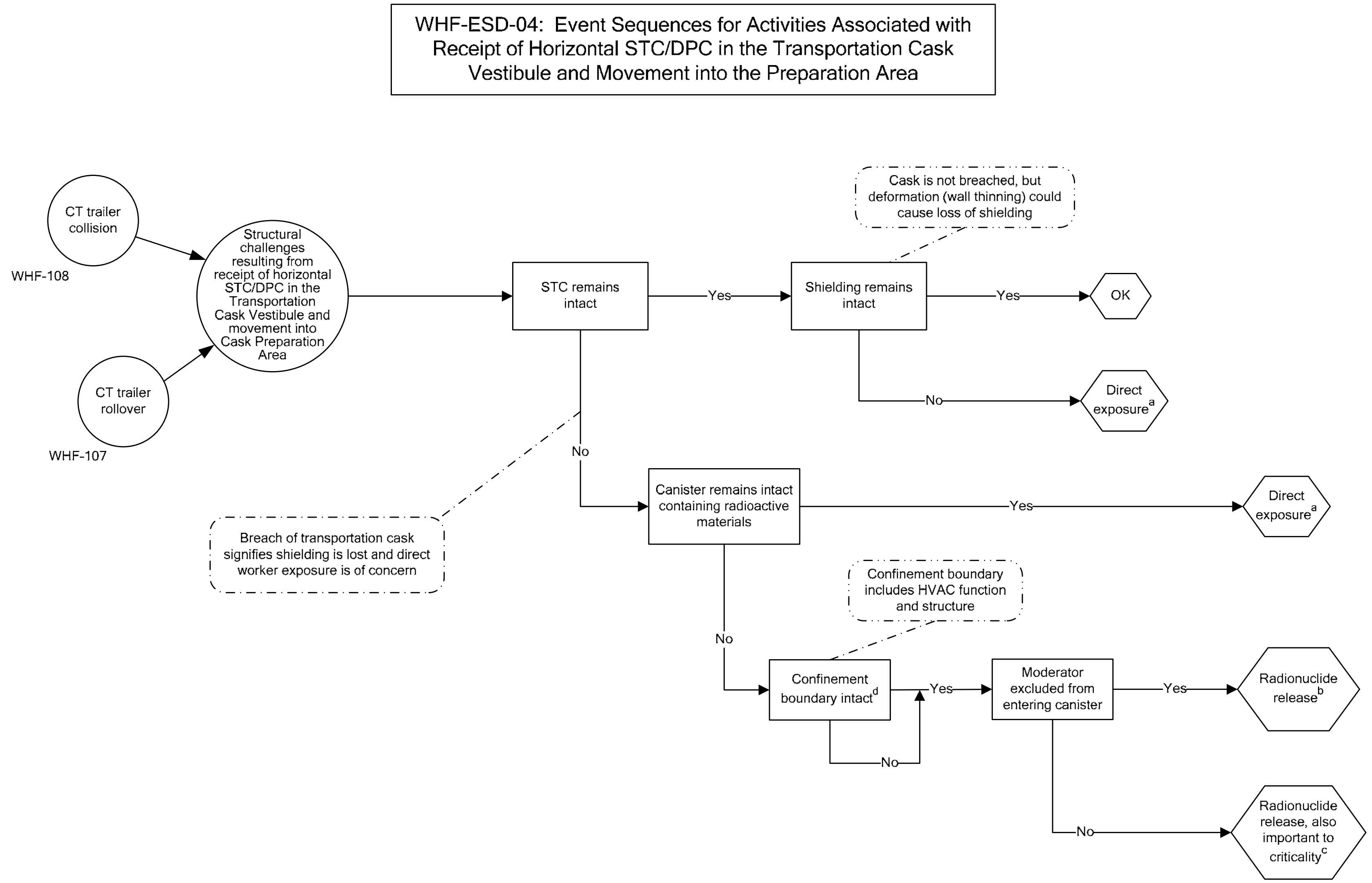
[d] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

Potential for fire analyzed in fire ESDs.

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

Source: Original

Figure F-3. WHF-ESD-03 Event Sequences for Activities Associated with Receipt of Aging Overpack in the Site Transporter Vestibule



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 which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.

[c] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

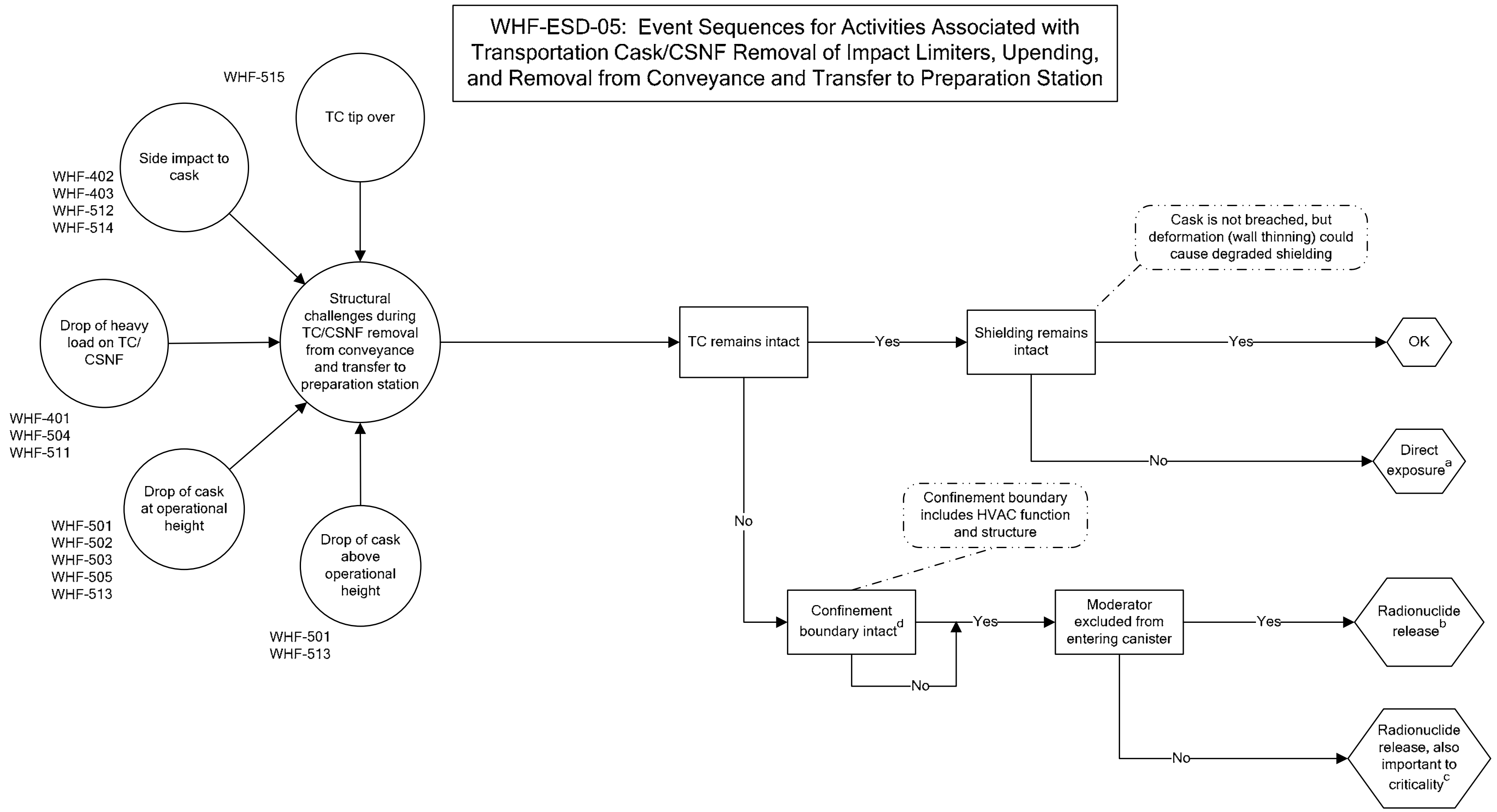
[d] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

Potential for fire analyzed in fire ESDs.

CT trailer = cask transfer trailer; DPC = dual-purpose canister; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; ST = site transporter; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

Figure F-4. WHF-ESD-04 Event Sequences for Activities Associated with Receipt of Horizontal STC/DPC in the Transportation Cask Vestibule and Movement into the Preparation Area



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 which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.

[c] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

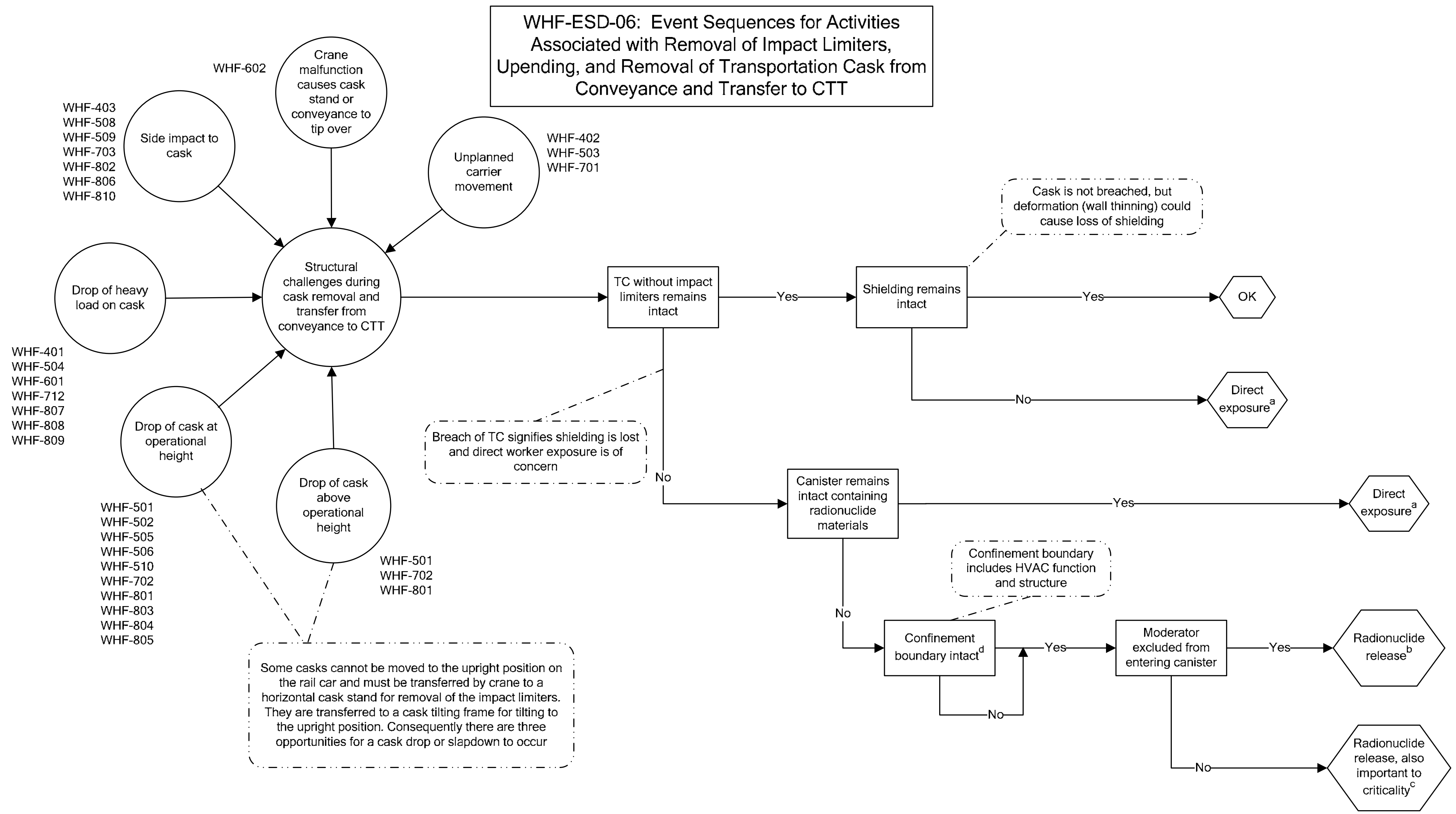
[d] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

Potential for fire analyzed in fire ESDs.

CSNF = commercial spent nuclear fuel; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; TC = transportation cask; WHF = Wet handling Facility.

Source: Original

Figure F-5. WHF-ESD-05 Event Sequences for Activities Associated with TC/CSNF Removal of Impact Limiters, Upending, and Removal from Conveyance and Transfer to Preparation Station



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 which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.

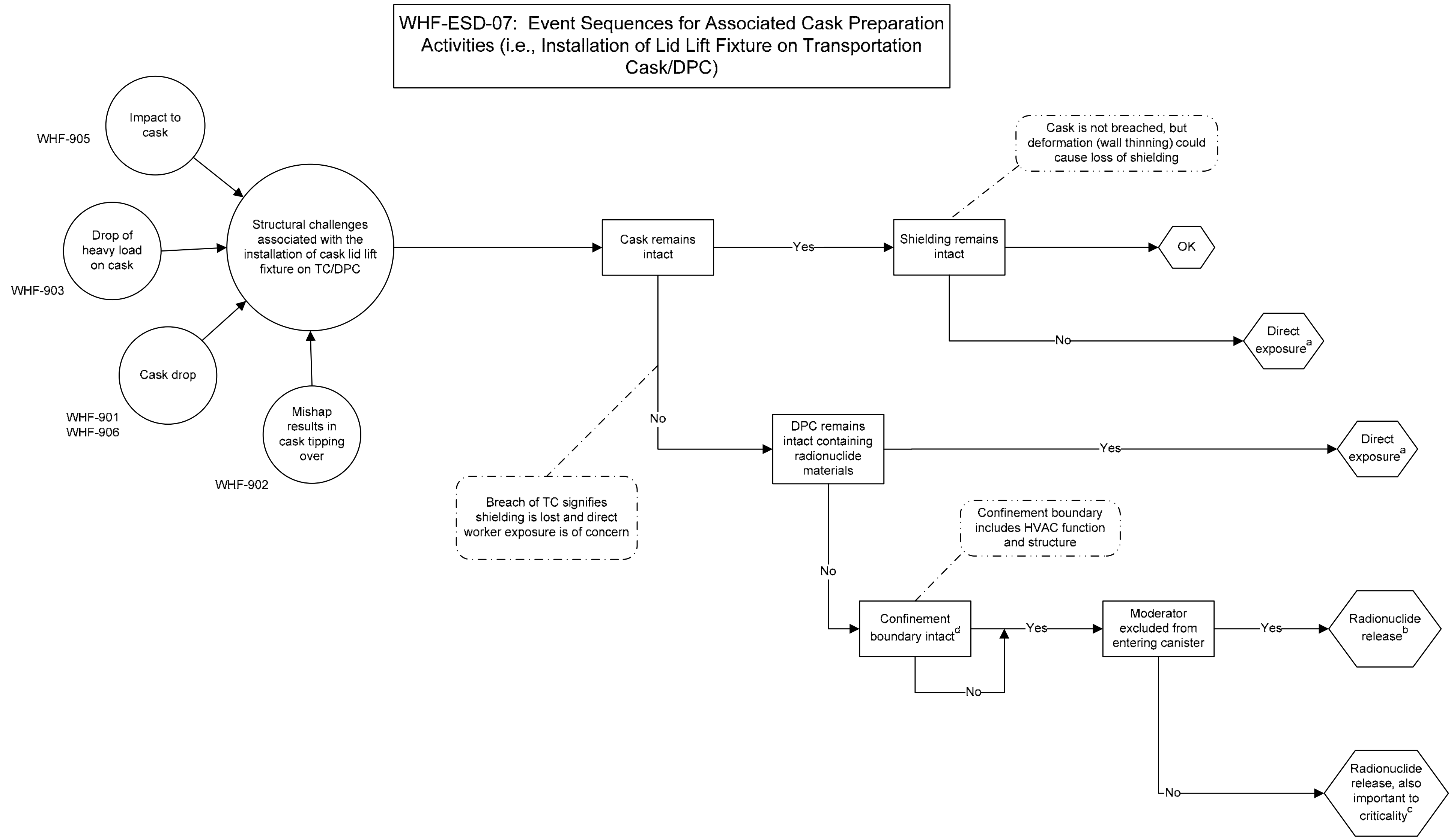
[c] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

[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. Potential for fire analyzed in fire ESDs.

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

Source: Original

Figure F-6. WHF-ESD-06 Event Sequences for Activities Associated with Removal of Impact Limiters, Upending, and Removal of Transportation Cask from Conveyance and Transfer to CTT



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 which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.

[c] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

[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.

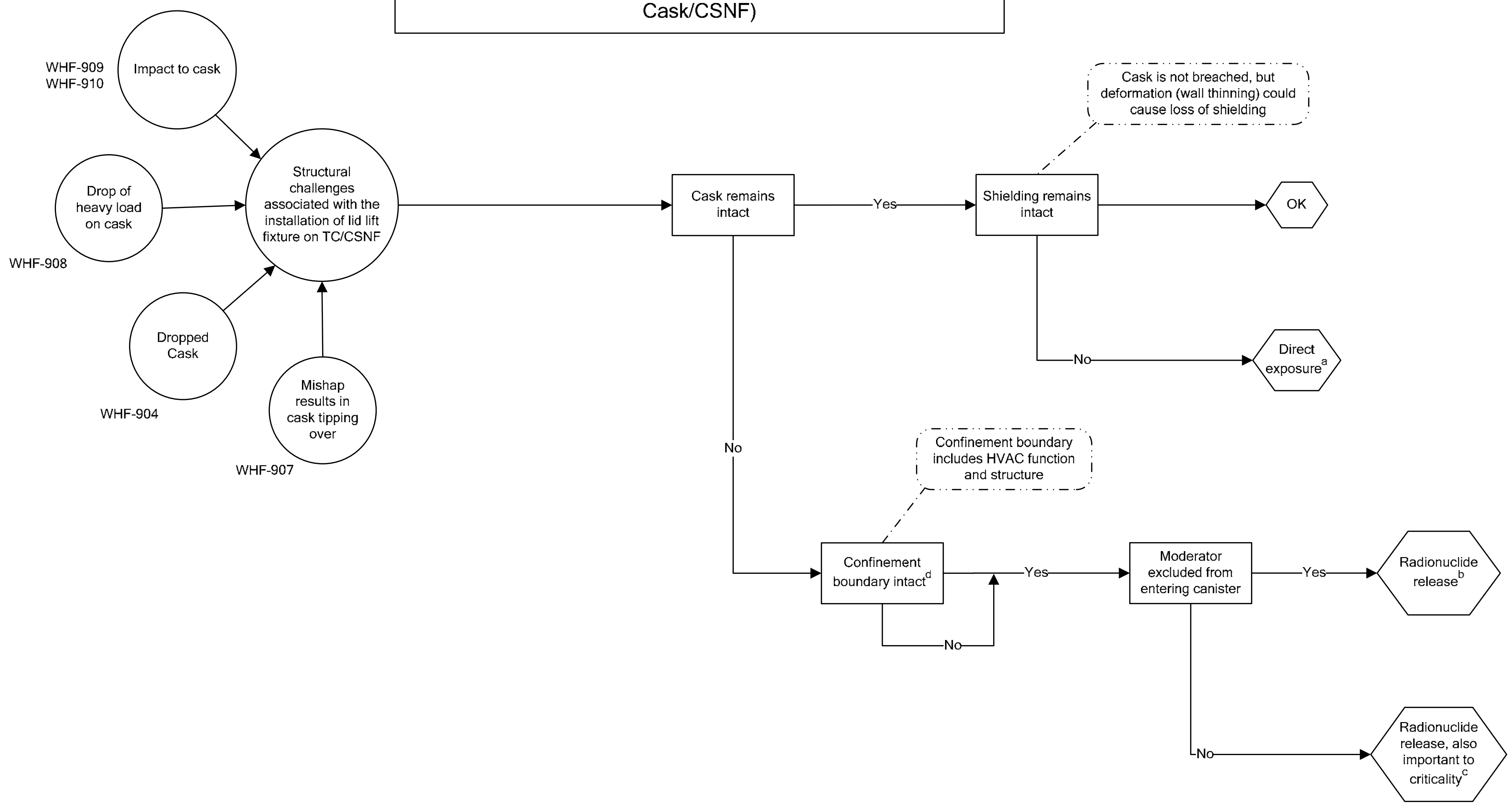
Potential for fire analyzed in fire ESDs.

DPC = dual-purpose canister; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Figure F-7. WHF-ESD-07 Event Sequences for Associated Cask Preparation Activities (i.e., Installation of Lid Lift Fixture on Transportation Cask/DPC)

WHF-ESD-08: Event Sequences for Associated Cask Preparation Activities (i.e. Installation of Cask Lid Lift Fixture – Transportation Cask/CSNF)



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 which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.

[c] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

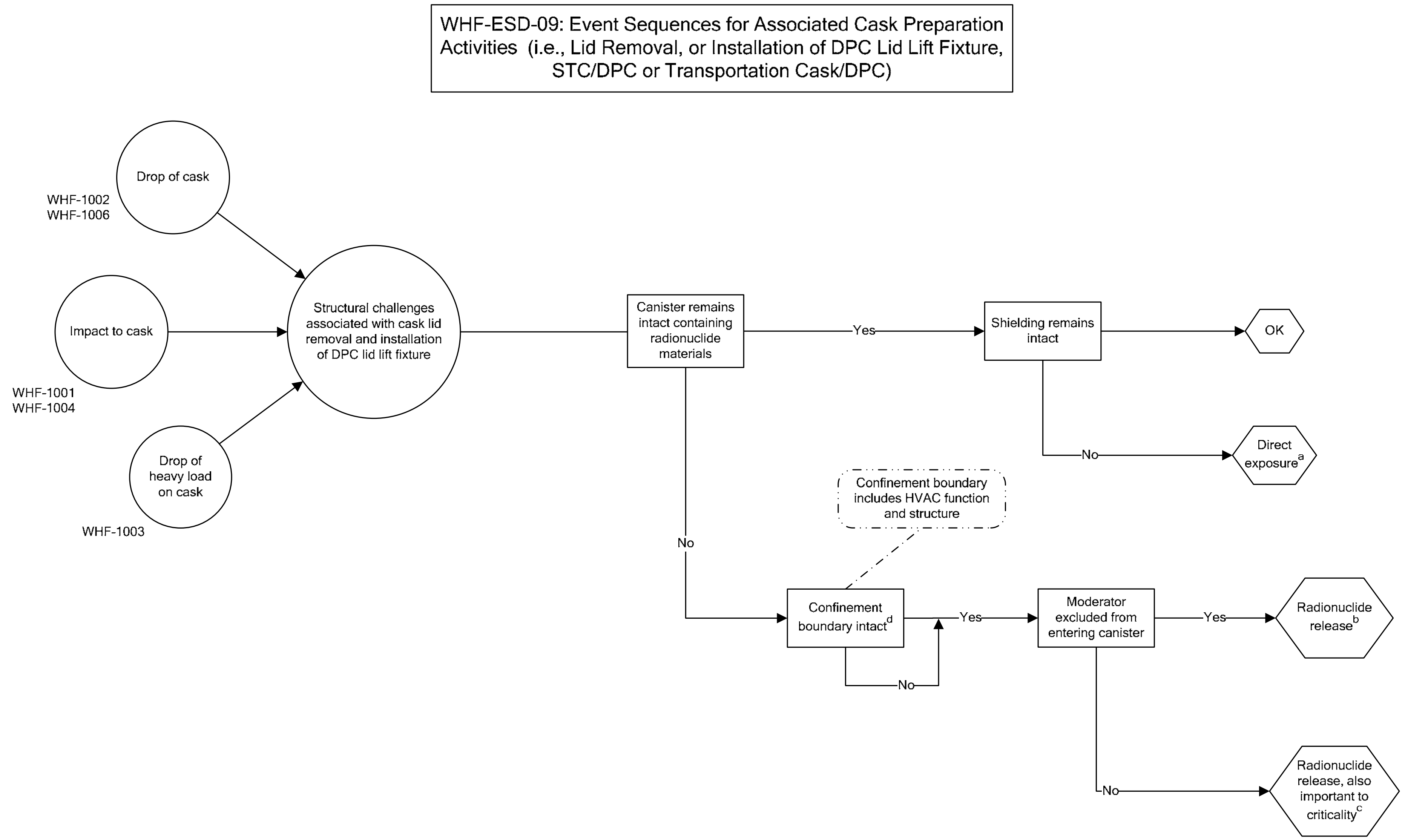
[d] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

Potential for fire analyzed in fire ESDs.

CSNF = commercial spent nuclear fuel; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Figure F-8. WHF-ESD-08 Event Sequences for Associated Cask Preparation Activities (i.e. Installation of Cask Lid Lift Fixture on Transportation Cask/CSNF)



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 which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.

[c] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

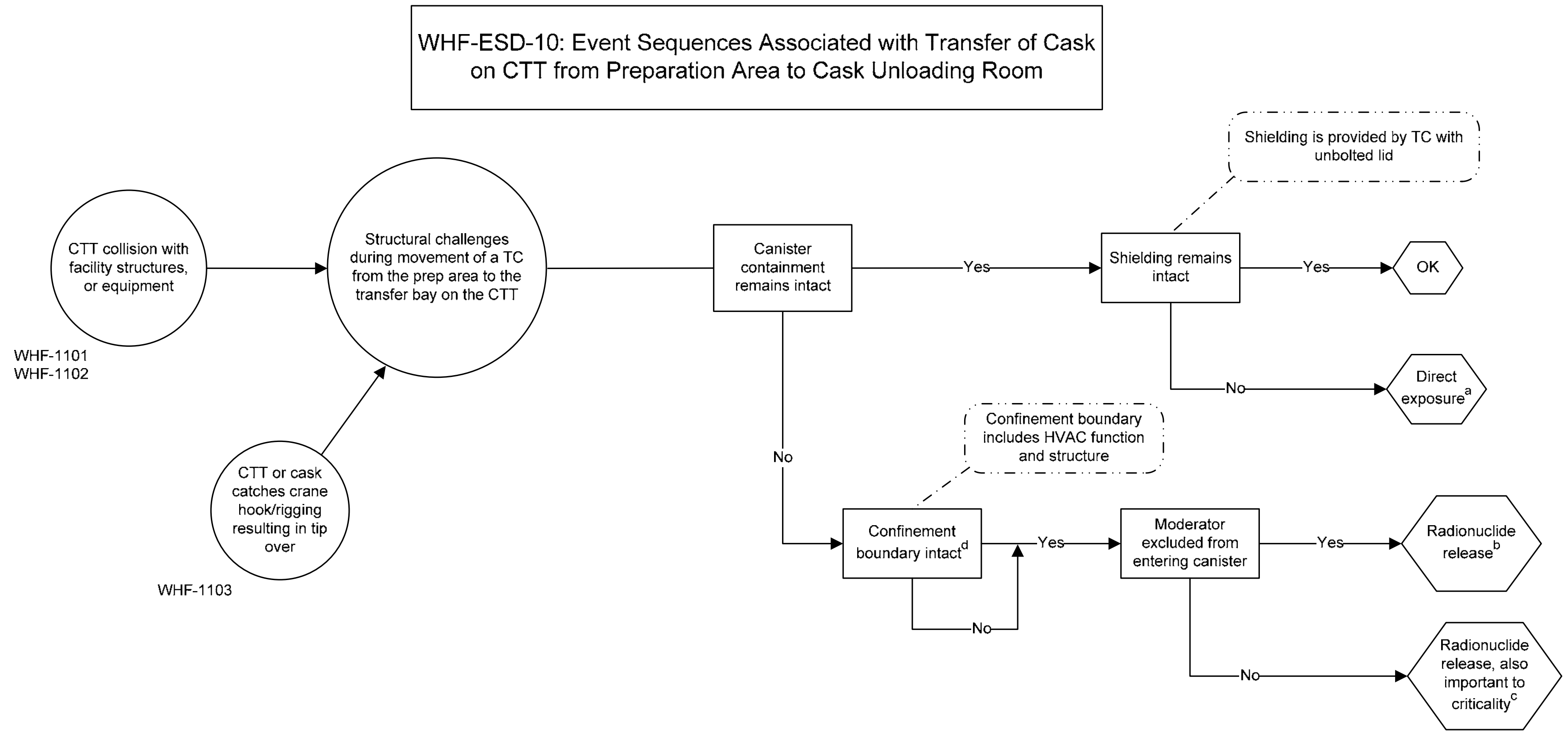
[d] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

Potential for fire analyzed in fire ESDs.

DPC = dual-purpose canister; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

Figure F-9. WHF-ESD-09 Event Sequences for Associated Cask Preparation Activities (i.e., Lid Removal, or Installation of DPC Lid Lift Fixture, STC/DPC or Transportation Cask/DPC)



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 which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.

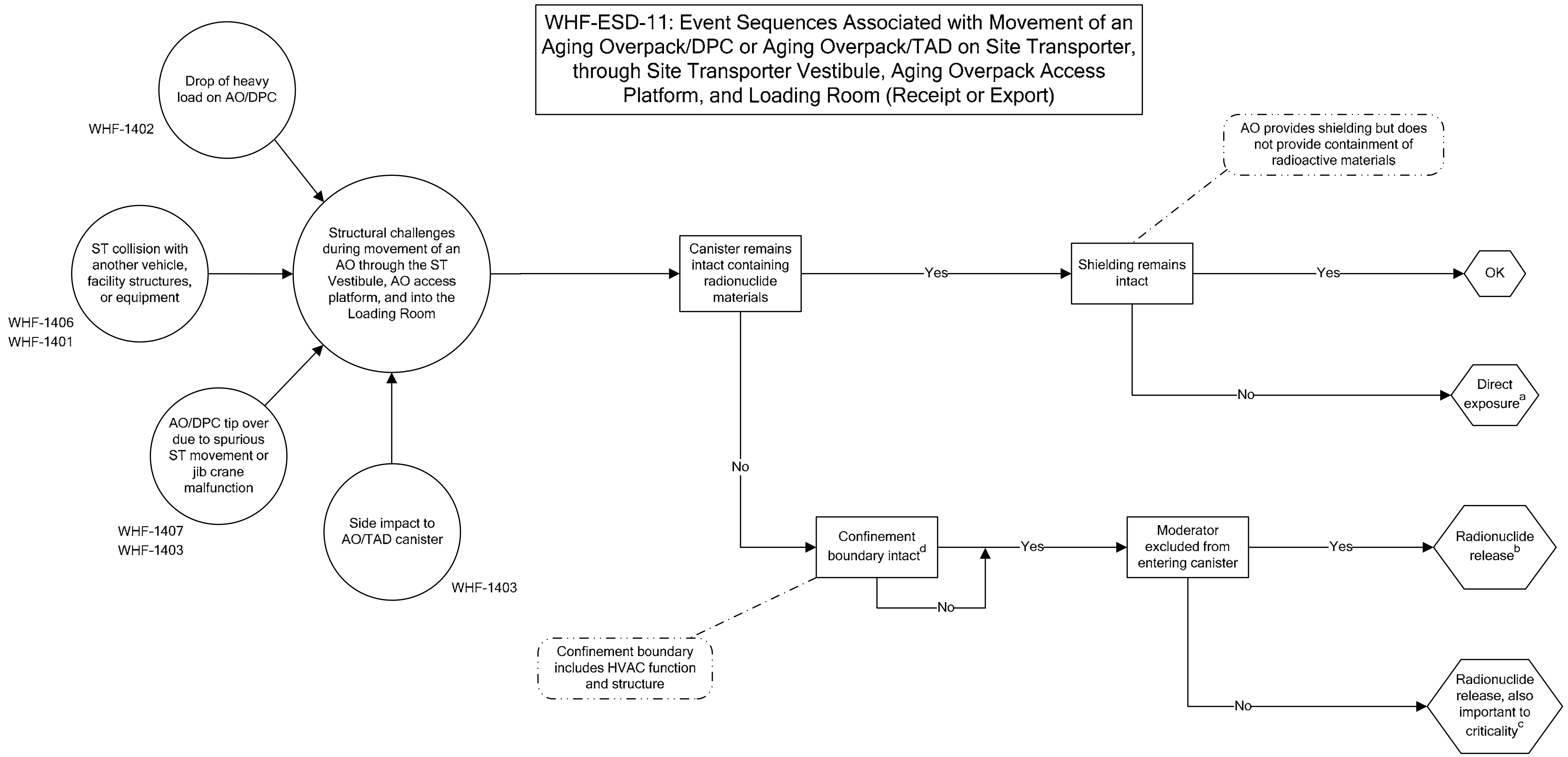
[c] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

[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.

Potential for fire analyzed in fire ESDs.
CTT = cask transfer trolley; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Figure F-10. WHF-ESD-10 Event Sequences Associated with Transfer of Cask on CTT from Preparation Area to Cask Unloading Room



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 which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.

[c] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

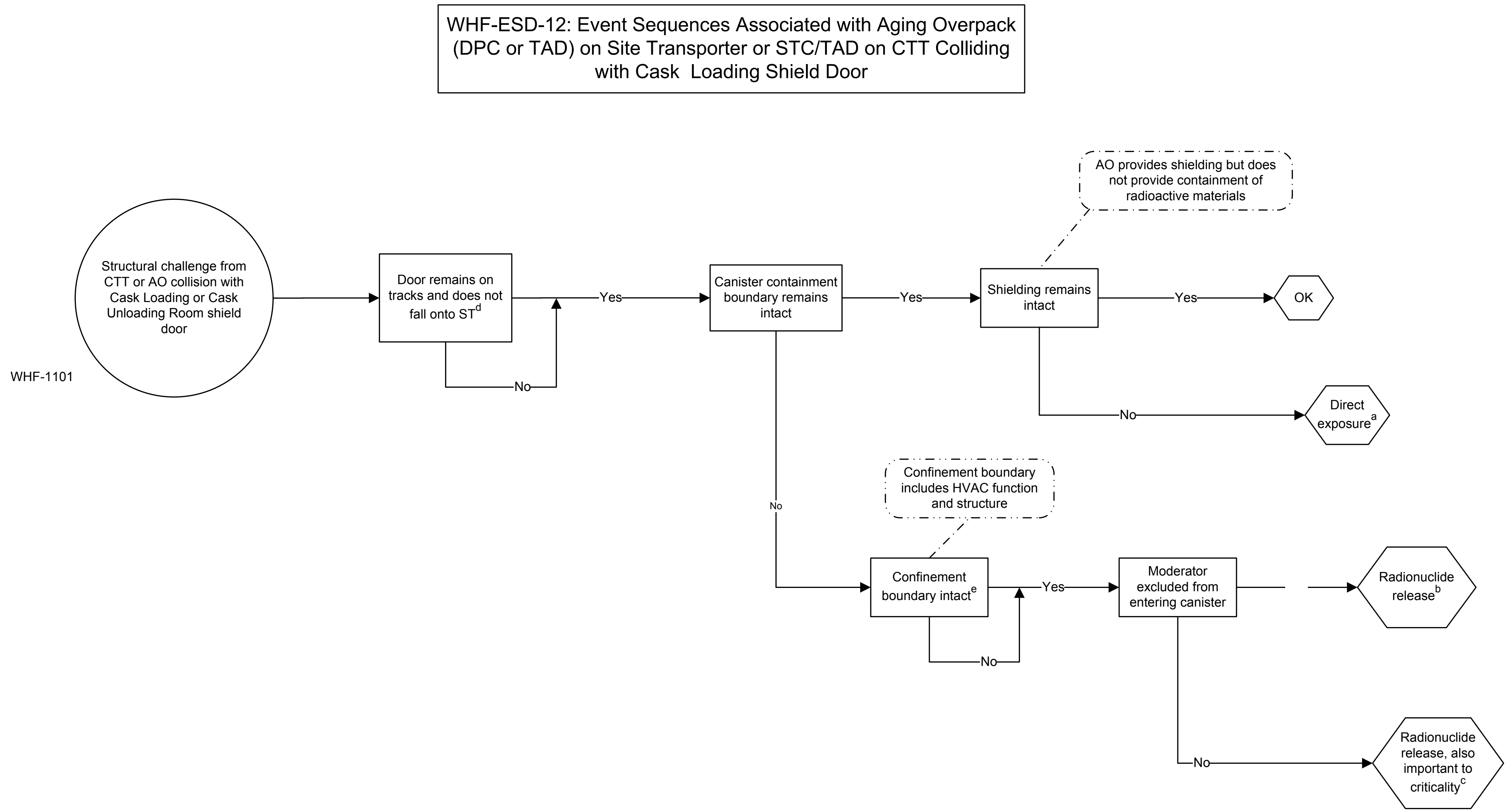
[d] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

Potential for fire analyzed in fire ESDs.

AO = aging overpack; DPC = dual-purpose container; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; ST = site transporter; TAD = transportation, aging, and disposal; WHF = Wet Handling Facility.

Source: Original

Figure F-11. WHF-ESD-11 Event Sequences Associated with Movement of an Aging Overpack/DPC or Aging Overpack/TAD on Site Transporter, through Site Transporter Vestibule, Aging Overpack Access Platform, and Loading Room (Receipt or Export)



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 which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.

[c]Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

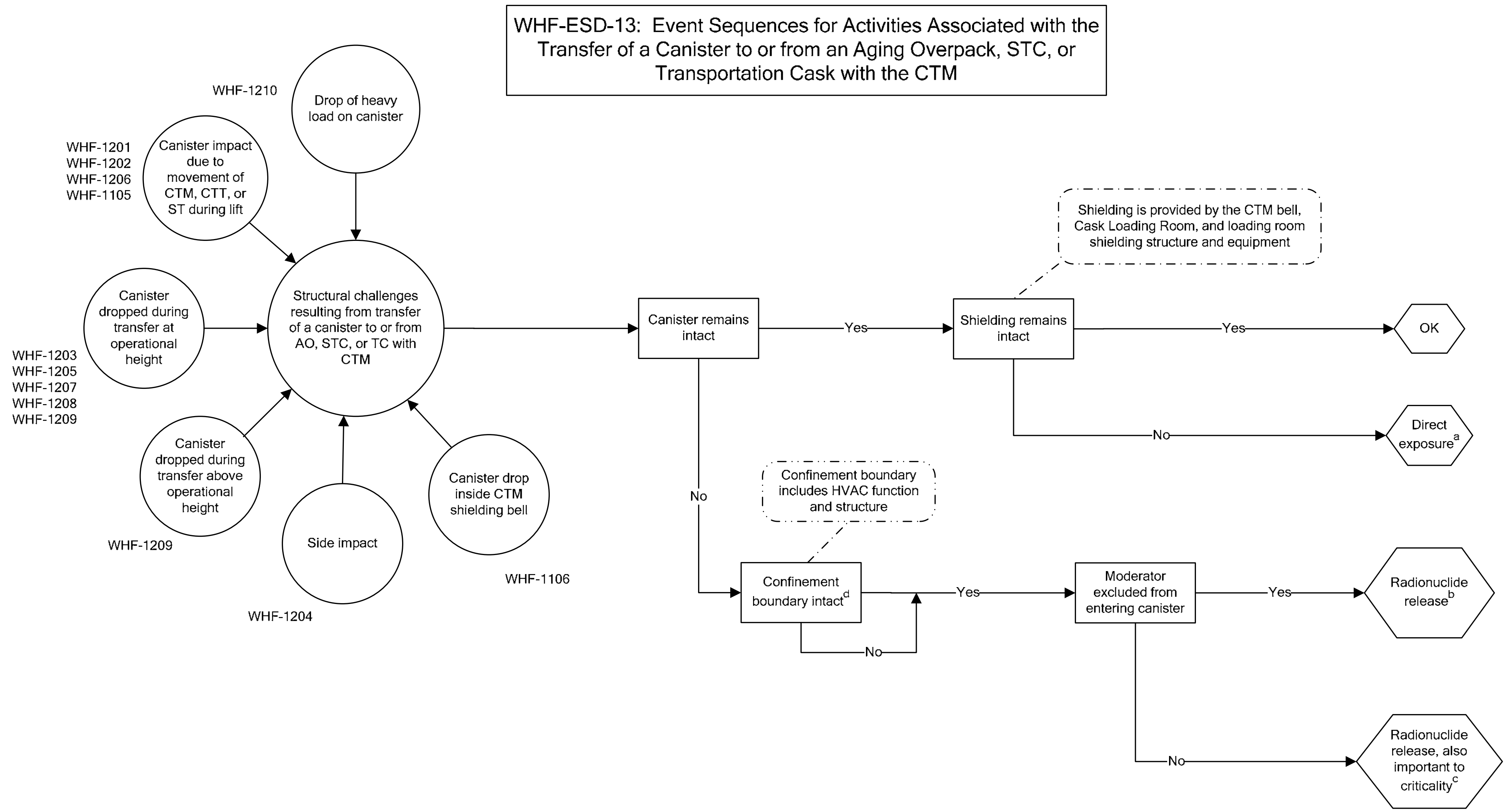
[d]Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

Potential for fire analyzed in fire ESDs.

AO = aging overpack; CTT = cask transfer trolley; DPC = dual-purpose canister; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; ST = site transporter; STC = shielded transfer cask; TAD = transportation, aging, and disposal; WHF = Wet Handling Facility.

Source: Original

Figure F-12. WHF-ESD-12 Event Sequences Associated with Aging Overpack (DPC or TAD) on Site Transporter or STC/TAD on CTT Colliding with Cask Loading Shield Door



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 which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.

[c] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister

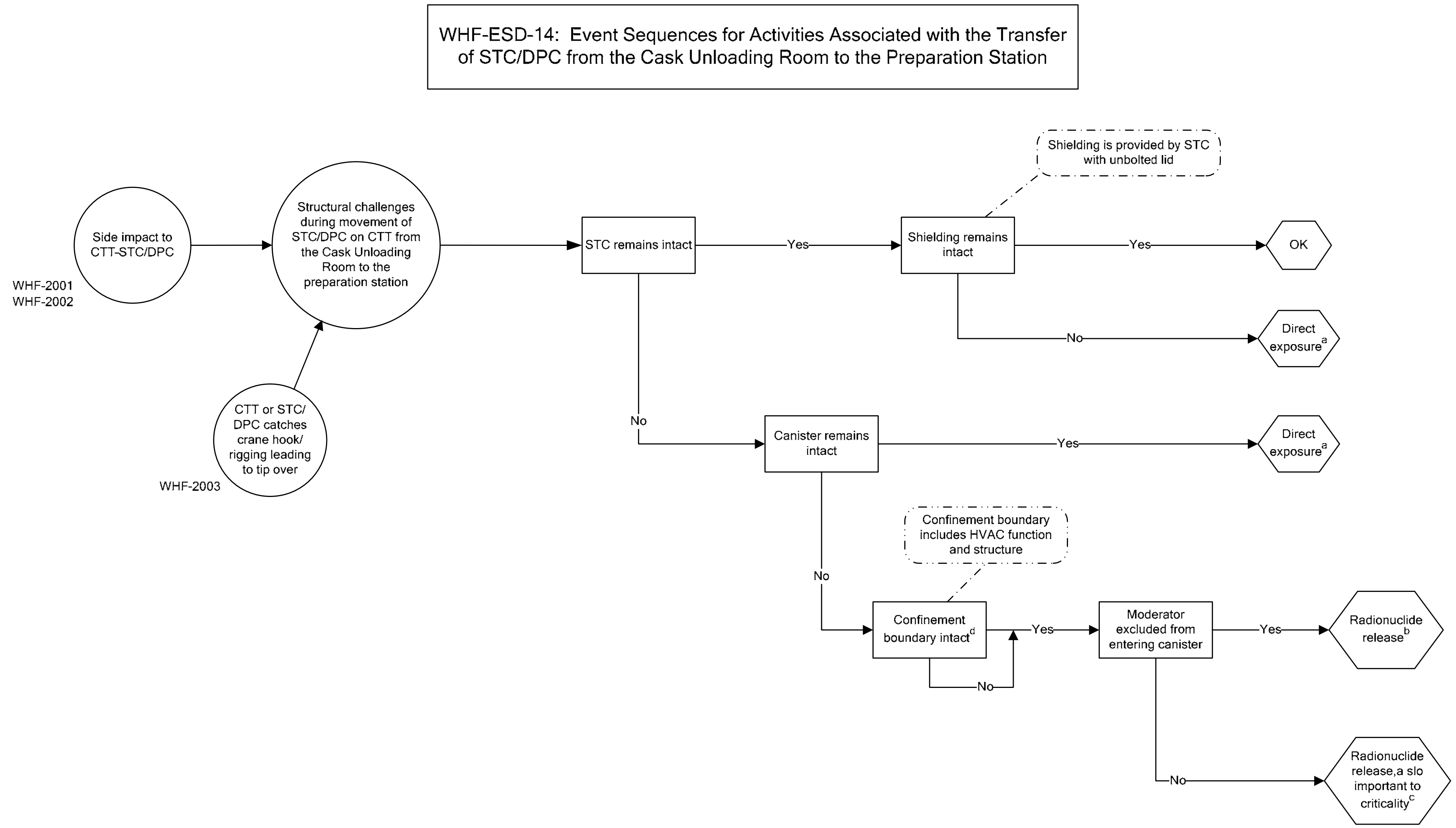
[d] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

Potential for fire analyzed in fire ESDs. Canister striking structures results in a drop. For sequence involving two containers, failure path of pivot event “One canister breached” represents the breach of two canisters.

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

Source: Original

Figure F-13. WHF-ESD-13 Event Sequences for Activities Associated with the Transfer of a Canister to or from an Aging Overpack, STC, or Transportation Cask with the CTM



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 which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.

[c] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

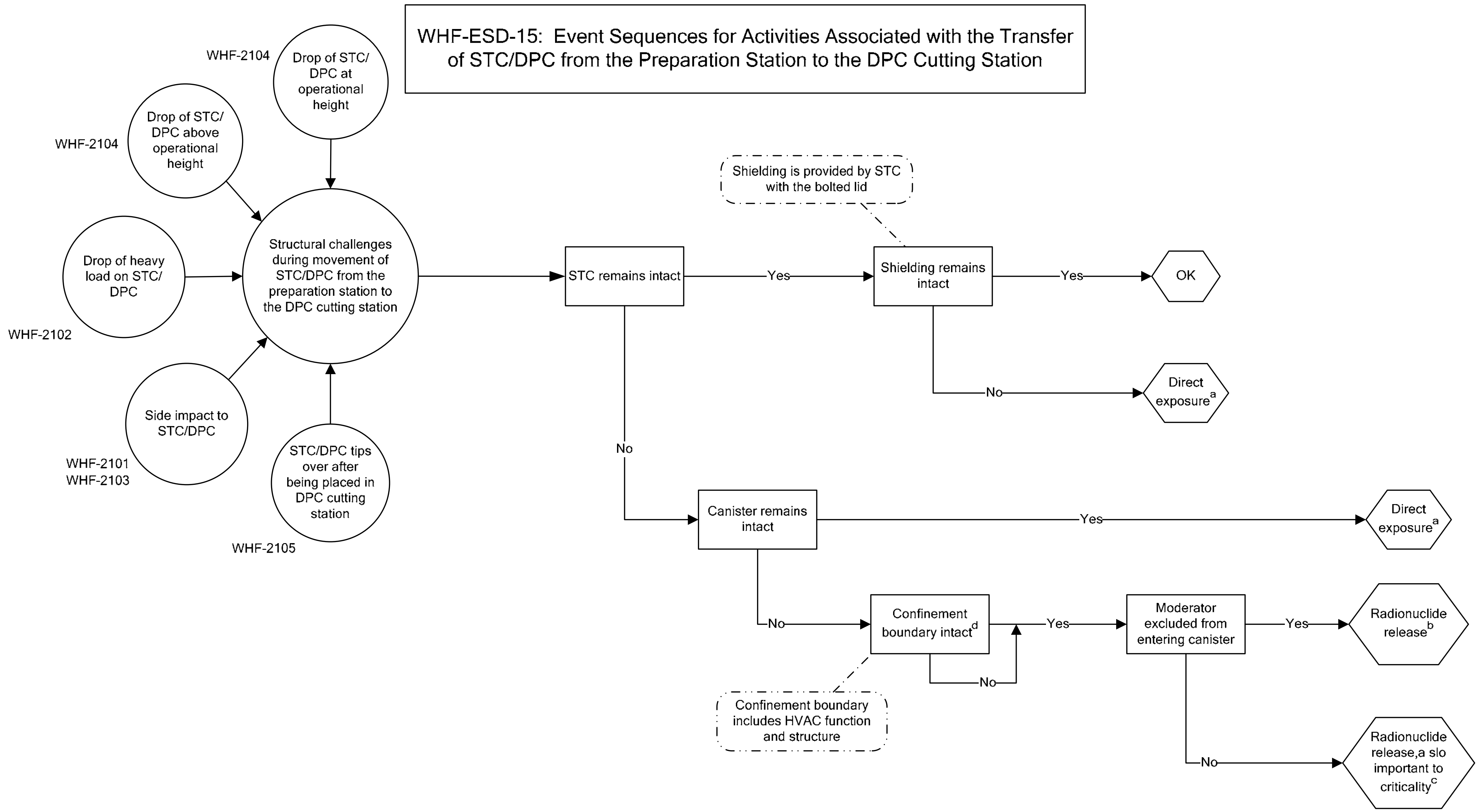
[d] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

Potential for fire analyzed in fire ESDs.

CTT = cask transfer trolley; DPC = dual-purpose container; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

Figure F-14. WHF-ESD-14 Event Sequences for Activities Associated with the Transfer of STC/DPC from the Cask Unloading Room to the Preparation Station



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

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

[b] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

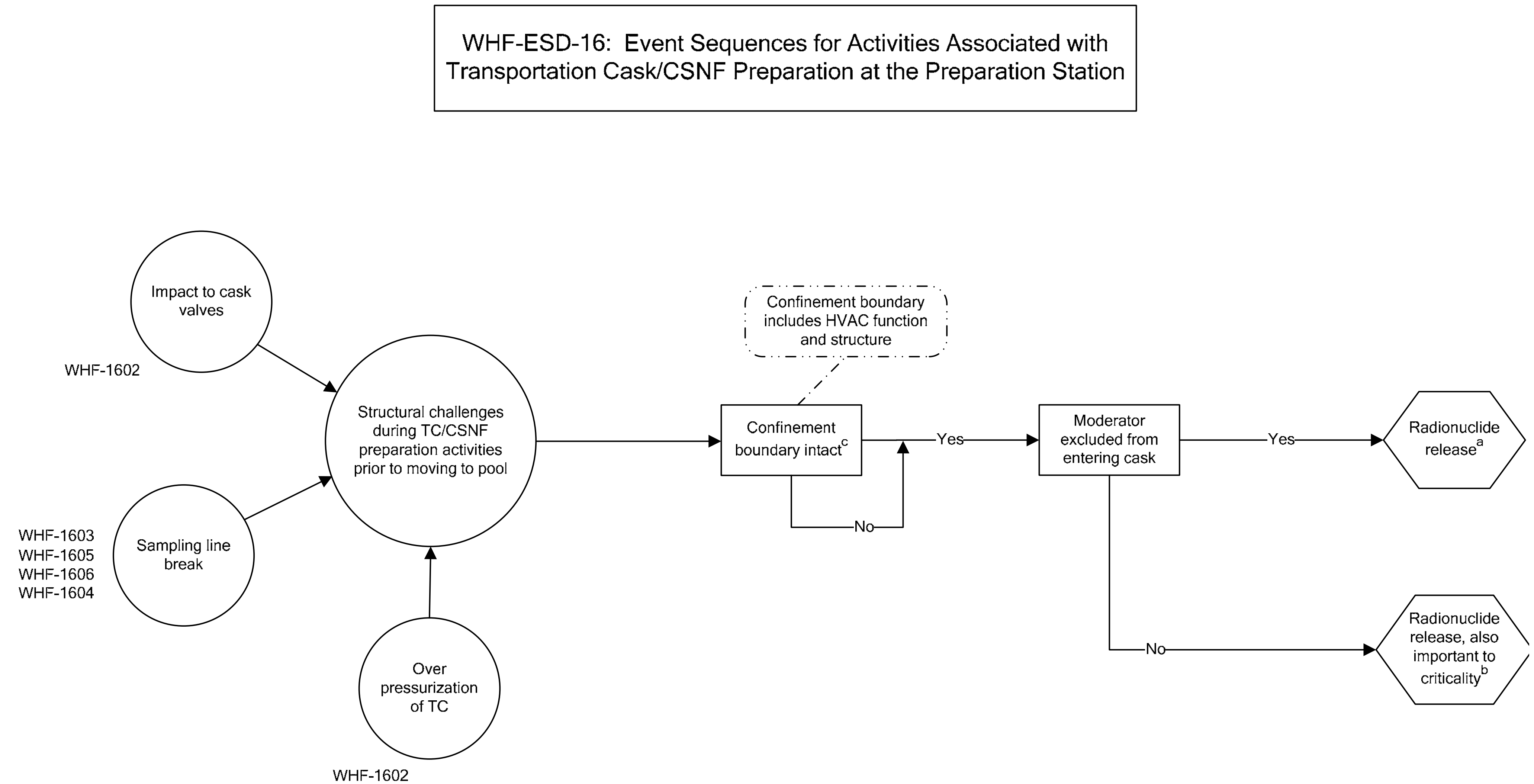
[c] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

[d] Potential for fire analyzed in fire ESDs.

DPC = dual-purpose container; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

Figure F-15. WHF-ESD-15 Event Sequences for Activities Associated with the Transfer of STC/DPC from the Preparation Station to the DPC Cutting Station



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

[b] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

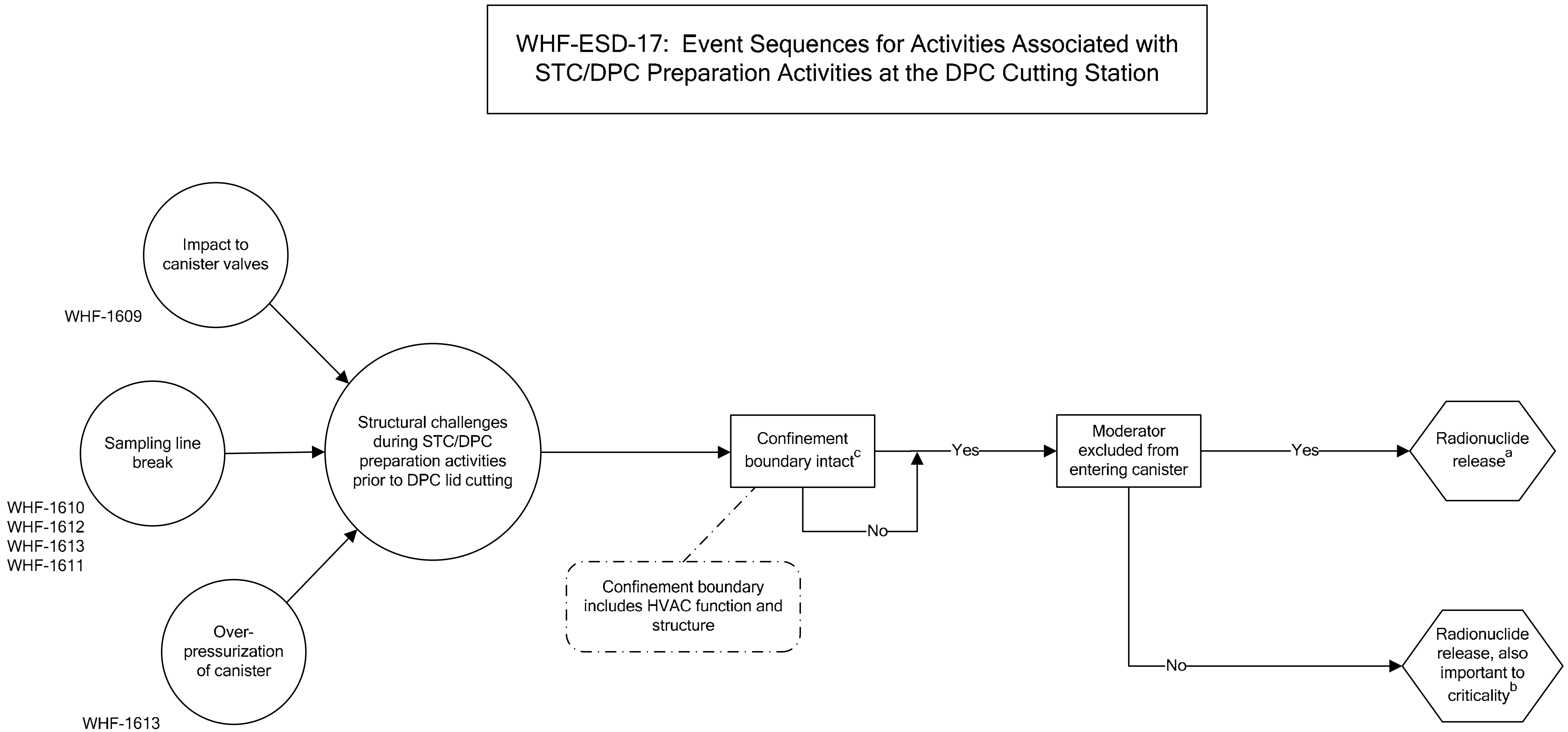
[c] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

Potential for fire analyzed in fire ESDs.

CSNF = commercial spent nuclear fuel; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Figure F-16. WHF-ESD-16 Event Sequences for Activities Associated with Transportation Cask/CSNF Preparation at the Preparation Station



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

Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

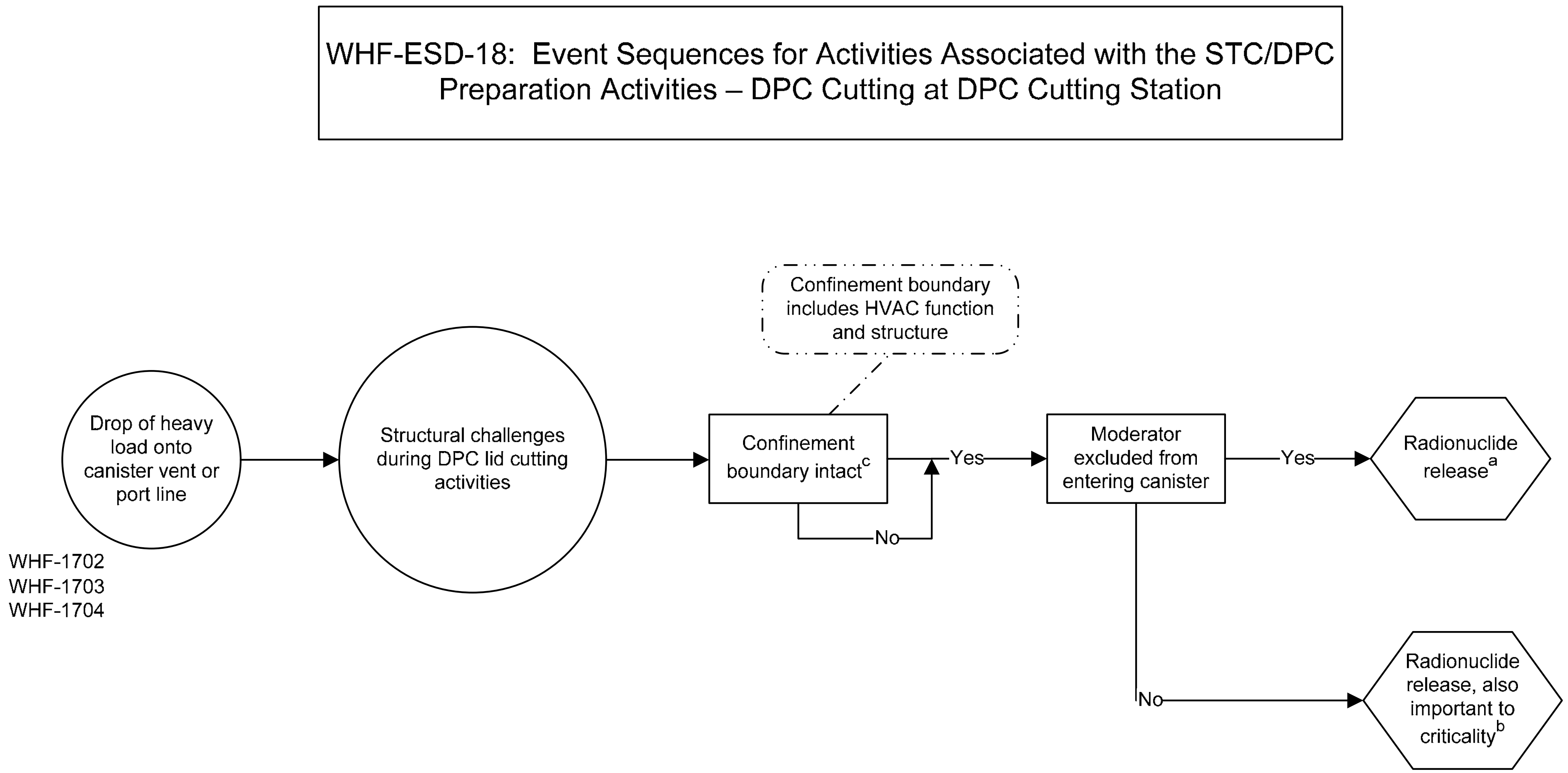
[b] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

[c] Potential for fire analyzed in fire ESDs.

DPC = dual-purpose canister; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

Figure F-17. WHF-ESD-17 Event Sequences for Activities Associated with STC/DPC Preparation Activities at the DPC Cutting Station



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

[b] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

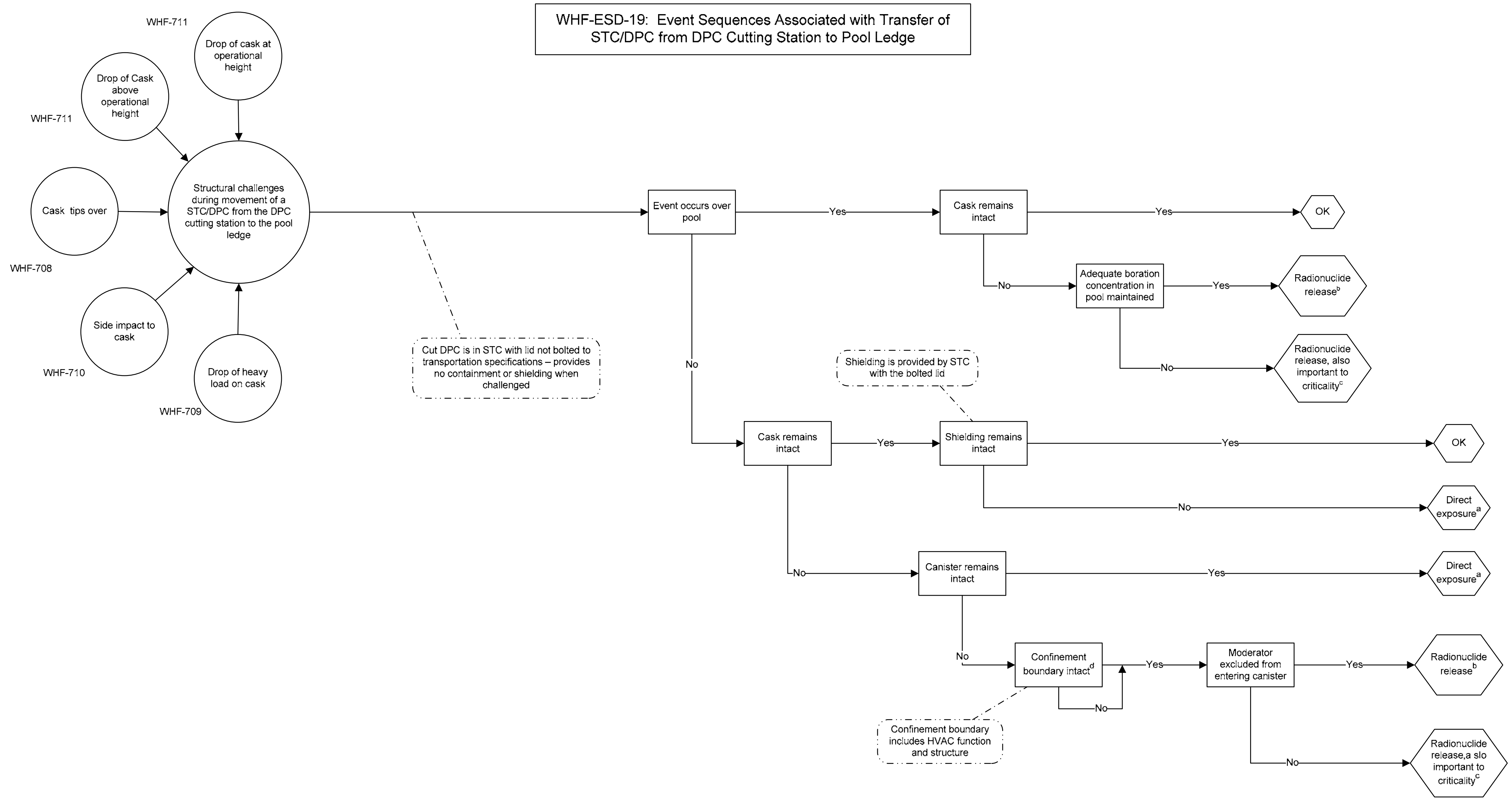
[c] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

Potential for fire analyzed in fire ESDs.

DPC = dual-purpose canister; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

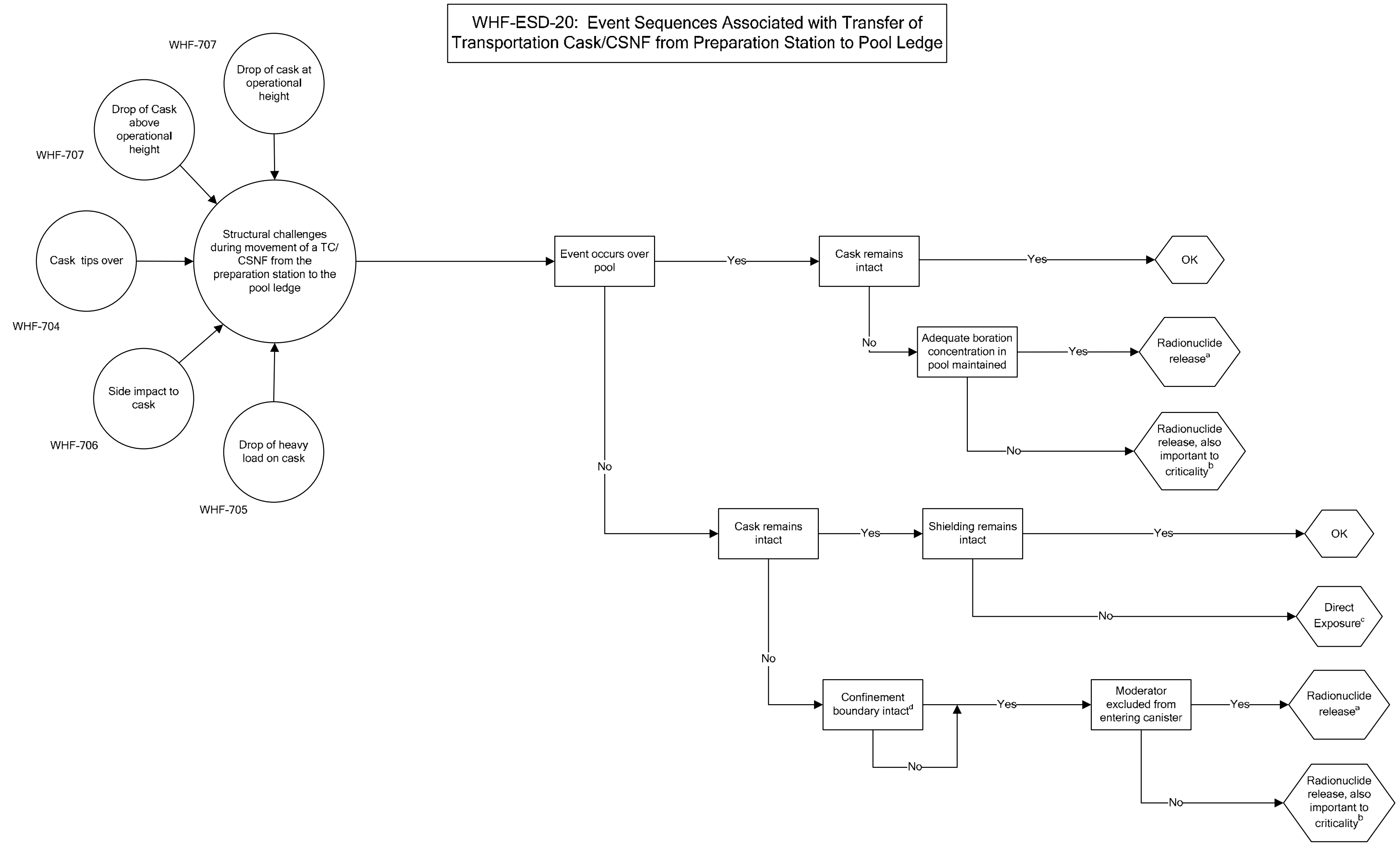
Figure F-18. WHF-ESD-18 Event Sequences for Activities Associated with the STC/DPC Preparation Activities–DPC Cutting at DPC Cutting Station



NOTE: [a] Direct exposure is that condition where individuals are directly exposed to the radiation beam streaming through areas where shielding has been compromised.
Radionuclide release describes a condition where radioactive material has been released from the container creating an inhalation or ingestion hazard which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.
Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material.
[b] A moderator is present and may enter the canister.
[c] 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.
DPC = dual-purpose canister; ESD = event sequence diagram; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

Figure F-19. WHF-ESD-19 Event Sequences Associated with Transfer of STC/DPC from DPC Cutting Station to Pool Ledge



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

Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

Direct exposure is that condition where individuals are directly exposed to the radiation beam streaming through areas where shielding has been compromised.

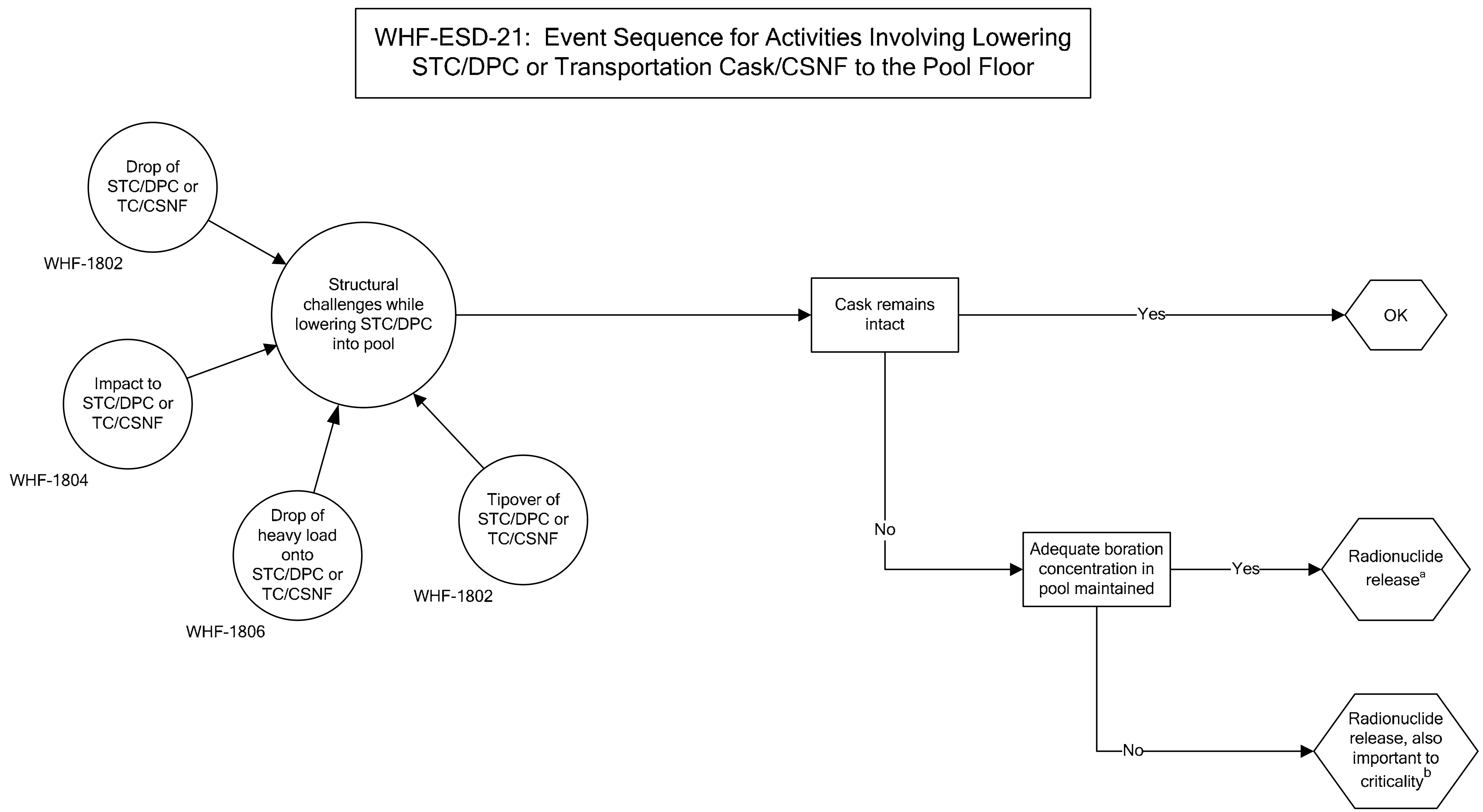
[b] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

[c] Potential for fire analyzed in fire ESDs.

[d] CSNF = commercial spent nuclear fuel; ESD = event sequence diagram; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Figure F-20. WHF-ESD-20 Event Sequences Associated with Transfer of Transportation Cask/CSNF from Preparation Station to Pool Ledge



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

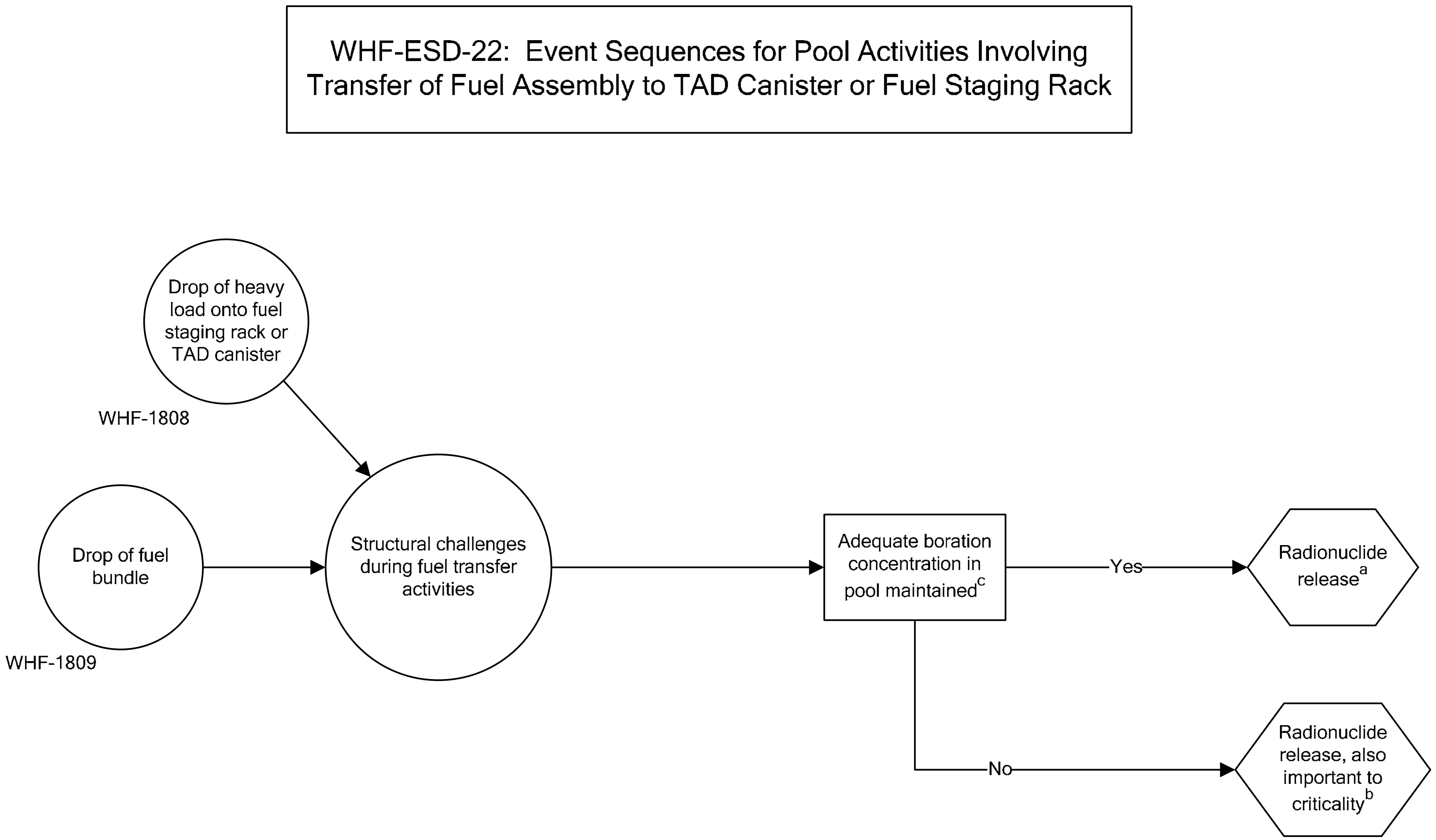
Radionuclide release, also important to criticality describes a condition where both a release occurs and the pool containment boundaries have been compromised such that boration of the pool water could be affected.

[b] Potential for fire analyzed in fire ESDs.

CSNF = commercial spent nuclear fuel; DPC = dual purpose canister; ESD = event sequence diagram; STC = shielded transfer cask; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Figure F-21. WHF-ESD-21 Event Sequences for Activities Involving Lowering STC/DPC or Transportation Cask/CSNF to the Pool Floor



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

Radionuclide release, also important to criticality describes a condition where both a release occurs and the pool containment boundaries have been compromised such that boration of the pool water could be affected.

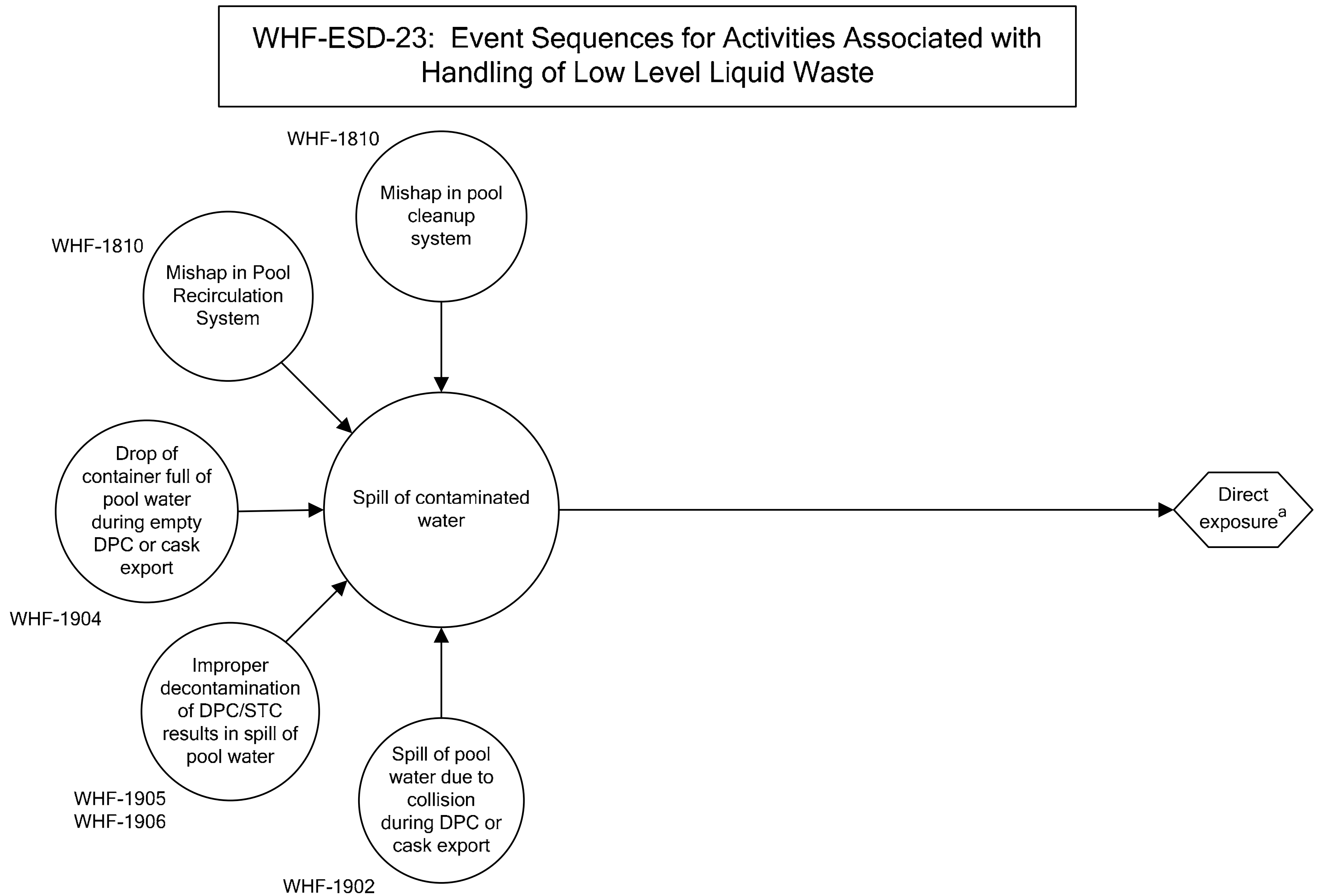
[b] Loss of boration concurrent with the right geometry (e.g., damaged fuel array, damaged fuel rack, collection of fissile material at bottom of pool) would lead to conditions important to a criticality.

[c] Potential for fire analyzed in fire ESDs.

ESD = event sequence diagram; TAD = transportation, aging, and disposal; WHF = Wet Handling Facility.

Source: Original

Figure F-22. WHF-ESD-22 Event Sequences for Pool Activities Involving Transfer of Fuel Assembly to TAD Canister or Fuel Staging Rack

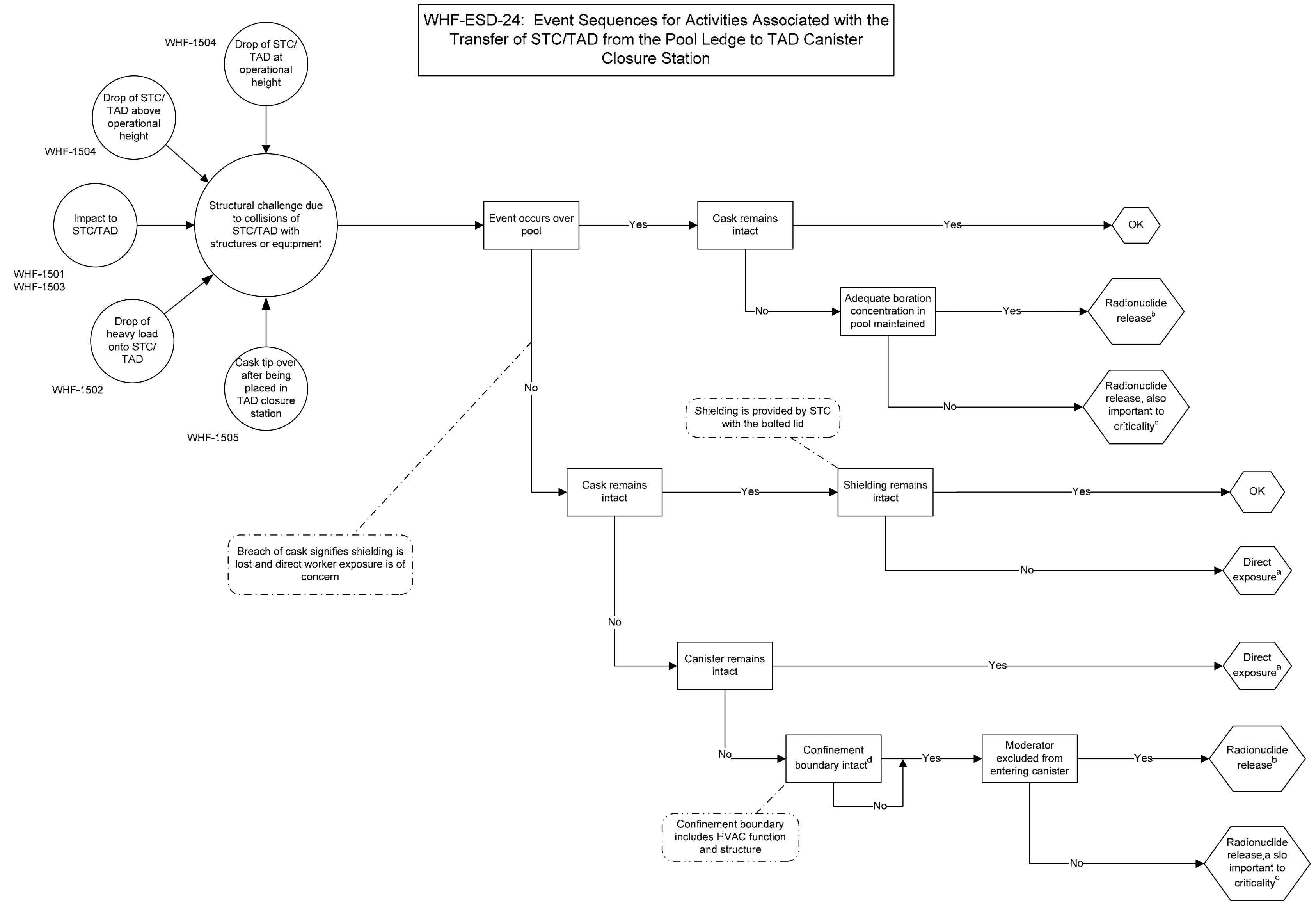


NOTE: [a]Direct exposure is that condition where individuals are directly exposed to the radiation beam streaming through areas where shielding has been compromised. Potential for fire analyzed in fire ESDs.

ESD = event sequence diagram; WHF = Wet Handling Facility.

Source: Original

Figure F-23. WHF-ESD-23 Event Sequences for Activities Associated with Handling of Low Level Liquid Waste



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 which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.

[c] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

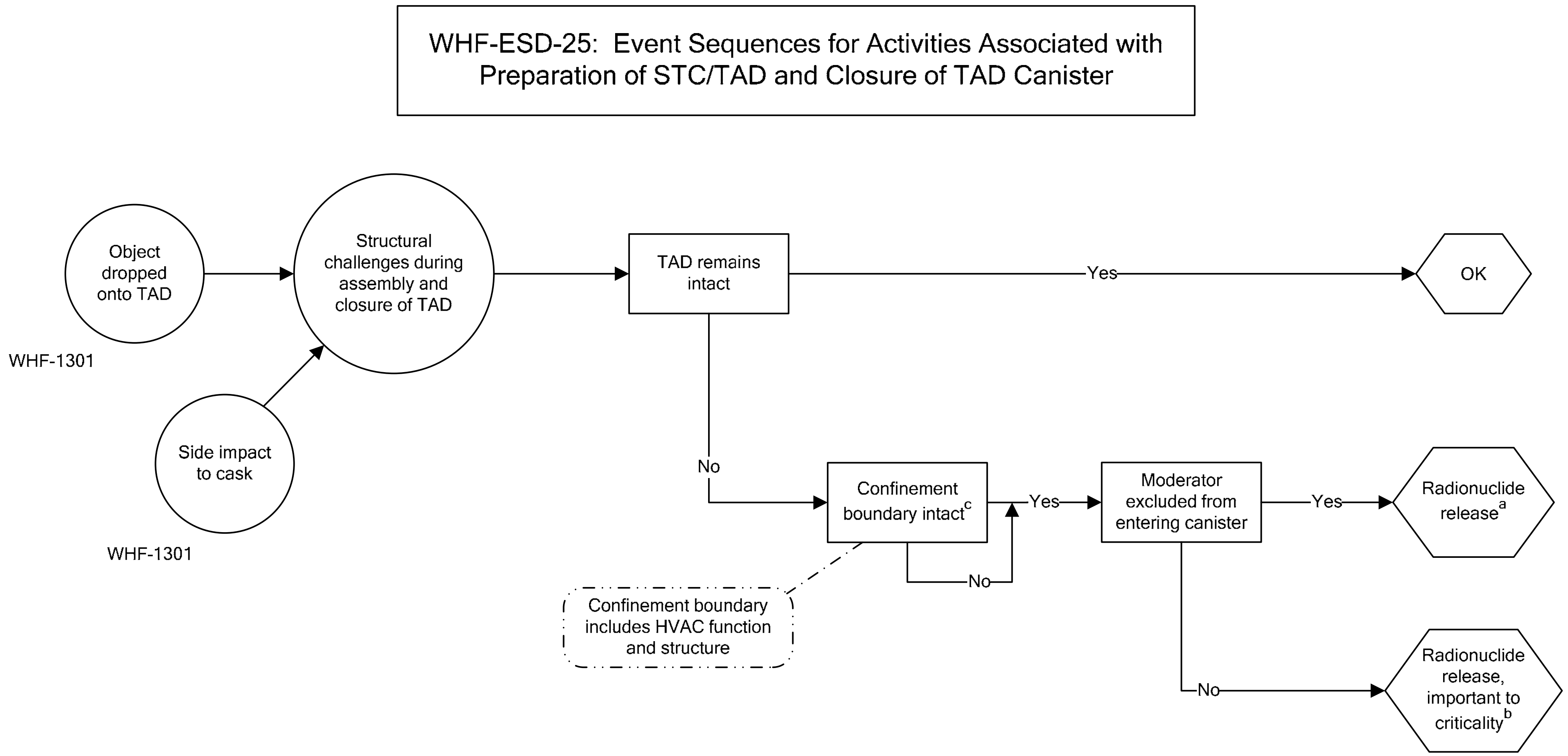
[d] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

Potential for fire analyzed in fire ESDs.

ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; STC = shielded transfer cask; TAD = transportation, aging, and disposal; WHF = Wet Handling Facility.

Source: Original

Figure F-24. WHF-ESD-24 Event Sequences for Activities Associated with the Transfer of STC/TAD from the Pool Ledge to TAD Canister Closure Station



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

Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

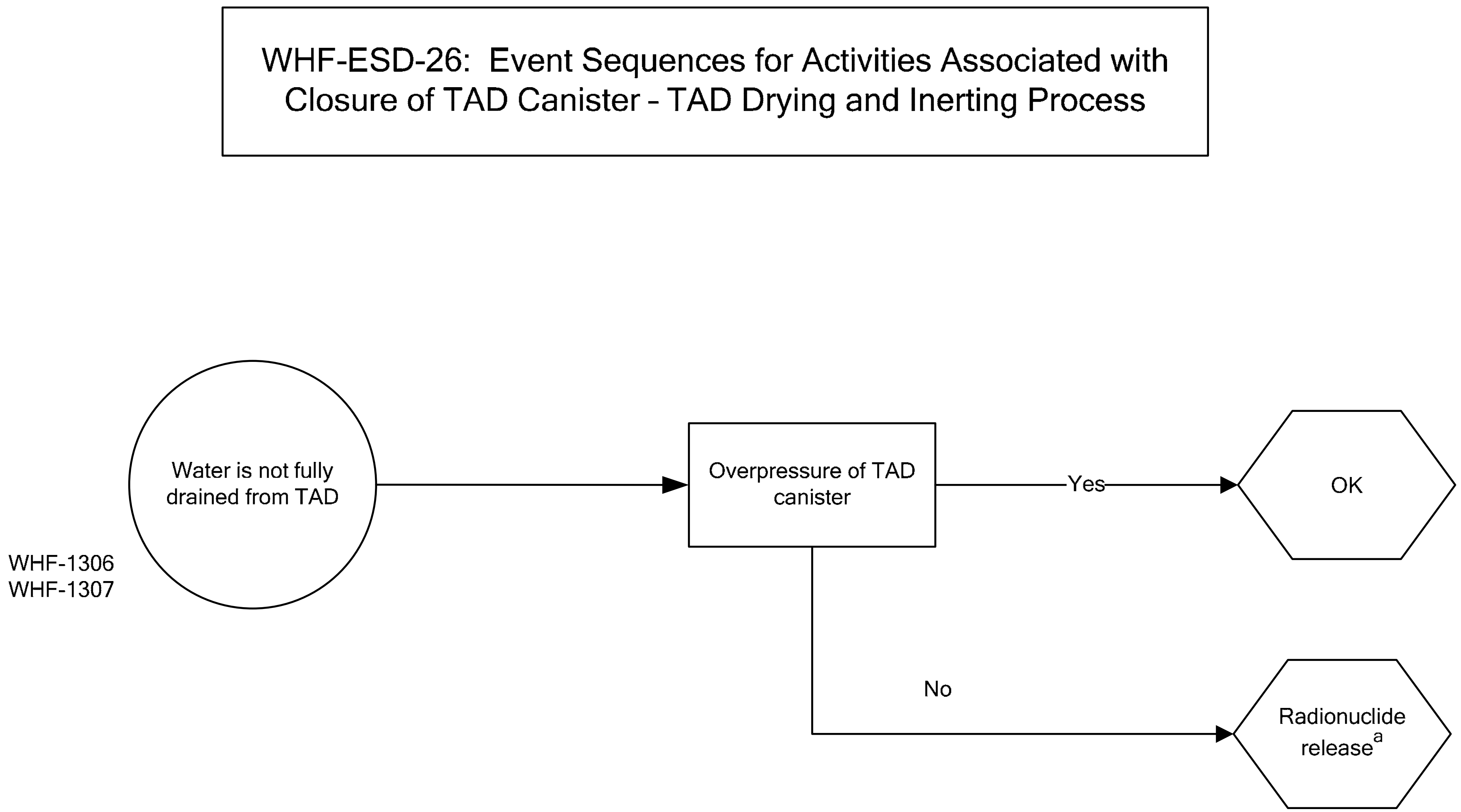
Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

[b] Potential for fire analyzed in fire ESDs.

[c] ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; STC = shielded transfer cask; TAD = transportation, aging, and disposal; WHF = Wet Handling Facility.

Source: Original

Figure F-25. WHF-ESD-25 Event Sequences for Activities Associated with Preparation of STC/TAD and Closure of TAD Canister

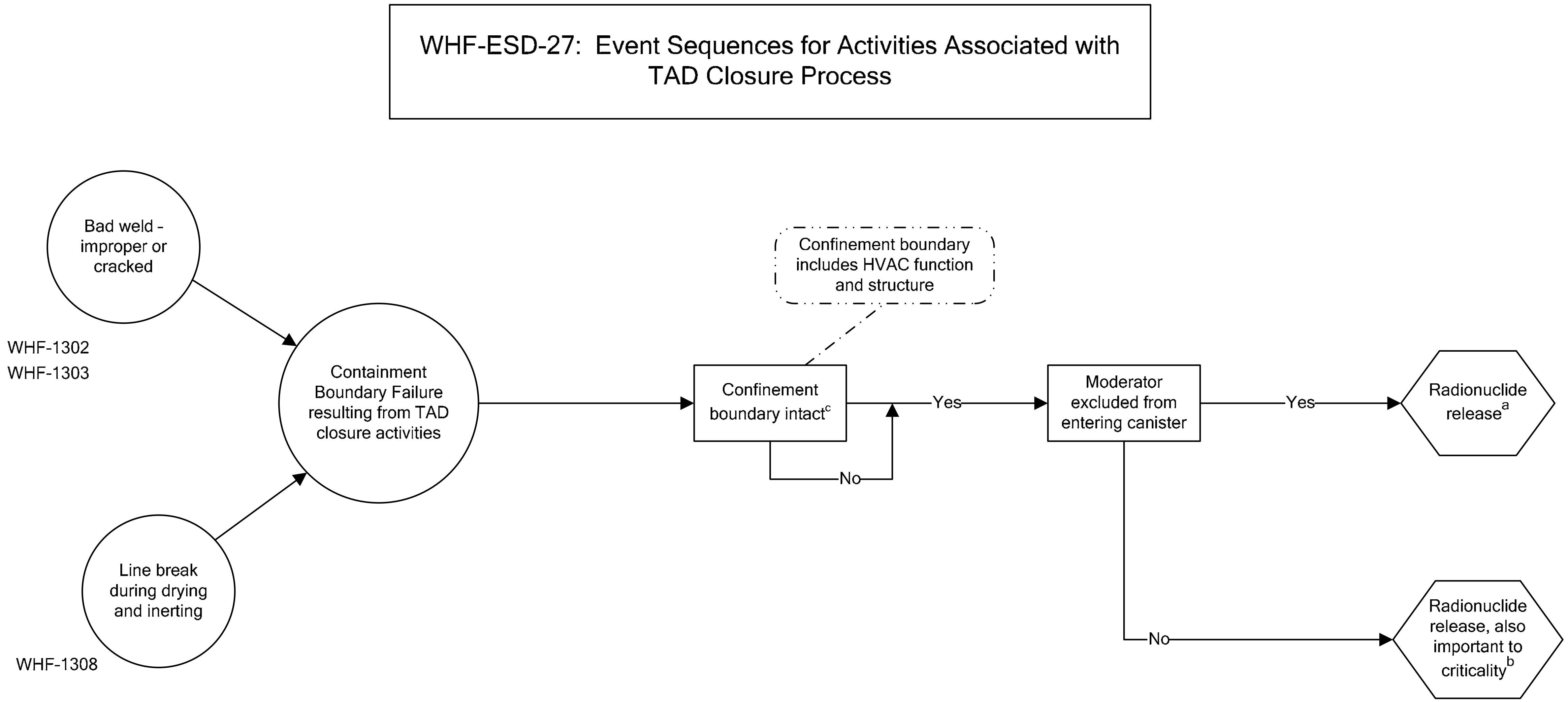


NOTE: [a]Radionuclide release describes a condition where radioactive material has been released from the container creating an inhalation or ingestion hazard which is accompanied by the dose received from emersion in the plume, and direct exposure, described above.
Potential for fire analyzed in fire ESDs.

ESD = event sequence diagram; STC = shielded transfer cask; TAD = transportation, aging, and disposal; WHF = Wet Handling Facility.

Source: Original

Figure F-26. WHF-ESD-26 Event Sequences for Activities Associated with Closure of TAD Canister – TAD Drying and Inerting Process



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

[b] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

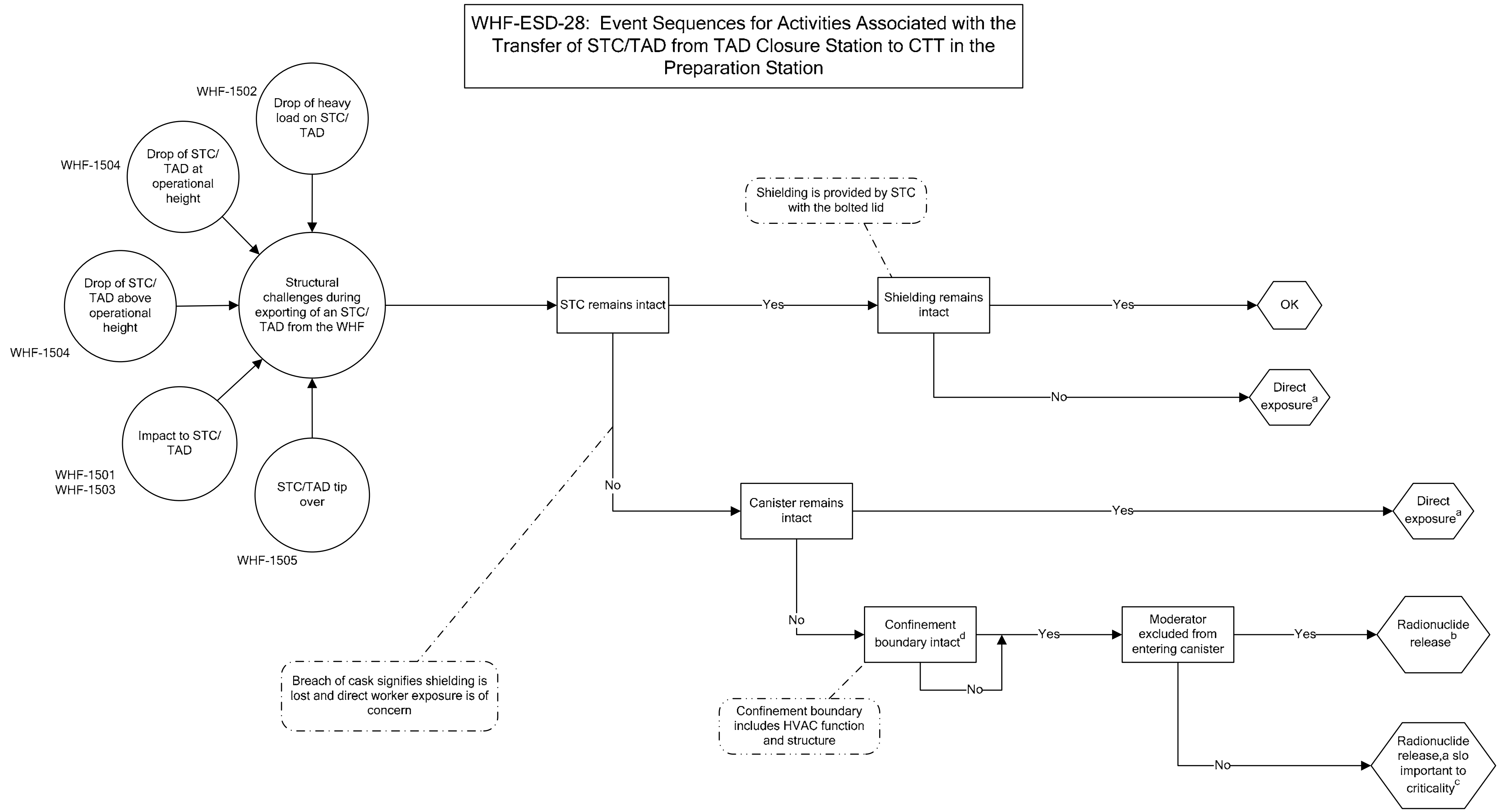
Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

[c] Potential for fire analyzed in fire ESDs.

ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; STC = shielded transfer cask; TAD = transportation, aging, and disposal; WHF = Wet Handling Facility.

Source: Original

Figure F-27. WHF-ESD-27 Event Sequences for Activities Associated with TAD Closure – Welding, Drying, and Inerting Process



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

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

[b] Radionuclide releases important to criticality describes a condition where the containment boundaries have been compromised, releasing radioactive material. A moderator is present and may enter the canister.

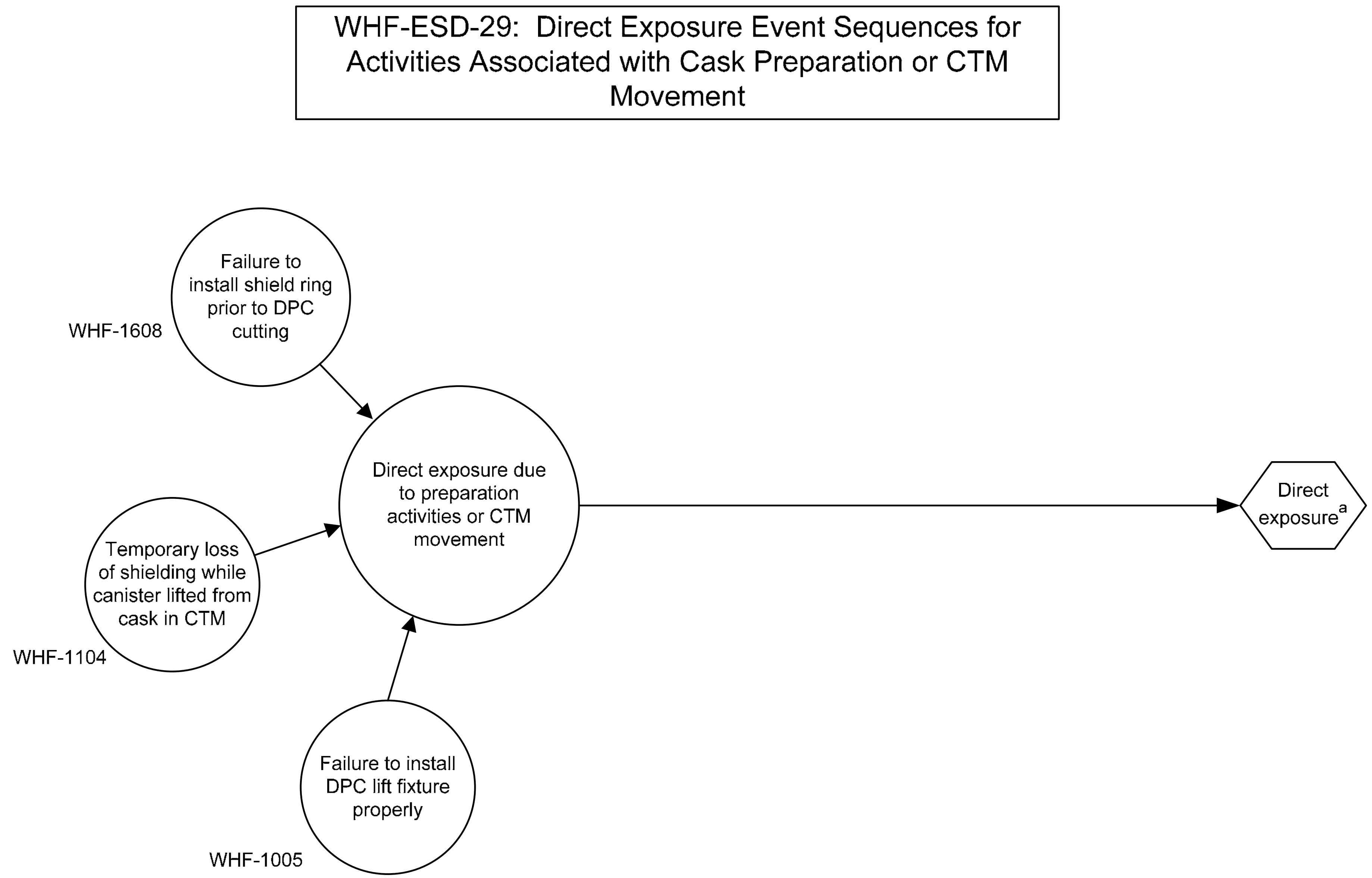
[c] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

[d] Potential for fire analyzed in fire ESDs.

CTT = cask transport trolley; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; STC = shielded transfer cask; TAD = transportation, aging, and disposal canister; WHF = Wet Handling Facility.

Source: Original

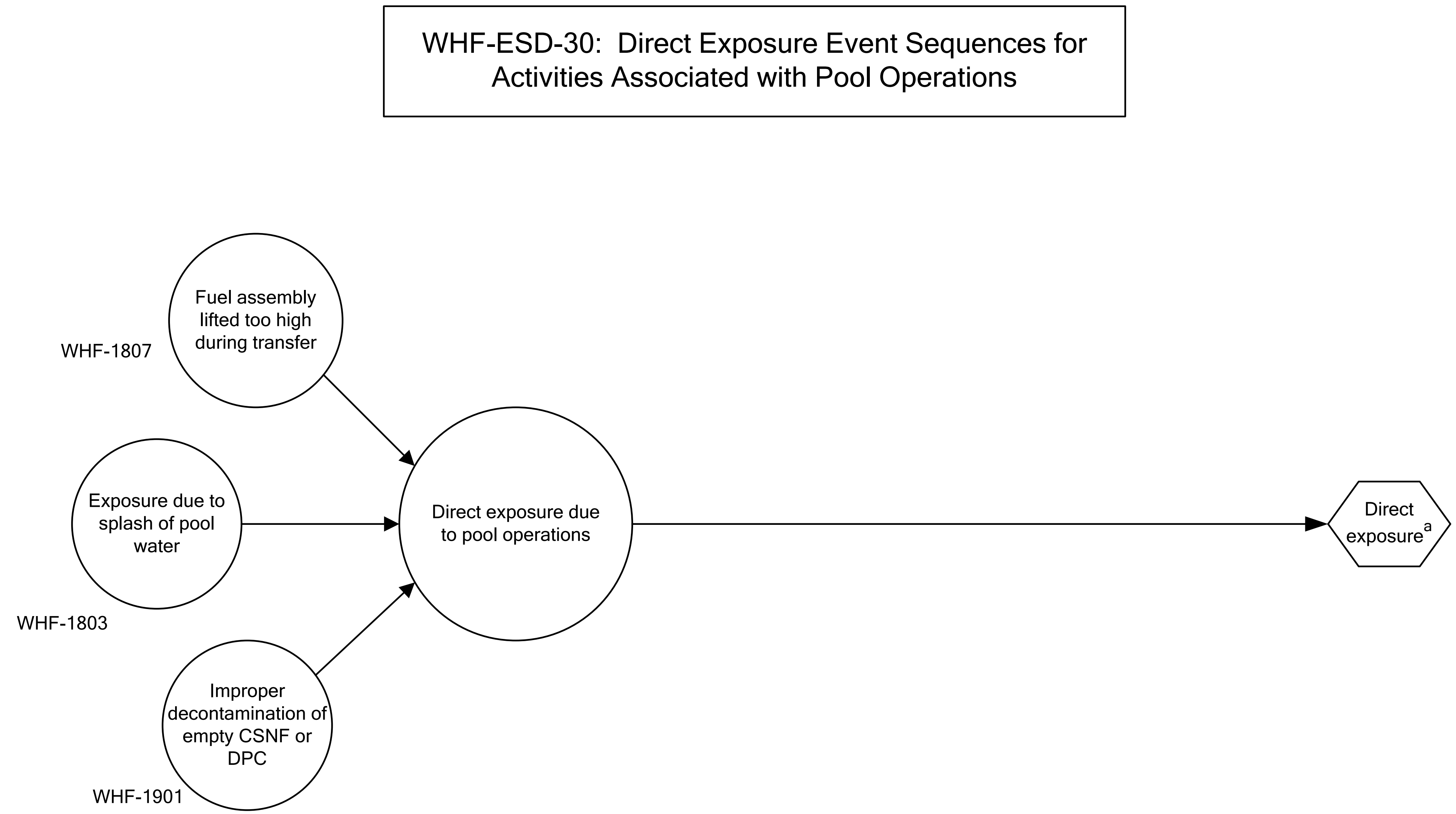
Figure F-28. WHF-ESD-28 Event Sequences for Activities Associated with Transfer of STC/TAD from TAD Closure Station to CTT in the Preparation Station



NOTE: [a]Direct exposure is that condition where individuals are directly exposed to the radiation beam streaming through areas where shielding has been compromised.
Potential for fire analyzed in fire ESDs.
CTM = cask transfer machine; DPC = dual-purpose canister; ESD = event sequence diagram; WHF = Wet Handling Facility.

Source: Original

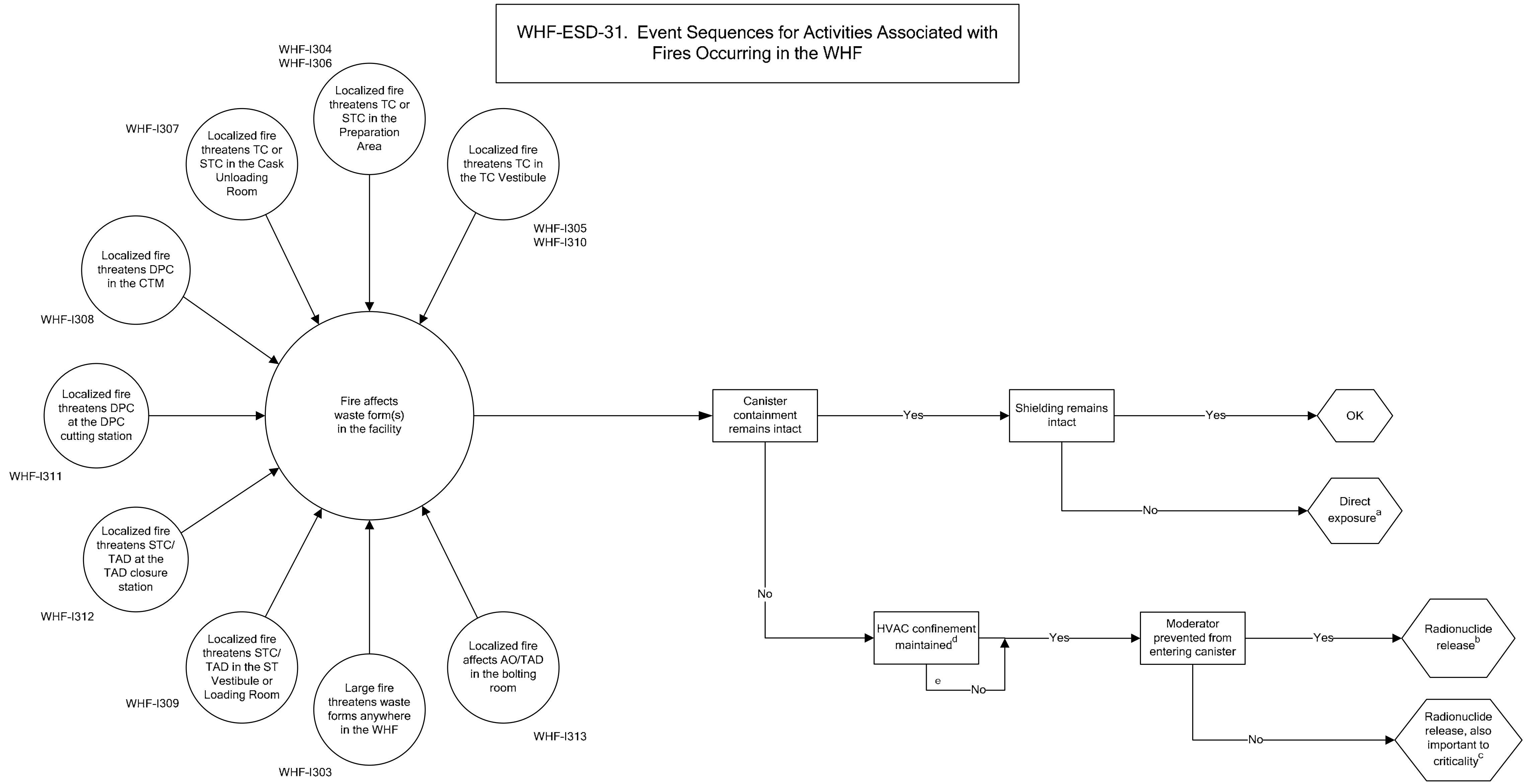
Figure F-29. WHF-ESD-29 Direct Exposure Event Sequences for Activities Associated with Cask Preparation or CTM Movement



NOTE: [a] Direct exposure is that condition where individuals are directly exposed to the radiation beam streaming through areas where shielding has been compromised.
Potential for fire analyzed in fire ESDs.
CSNF = commercial spent nuclear fuel; DPC = dual-purpose canister; ESD = event sequence diagram; WHF = Wet Handling Facility.

Source: Original

Figure F-30. WHF-ESD-30 Direct Exposure Event Sequences for Activities Associated with Pool Operations



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 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.

CTM = canister transfer machine; DPC = dual-purpose canister; HVAC = heating, ventilation, and air conditioning; ST = site transporter; STC = shielded transfer cask; TAD = transportation, aging, and disposal; TC = transportation cask; WHF = Wet Handling Facility.

Source: Original

Figure F-31. WHF-ESD-31 Event Sequences for Activities Associated with Fires Occurring in the WHF

ATTACHMENT G
WET HANDLING FACILITY EVENT TREES

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

The event trees are presented in Figures G-2 through G-52 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.

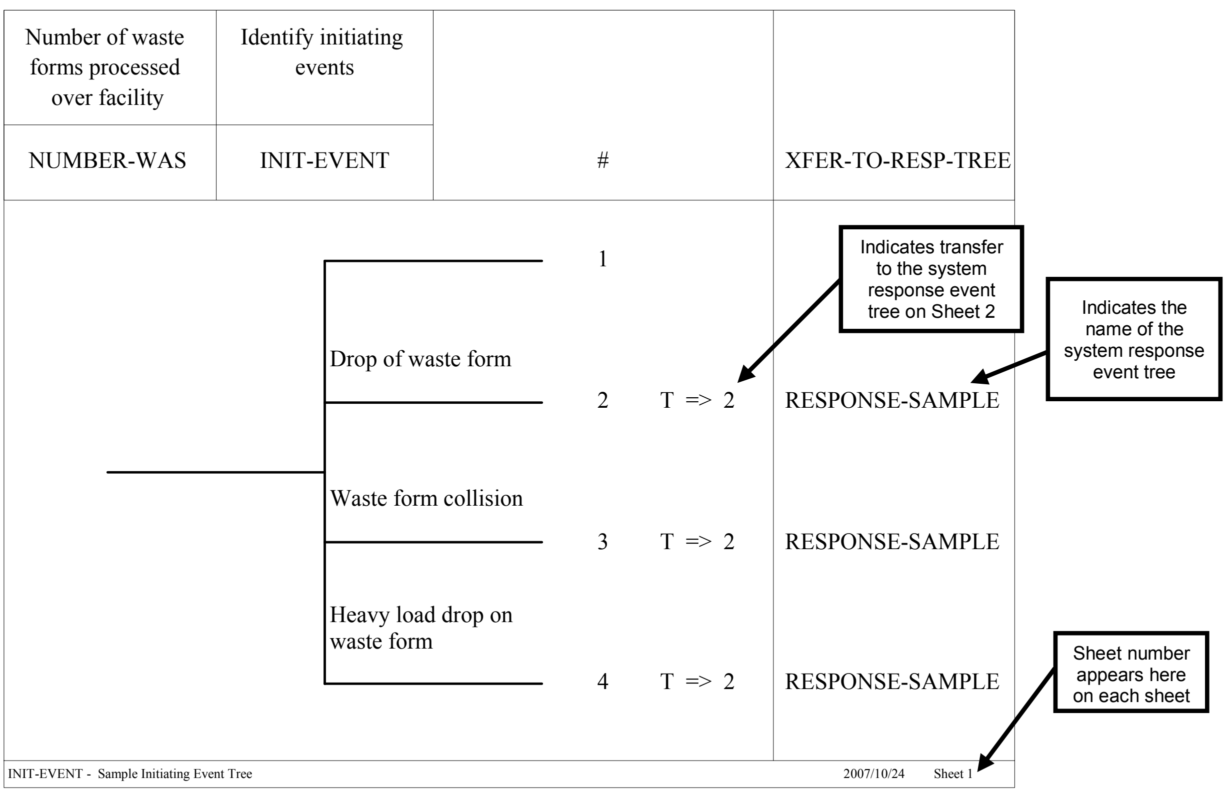


Figure G-1. Example Initiator Event Tree Showing Navigation Aids

Table G-1. ESDs to Event Trees

ESD#	ESD Title	IE Event Tree Name	IE Event Tree Location	Response Tree Name	Response Tree Location
WHF-ESD-01	Event Sequences for Activities Associated with Receipt of Transportation Cask with Spent Nuclear Fuel in the Transportation Cask Vestibule and Movement into Cask Preparation Area	WHF-ESD01-CSNF	Figure G-2	RESPONSE-TCASK-CSNF	Figure G-3
WHF-ESD-02	Event Sequences for Activities Associated with Receipt of Transportation Cask with DPC in the Transportation Cask Vestibule and Movement into Cask Preparation Area	WHF-ESD02-DPC	Figure G-4	RESPONSE-TCASK-DPC	Figure G-5
WHF-ESD-03	Event Sequences for Activities Associated with Receipt of Aging Overpack in the Site Transporter Vestibule	WHF-ESD03-AODPC	Figure G-6	RESPONSE-CANISTER1	Figure G-7
WHF-ESD-04	Event Sequences for Activities Associated with Receipt of Horizontal STC/DPC in the Transportation Cask Vestibule and Movement into the Cask Preparation Area	WHF-ESD04-DPC	Figure G-8	RESPONSE-STC1	Figure G-9
WHF-ESD-05	Event Sequences for Activities Associated with TC/CSNF Removal of Impact Limiters, Upending, and Removal from Conveyance and Transfer to Preparation Station	WHF-ESD05-CSNF	Figure G-10	RESPONSE-TCASK-CSNF	Figure G-3
WHF-ESD-06	Event Sequences for Activities Associated with Removal of Impact Limiters, Upending, and Removal of Transportation Cask from Conveyance and Transfer to CTT	WHF-ESD06-VTC WHF-ESD06-TTC	Figure G-11 Figure G-13	RESPONSE-TCASK	Figure G-12

Table G-1. ESDs to Event Trees (Continued)

ESD#	ESD Title	IE Event Tree Name	IE Event Tree Location	Response Tree Name	Response Tree Location
WHF-ESD-07	Event Sequences for Associated Cask Preparation Activities (i.e., Installation of Lid Lift Fixture on Transportation Cask/DPC)	WHF-ESD07-DPC	Figure G-14	RESPONSE-TCASK	Figure G-12
WHF-ESD-08	Event Sequences for Associated Cask Preparation Activities (i.e., Installation of Cask Lid Lift Fixture on Transportation Cask/CSNF)	WHF-ESD08-CSNF	Figure G-15	RESPONSE-TCASK-CSNF	Figure G-3
WHF-ESD-09	Event Sequences for Associated Cask Preparation Activities (i.e., Lid Removal, or Installation of DPC Lid Lift Fixture, STC/DPC or Transportation Cask/DPC)	WHF-ESD09-DPC	Figure G-16	RESPONSE-CANISTER1	Figure G-7
WHF-ESD-10	Event Sequences for Associated with Transfer of Cask on CTT from Preparation Area to Cask Unloading Room	WHF-ESD10-DPC	Figure G-17	RESPONSE-CANISTER1	Figure G-7
WHF-ESD-11	Event Sequences Associated with Transfer of an Aging Overpack/DPC or Aging Overpack/TAD on Site Transporter, through Site Transporter Vestibule, Aging Overpack Access Platform, and Loading Room (Receipt or Export)	WHF-ESD11-AODPC WHF-ESD11-AOTAD	Figure G-18 Figure G-19	RESPONSE-CANISTER1	Figure G-7
WHF-ESD-12	Event Sequences Associated with Aging Overpack (DPC or TAD) on Site Transporter or STC/TAD on CTT Colliding with Cask Loading Shield Door	WHF-ESD12-DPC WHF-ESD12-TAD	Figure G-20 Figure G-21	N/A	N/A
WHF-ESD-13	Event Sequences for Activities Associated with the Transfer of a Canister to or from an Aging Overpack, STC, or Transportation Cask with the CTM	WHF-ESD13-DPC WHF-ESD13-TAD	Figure G-22 Figure G-23	RESPONSE-CANISTER1	Figure G-7

Table G-1. ESDs to Event Trees (Continued)

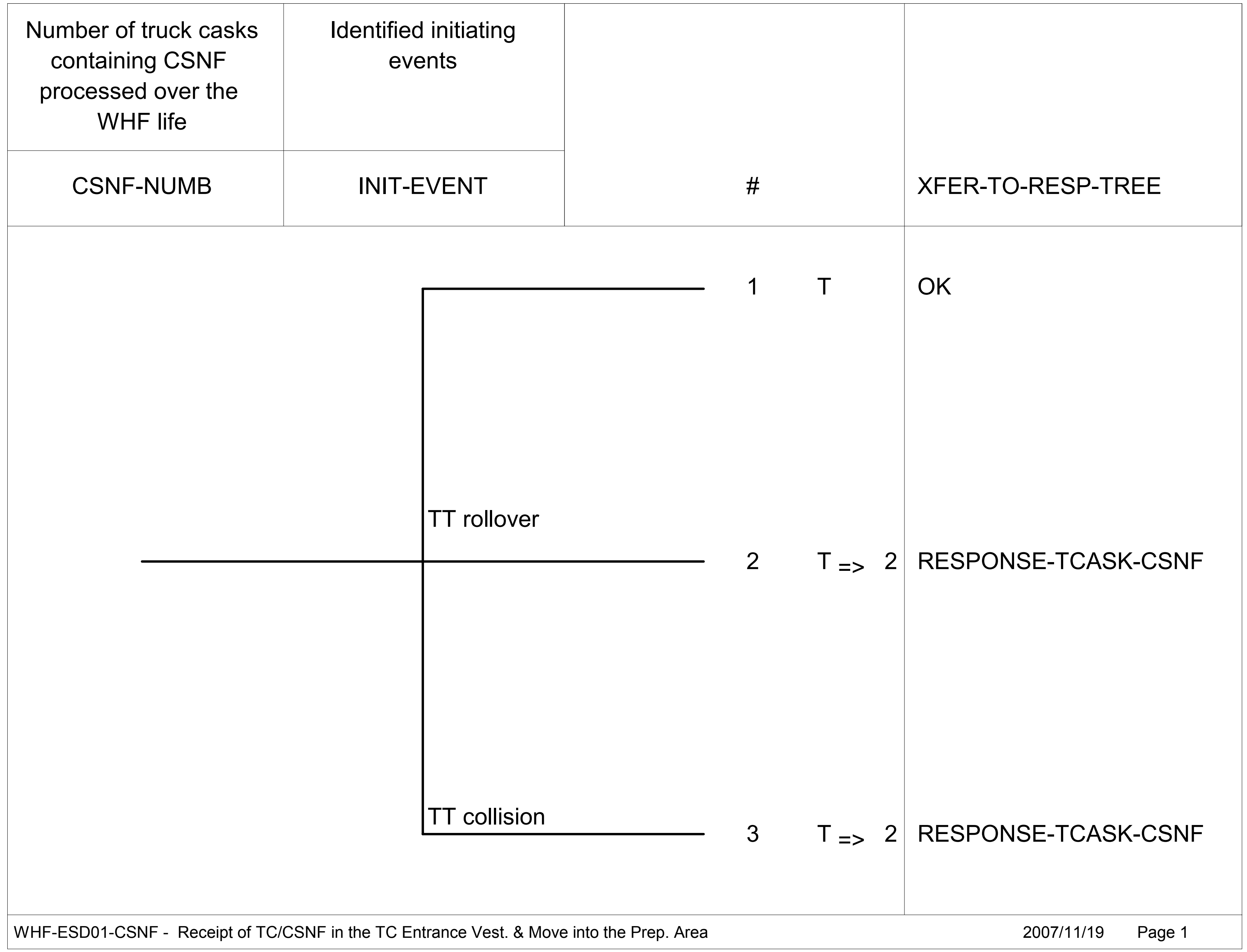
ESD#	ESD Title	IE Event Tree Name	IE Event Tree Location	Response Tree Name	Response Tree Location
WHF-ESD-14	Event Sequences for Activities Associated with the Transfer of STC/DPC from the Cask Unloading Room to the Preparation Station	WHF-ESD14-DPC	Figure G-24	RESPONSE-STC1	Figure G-9
WHF-ESD-15	Event Sequences for Activities Associated with the Transfer of STC/DPC from the Preparation Station to the DPC Cutting Station	WHF-ESD15-DPC	Figure G-25	RESPONSE-STC1	Figure G-9
WHF-ESD-16	Event Sequences for Activities Associated with the STC/DPC Preparation at the Preparation Station	WHF-ESD16-CSNF	Figure G-26	RESPONSE-PREPSTATION	Figure G-27
WHF-ESD-17	Event Sequences for Activities Assoicated with the STC/DPC Preparation Activities at the DPC Cutting Station	WHF-ESD17-DPC	Figure G-28	RESPONSE-PREPSTATION	Figure G-27
WHF-ESD-18	Event Sequences for Activities Associated with the STC/DPC Preparation Activities – DPC Cutting at DPC Cutting Station	WHF-ESD18-DPC	Figure G-29	RESPONSE-PREPSTATION	Figure G-27
WHF-ESD-19	Event Sequences Associated with Transfer of STC/DPC from DPC Cutting Station to Pool Ledge	WHF-ESD19-DPC	Figure G-30	RESPONSE-POOLMOVE RESPONSE-STC1	Figure G-31 Figure G-9
WHF-ESD-20	Event Sequences Associated with Transfer of Transportation Cask/CSNF from Preparation Station to Pool Ledge	WHF-ESD20-CSNF	Figure G-32	RESPONSE-POOLMOVE RESPONSE-TCASK-CSNF	Figure G-31 Figure G-3
WHF-ESD-21	Event Sequences for Activities Involving Lowering STC/DPC or Transportation Cask/CSNF to the Pool Floor	WHF-ESD21-CSNF WHF-ESD21-DPC WHF-ESD21-TAD	Figure G-33 Figure G-34 Figure G-35	RESPONSE-POOLMOVE	Figure G-31
WHF-ESD-22	Event Sequences for Pool Activities Involving Transfer of Fuel Assembly to TAD Canister or Fuel Staging Rack	WHF-ESD22-FUEL	Figure G-36	RESPONSE-POOLCONFINE	Figure G-37

Table G-1. ESDs to Event Trees (Continued)

ESD#	ESD Title	IE Event Tree Name	IE Event Tree Location	Response Tree Name	Response Tree Location
WHF-ESD-23	Event Sequences for Activities Associated with Handling of Low Level Liquid Waste	WHF-ESD23-POOL	Figure G-38	N/A	N/A
WHF-ESD-24	Event Sequences for Activities Associated with the Transfer of STC/TAD from the Pool Ledge to the TAD Canister Closure Station	WHF-ESD24-TAD	Figure G-39	RESPONSE-POOLMOVE RESPONSE-STC1	Figure G-31 Figure G-9
WHF-ESD-25	Event Sequences for Activities Associated with Preparation of STC/TAD and Closure of TAD Canister	WHF-ESD25-TAD	Figure G-40	RESPONSE-TAD	Figure G-41
WHF-ESD-26	Event Sequences for Activities Associated with Closure of TAD Canister – TAD Drying and Inerting Process	WHF-ESD26-TAD	Figure G-42	N/A	N/A
WHF-ESD-27	Event Sequences for Activities Associated with TAD Closure – Welding, Drying, and Inerting Process	WHF-ESD27-TAD	Figure G-43	RESPONSE-PREPSTATION	Figure G-27
WHF-ESD-28	Event Sequences for Activities Associated with Transfer of STC/TAD from TAD Closure Station to CTT in the Preparation Station	WHF-ESD28-TAD	Figure G-44	RESPONSE-STC1	Figure G-9
WHF-ESD-29	Direct Expsoure Event Sequences for Activities Associated with Cask Preparation or CTM Movement	WHF-ESD29-DPC WHF-ESD29-TAD	Figure G-45 Figure G-46	N/A	N/A
WHF-ESD-30	Direct Exposure Event Sequences for Activities Associated with Pool Operations	WHF-ESD30-DPC WHF-ESD30-FUEL	Figure G-47 Figure G-48	N/A	N/A
WHF-ESD-31	Event Sequences for Activities Associated with Fires Occurring in the WHF	WHF-ESD31-CSNF WHF-ESD31-DPC WHF-ESD31-TAD	Figure G-49 Figure G-51 Figure G-52	RESPONSE-FIRE	Figure G-50

NOTE: CSNF = commercial spent nuclear fuel; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; STC = shielded transportation cask; TAD = Transportation, aging, and disposal canister; TC = transportation cask.

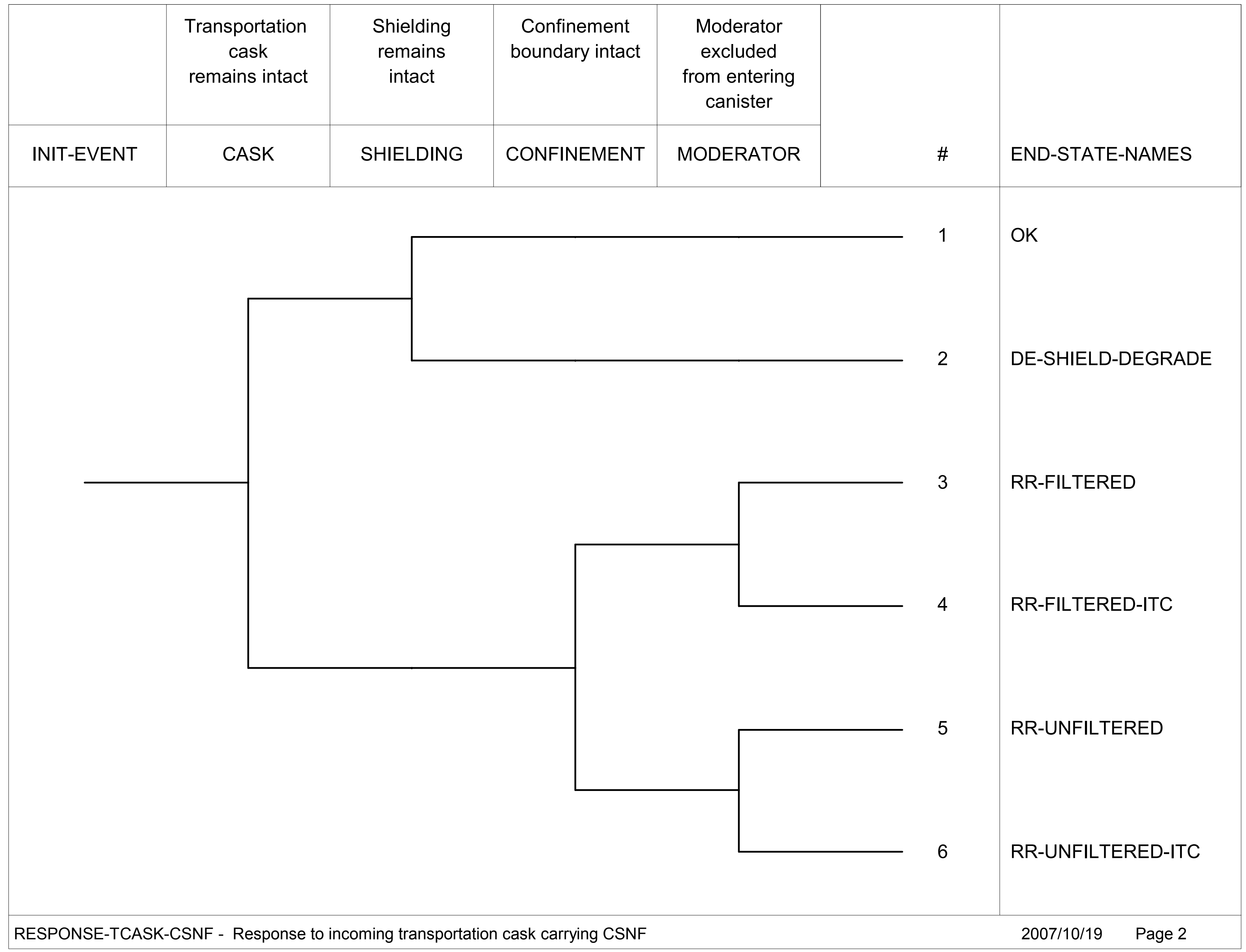
Source: Original



NOTE: CSNF = commercial spent nuclear fuel; DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; T = transfer; TT = tractor trailer; WHF = Wet Handling Facility; XFER = transfer.

Source: Original

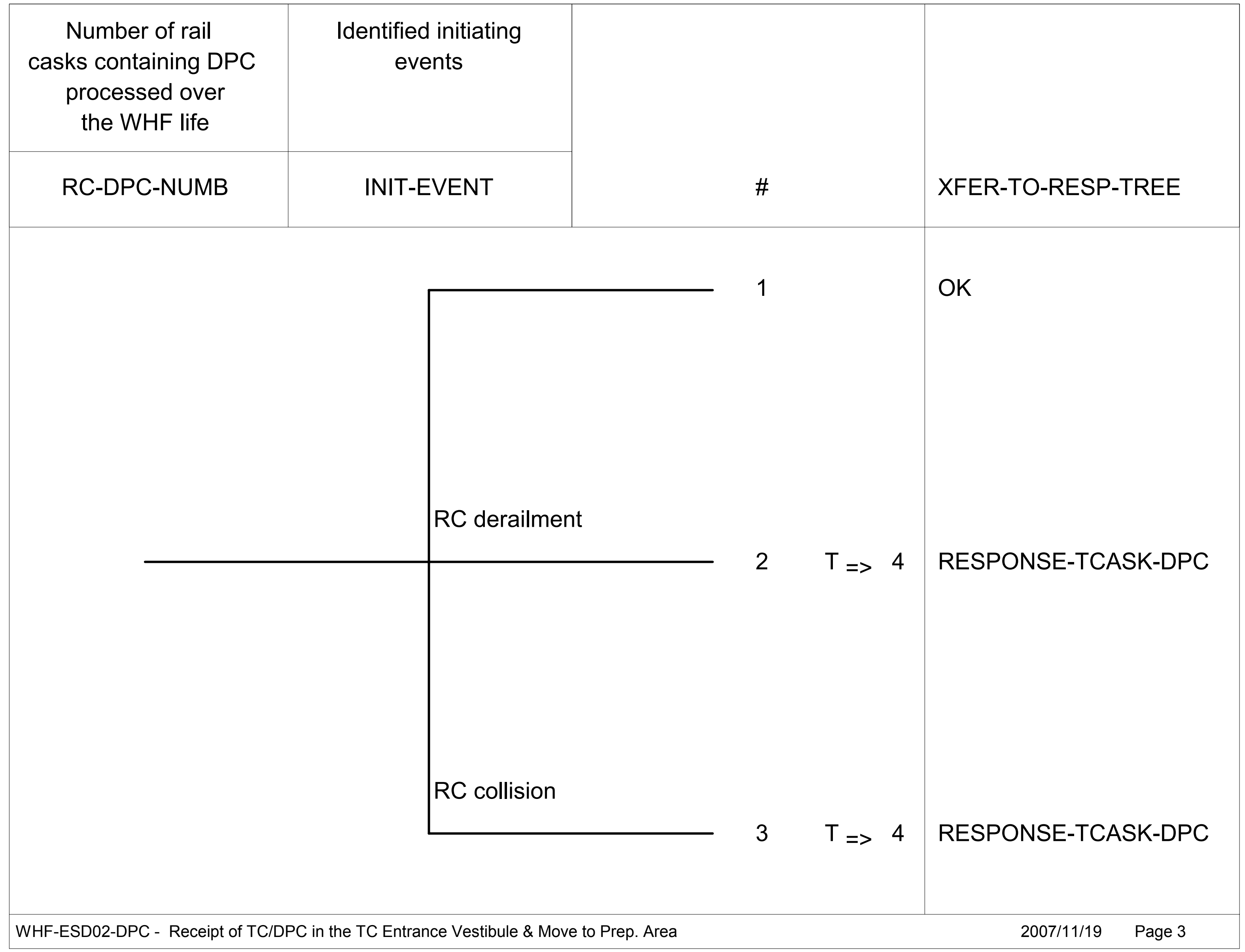
Figure G-2. Event Tree WHF-ESD01-CSNF – Receipt of Transportation Cask with Commercial SNF in the Transportation Cask Entrance Vestibule and Move into the Preparation Area



NOTE: CSNF = commercial spent nuclear fuel; DE = direct exposure; ESD = event sequence diagram; INIT = initiating; ITC = important to criticality; RR = radionuclide release; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

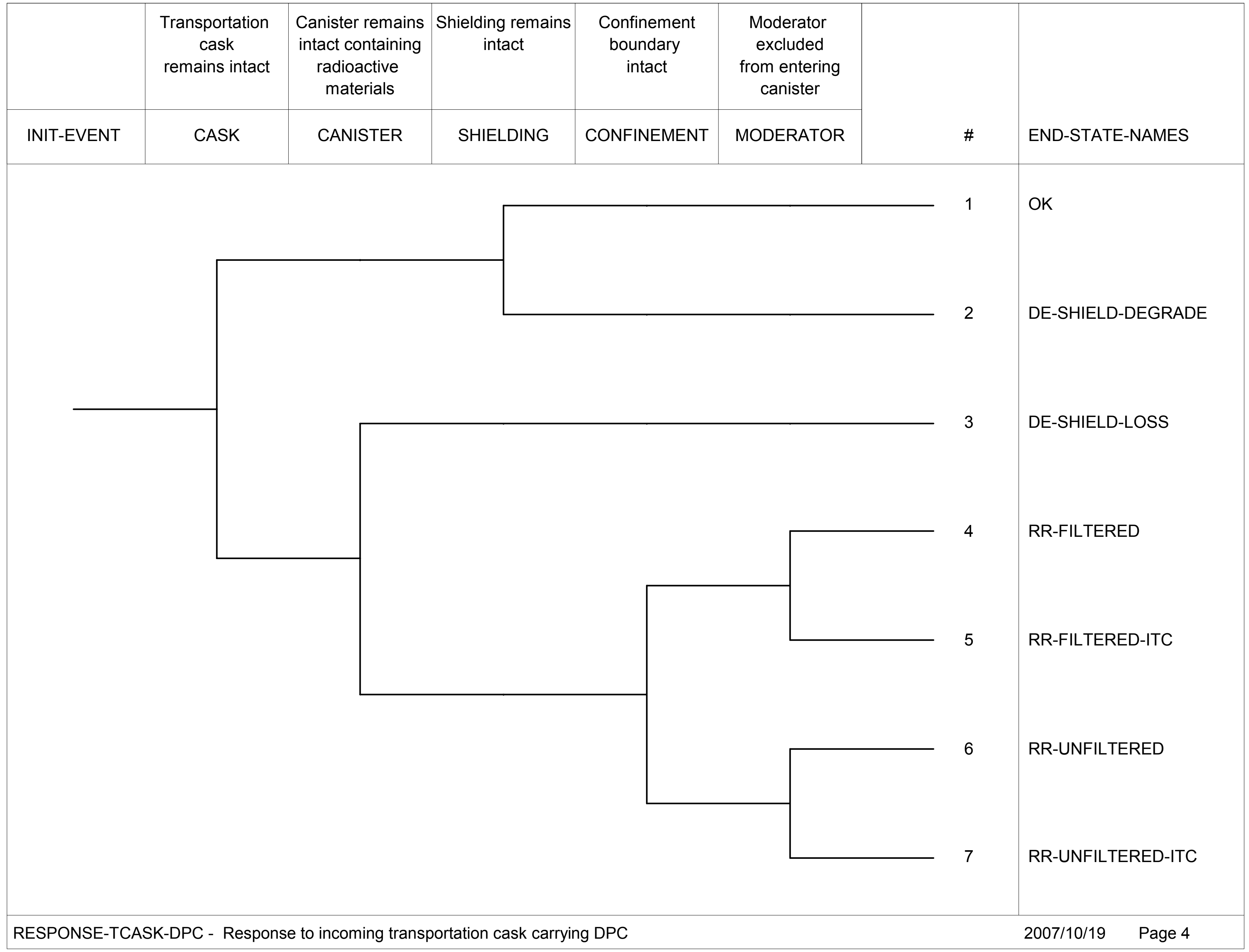
Figure G-3. Event Tree RESPONSE-TCASK-CSNF – Response to Incoming Transportation Cask Carrying Commercial SNF



NOTE: DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; NUMB = number; RC = railcar; RESP = response; T = transfer; TC = transportation cask; WHF = Wet Handling Facility; XFER = transfer.

Source: Original

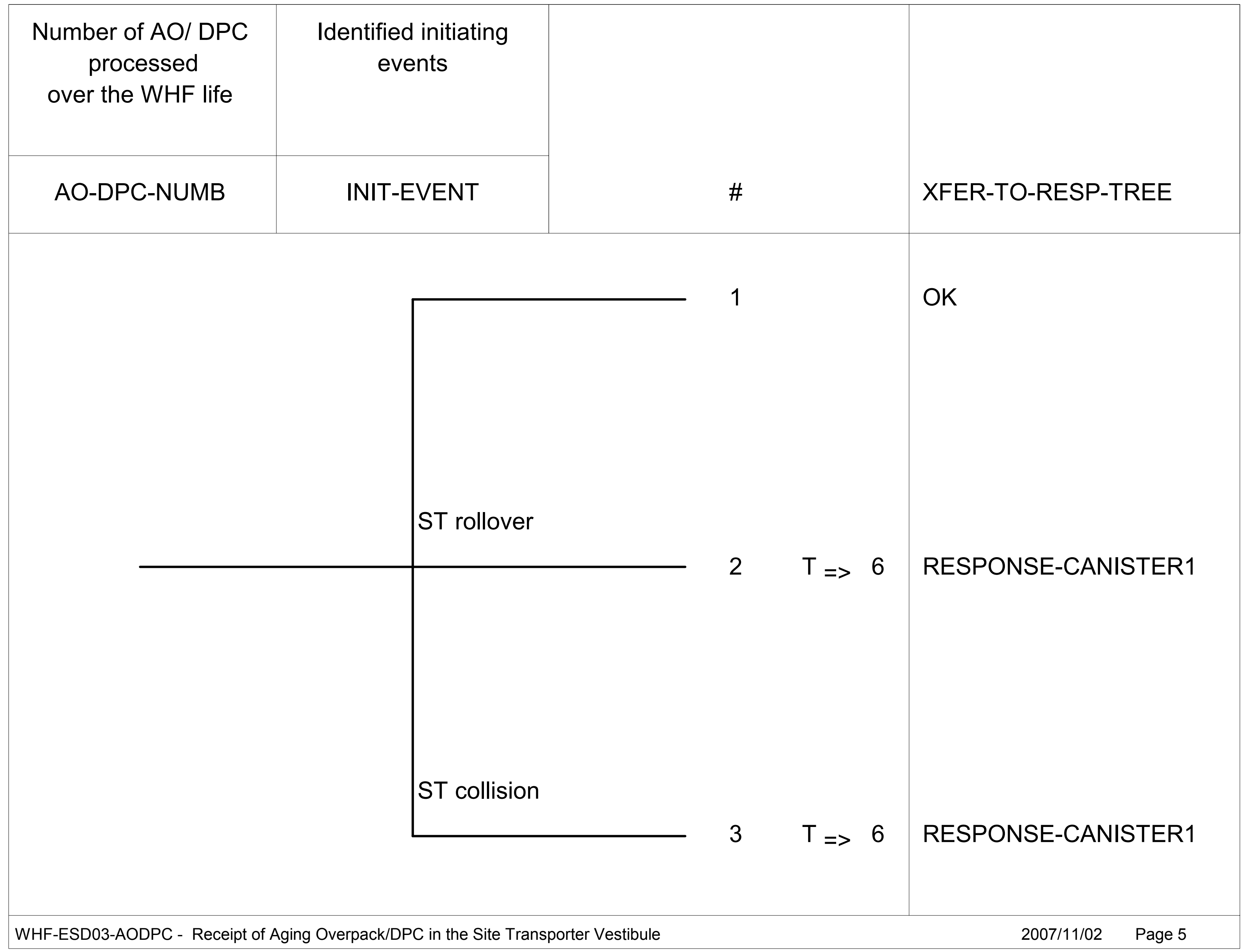
Figure G-4. Event Tree WHF-ESD02-DPC – Receipt of Transportation Cask with DPC in the Transportation Cask Entrance Vestibule and Move into the Preparation Area



NOTE: DE = direct exposure; ESD = event sequence diagram; INIT = initiating; ITC = important to criticality; RR = radionuclide release; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

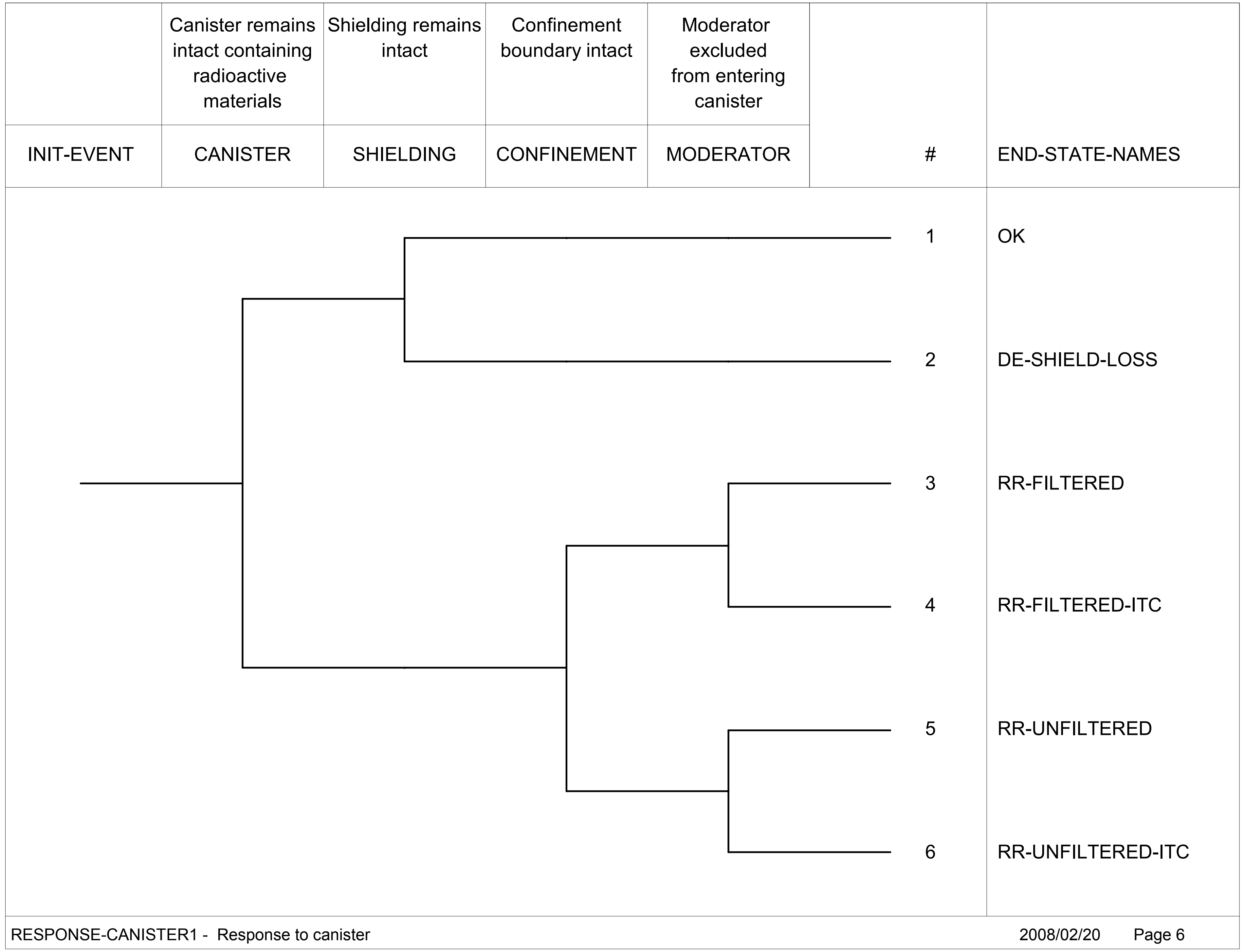
Figure G-5. Event Tree RESPONSE-TCASK-DPC – Response to Incoming Transportation Cask Carrying DPC



NOTE: AO = aging overpack; DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; ST = site transporter; T = transfer; WHF = Wet Handling Facility; XFER = transfer.

Source: Original

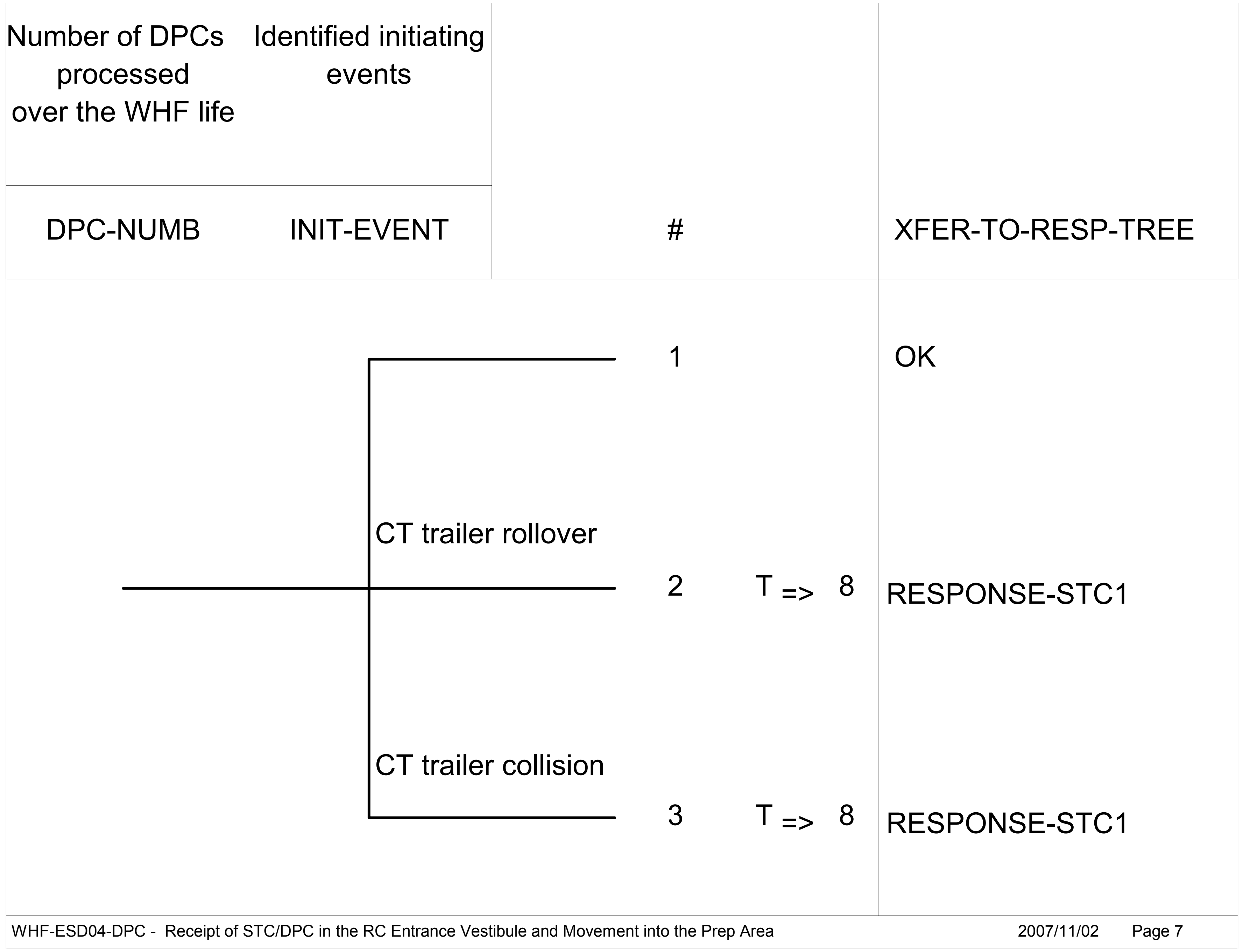
Figure G-6. Event Tree WHF-ESD03-AODPC – Receipt of Aging Overpack with DPC in the Site Transporter Vestibule



NOTE: DE = direct exposure; ESD = event sequence diagram; INIT = initiating; ITC = important to criticality; RR = radionuclide release; WHF = Wet Handling Facility.

Source: Original

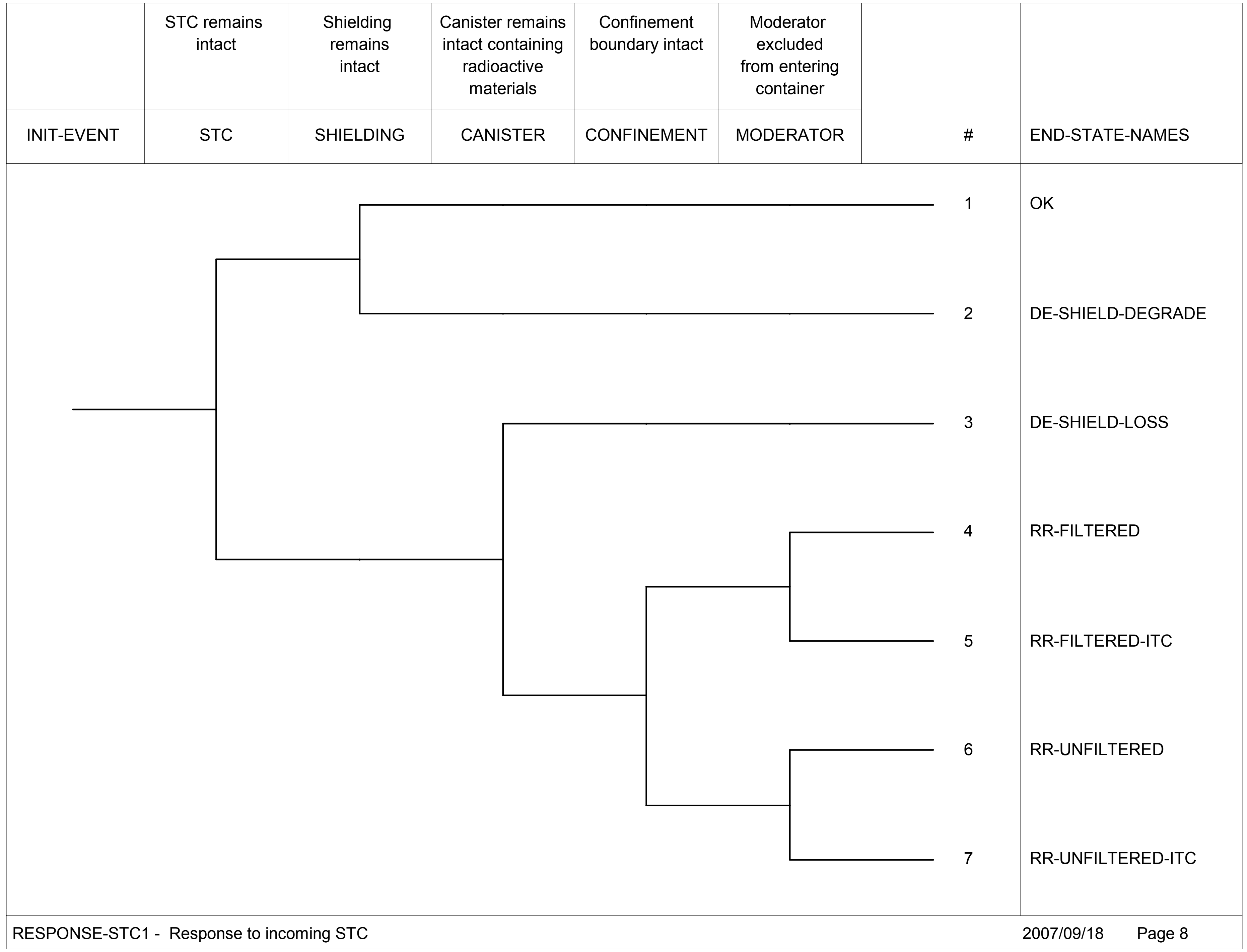
Figure G-7. Event Tree RESPONSE-CANISTER1 – Response to Canister



NOTE: CT = cask transfer; DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; T = transfer; STC = shielded transfer cask; WHF = Wet Handling Facility; XFER = transfer.

Source: Original

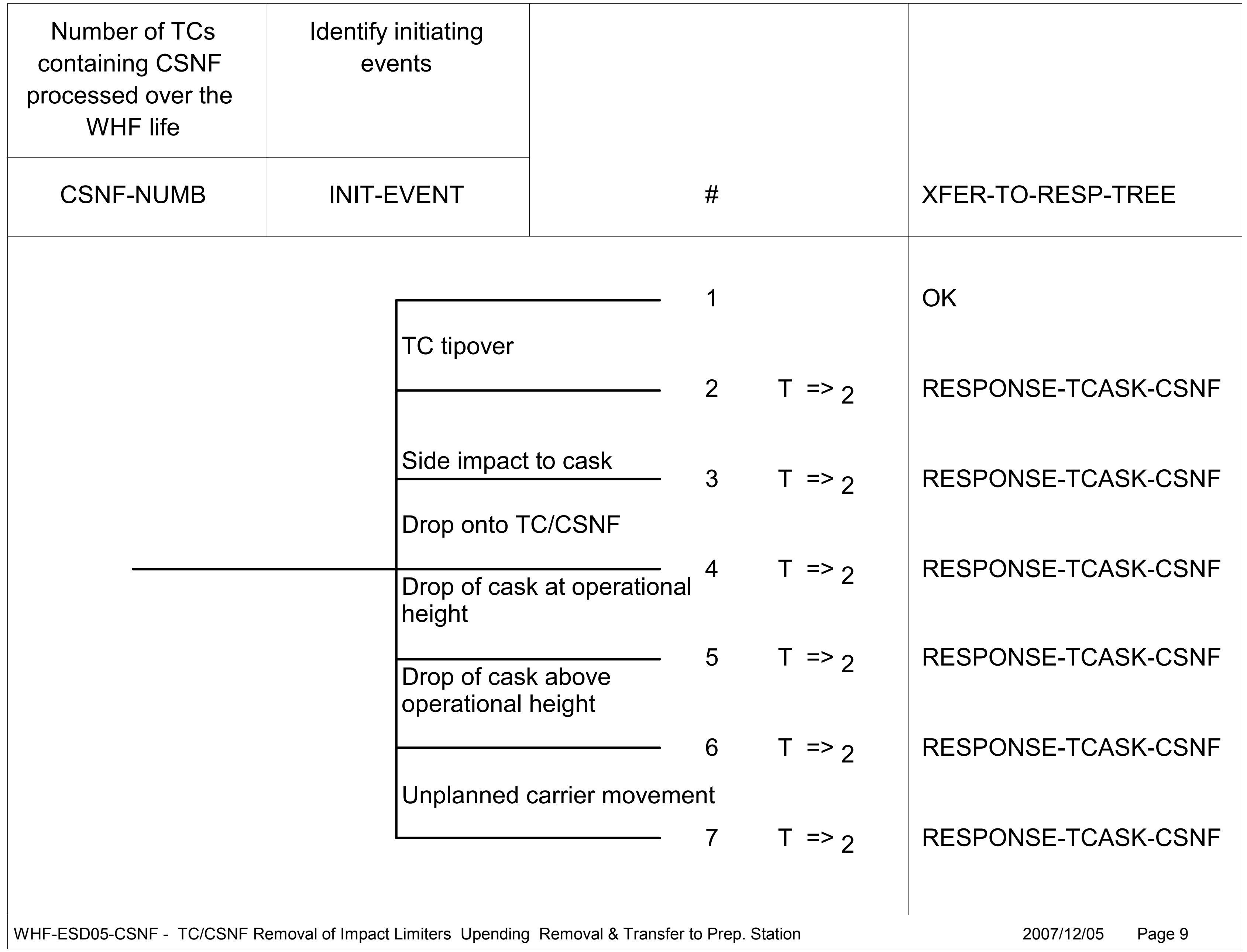
Figure G-8. Event Tree WHF-ESD04-DPC – Receipt of STC with DPC in the Railcar Entrance Vestibule and Movement into the Preparation Area



NOTE: DE = direct exposure; ESD = event sequence diagram; INIT = initiating; ITC = important to criticality; RR = radionuclide release; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original

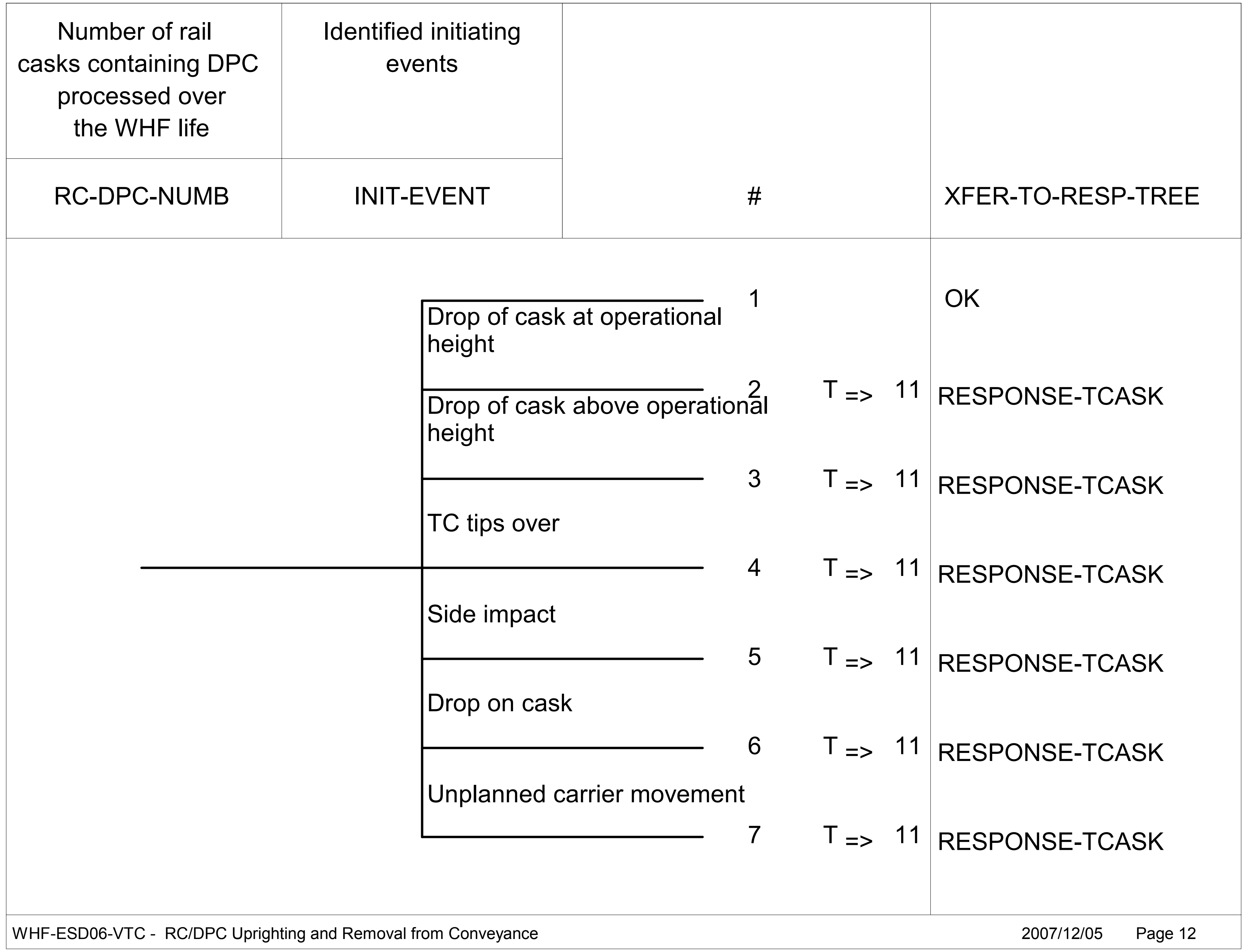
Figure G-9. Event Tree RESPONSE-STC1 – Response to Incoming STC



NOTE: CSNF = commercial spent nuclear fuel; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; T = transfer; TC = transportation cask; WHF = Wet Handling Facility; XFER = transfer.

Source: Original

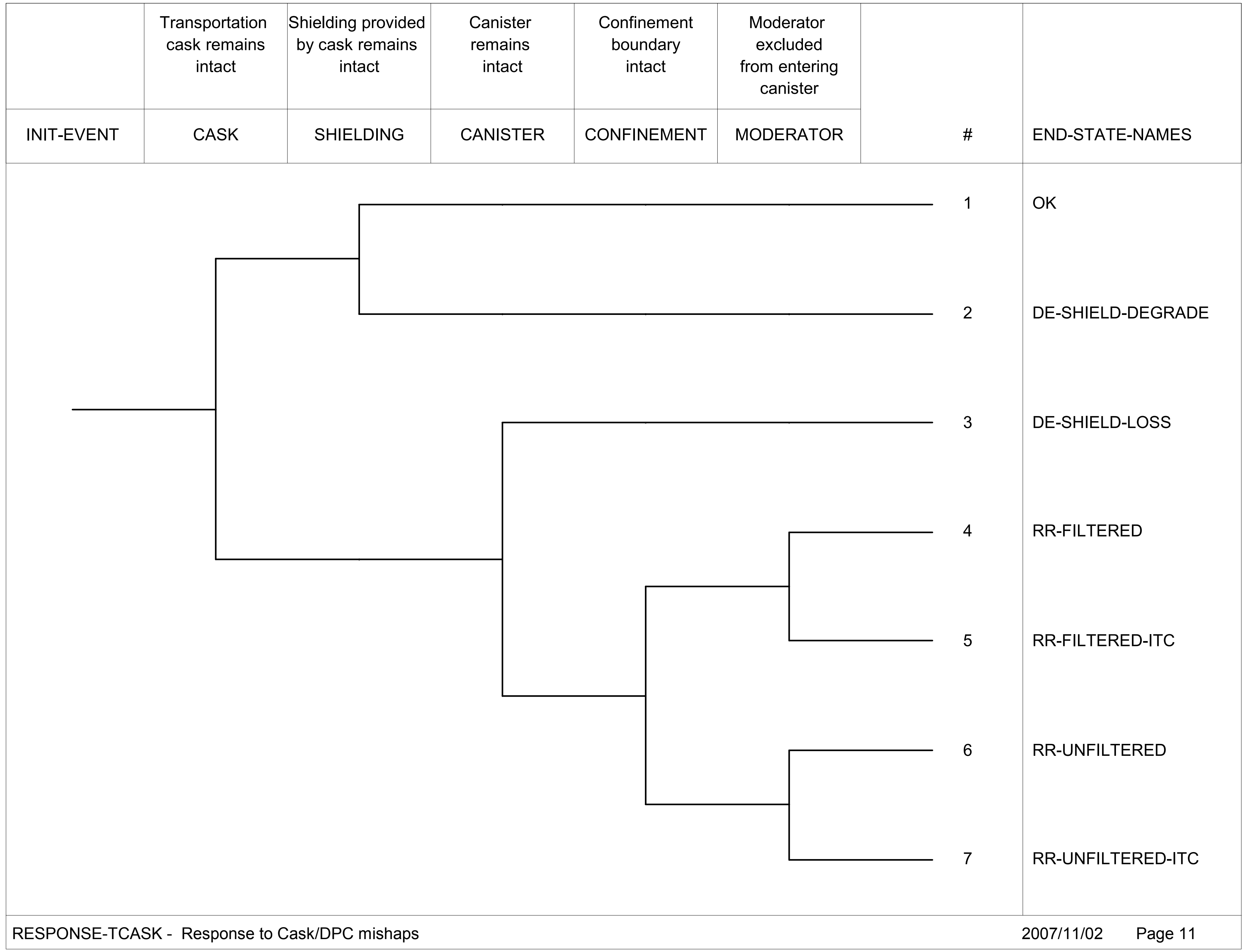
Figure G-10. Event Tree WHF-ESD05-CSNF – Transportation Cask with Commercial SNF Removal of Impact Limiters, Upending, Removal, and Transfer to Preparation Station



NOTE: DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; NUMB = number; RC = railcar; RESP = response; T = transfer; TC = transportation cask; VTC = vertical transportation cask; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

Figure G-11. Event Tree WHF-ESD06-VTC – Railcar with DPC Upright and Removal from Conveyance



NOTE: DE = direct exposure; DPC = dual-purpose canister; INIT = initiating; ITC = important to criticality; RR = radionuclide release.

Source: Original.

Figure G-12. Event Tree RESPONSE-TCASK – Response to Cask/DPC Mishaps

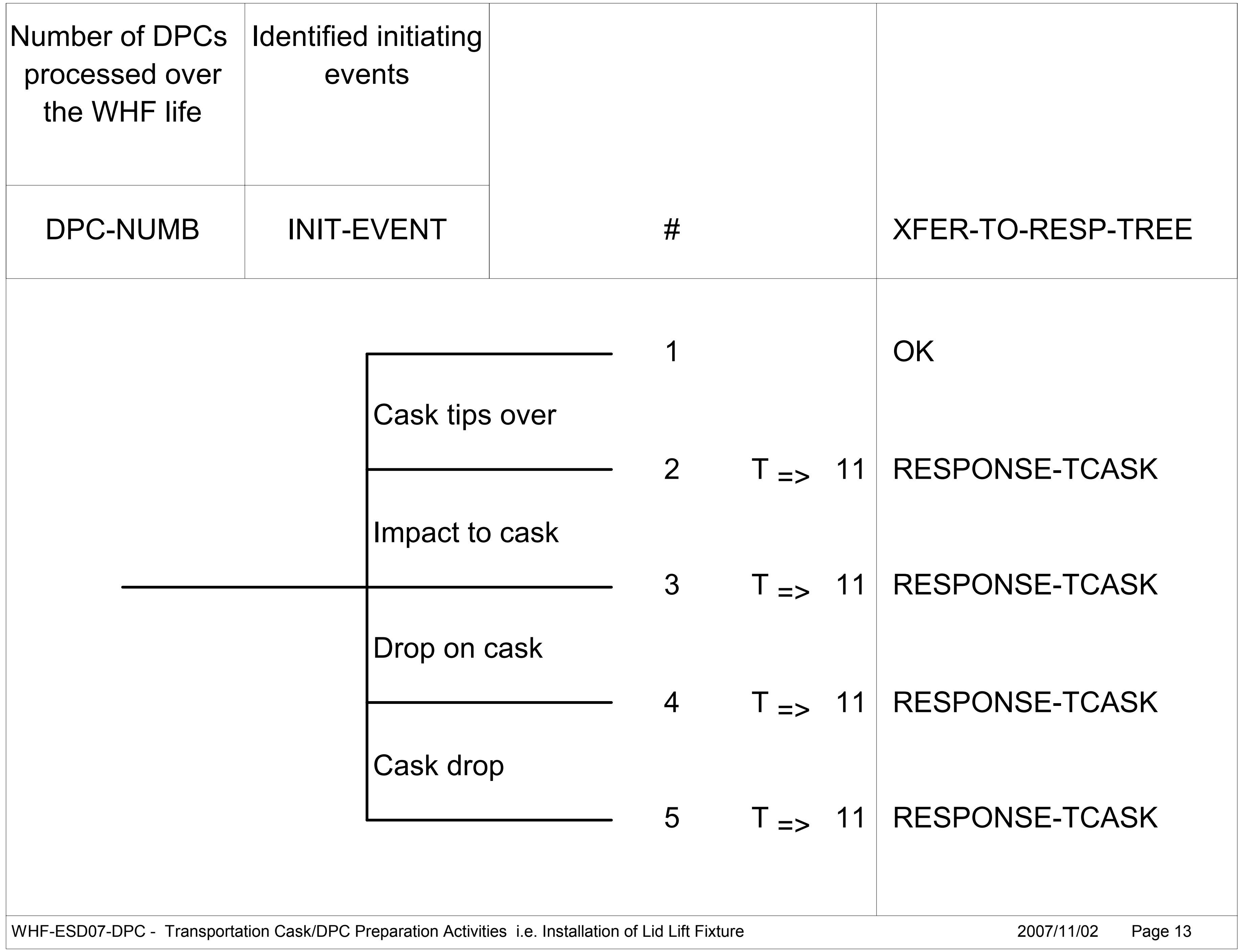
Number of horizontal STC/ DPC processed over the WHF life	Identified initiating events		
HSTC-DPC-NUMB	INIT-EVENT	#	XFER-TO-RESP-TREE
		1	OK
	Drop of cask at operational height	2 T => 11	RESPONSE-TCASK
	Drop of cask above operational height	3 T => 11	RESPONSE-TCASK
	TC tips over	4 T => 11	RESPONSE-TCASK
	Side impact	5 T => 11	RESPONSE-TCASK
	Drop on cask	6 T => 11	RESPONSE-TCASK
	Unplanned carrier movement	7 T => 11	RESPONSE-TCASK

WHF-ESD06-TTC - HS/DPC Uprighting and Removal from Conveyance 2007/12/05 Page 10

NOTE: CTT = cask transfer trolley; DPC = dual-purpose canister; ESD = event sequence diagram; HSTC = horizontal shielded transfer cask; INIT = initiating; NUMB = number; PREP = preparation; RESP = response; STC = shielded transfer cask; T = transfer; TC = transportation cask; TTC = a transportation cask that is upended using a tilt frame; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

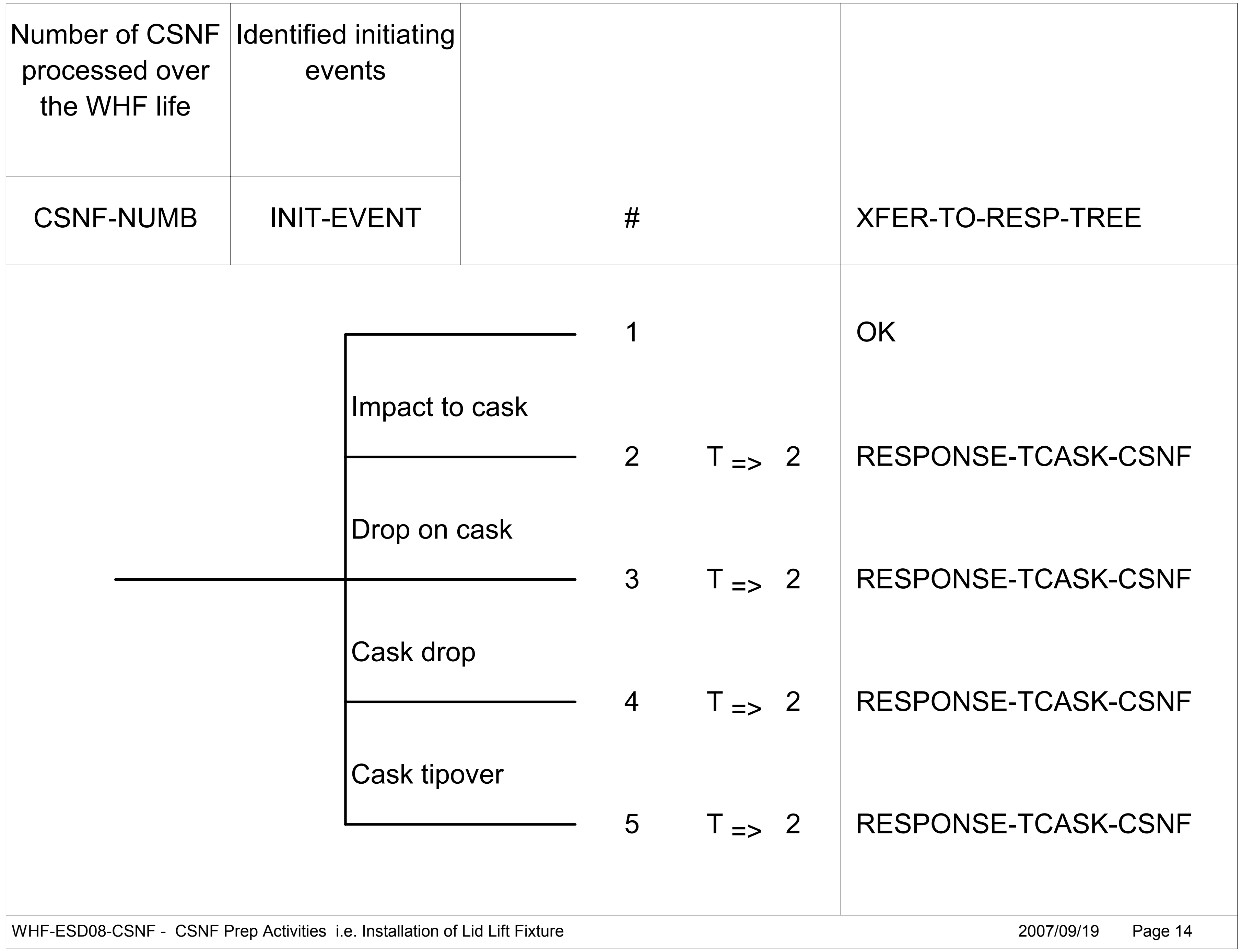
Figure G-13. Event Tree WHF-ESD06-TTC – HISTAR/DPC Upright and Removal from Conveyance



NOTE: DPC = dual-purpose canister; INIT = initiating; NUMB = number; RESP = response; T = transfer; XFER = transfer.

Source: Original.

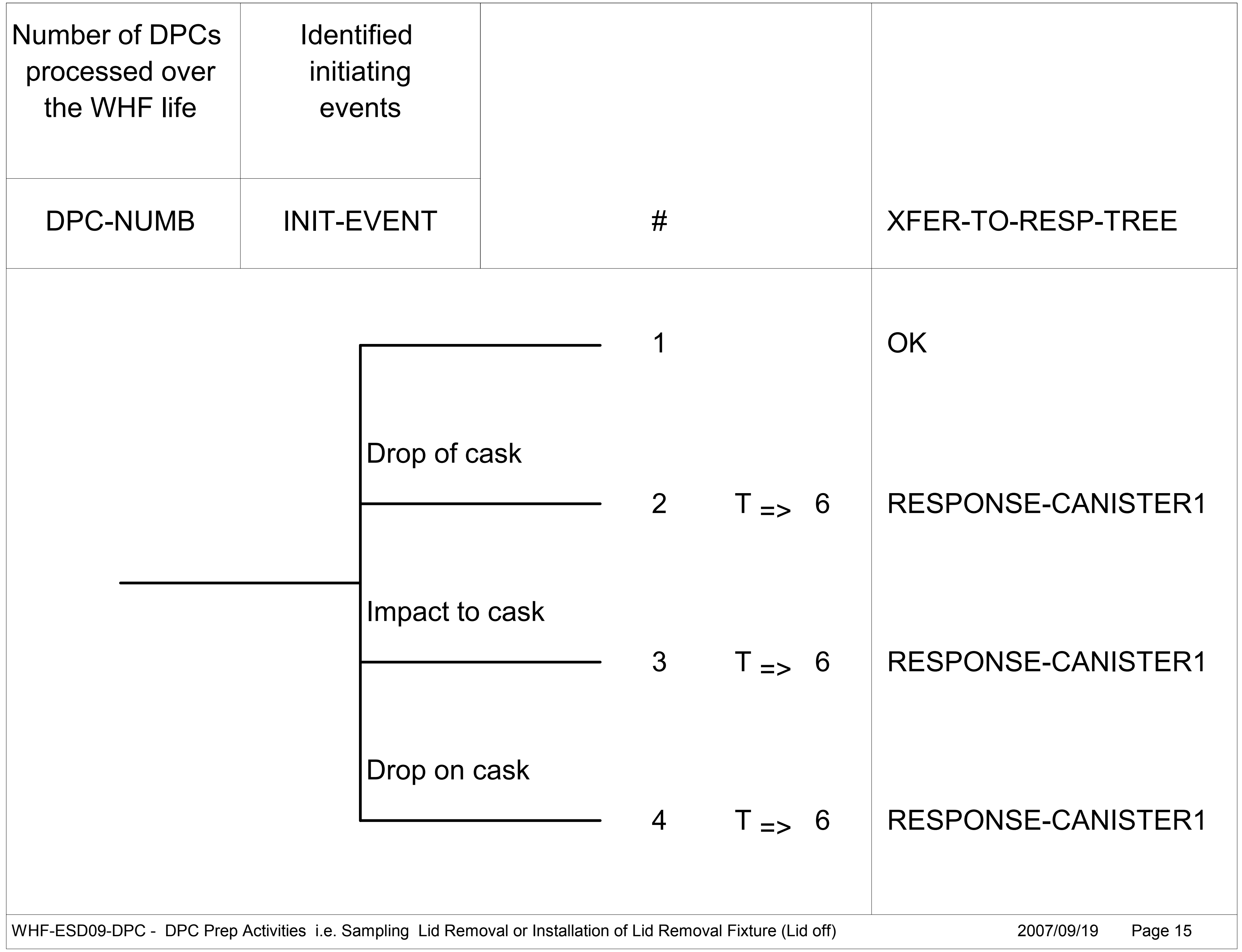
Figure G-14. Event Tree WHF-ESD07-DPC – Transportation Cask/DPC Preparation Activities (i.e., Installation of Lid-Lift Fixture)



NOTE: CSNF = commercial spent nuclear fuel; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; T = transfer; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

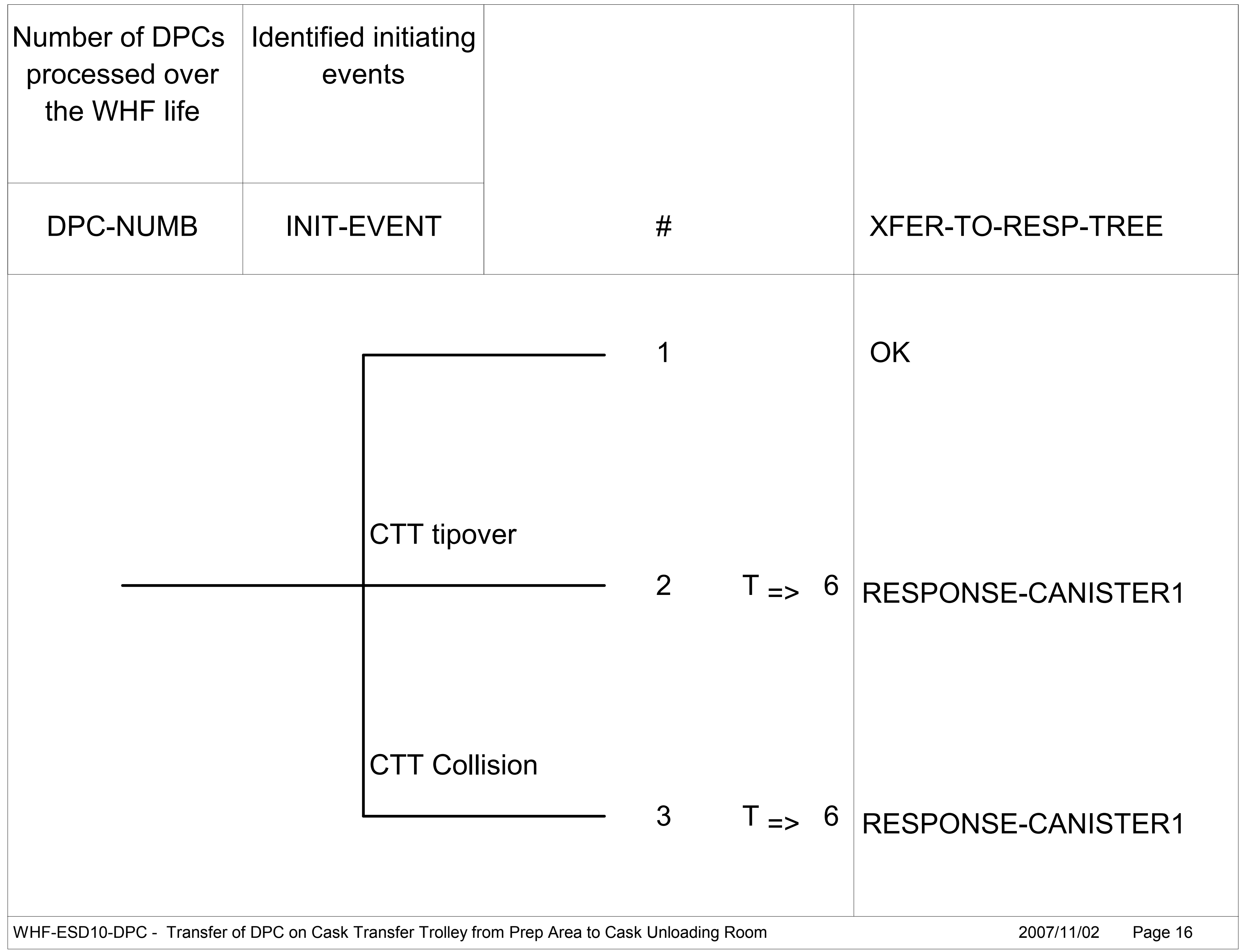
Figure G-15. Event Tree WHF-ESD08-CSNF – Commercial SNF Preparation Activities (i.e., Installation of Lid-Lift Fixture)



NOTE: DPC = dual-purpose canister; INIT = initiating; RESP = response; WHF = Wet Handling Facility.

Source: Original.

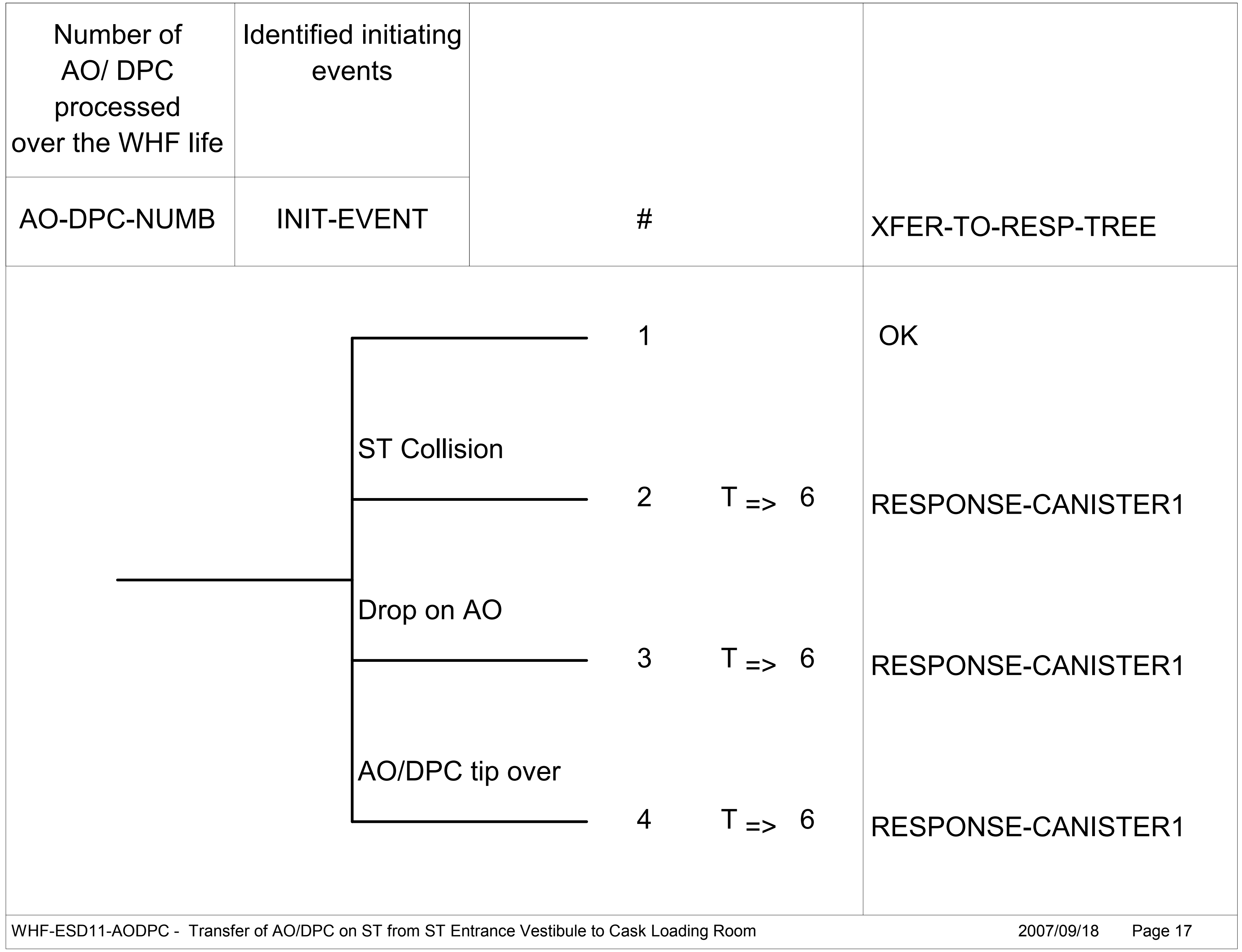
Figure G-16. Event WHF-ESD09-DPC – DPC Preparation Activities (i.e., Sampling Lid Removal or Installation of Lid-Lift Fixture (Lid Off))



NOTE: CTT = cask transfer trolley; DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; T = transfer; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

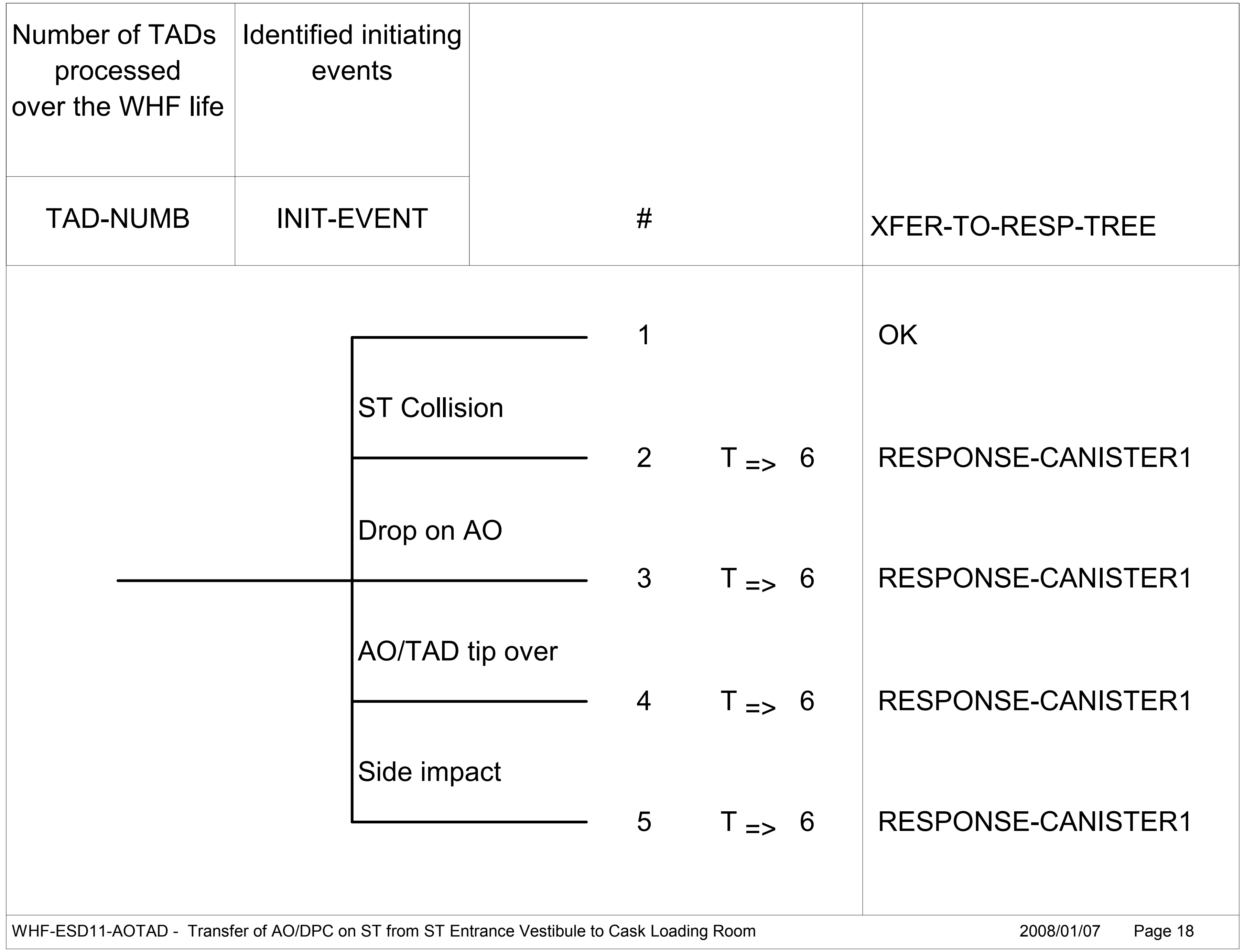
Figure G-17. Event Tree WHF-ESD10-DPC – Transfer of DPC on CTT from Preparation Area to Cask Unloading Room



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

Source: Original.

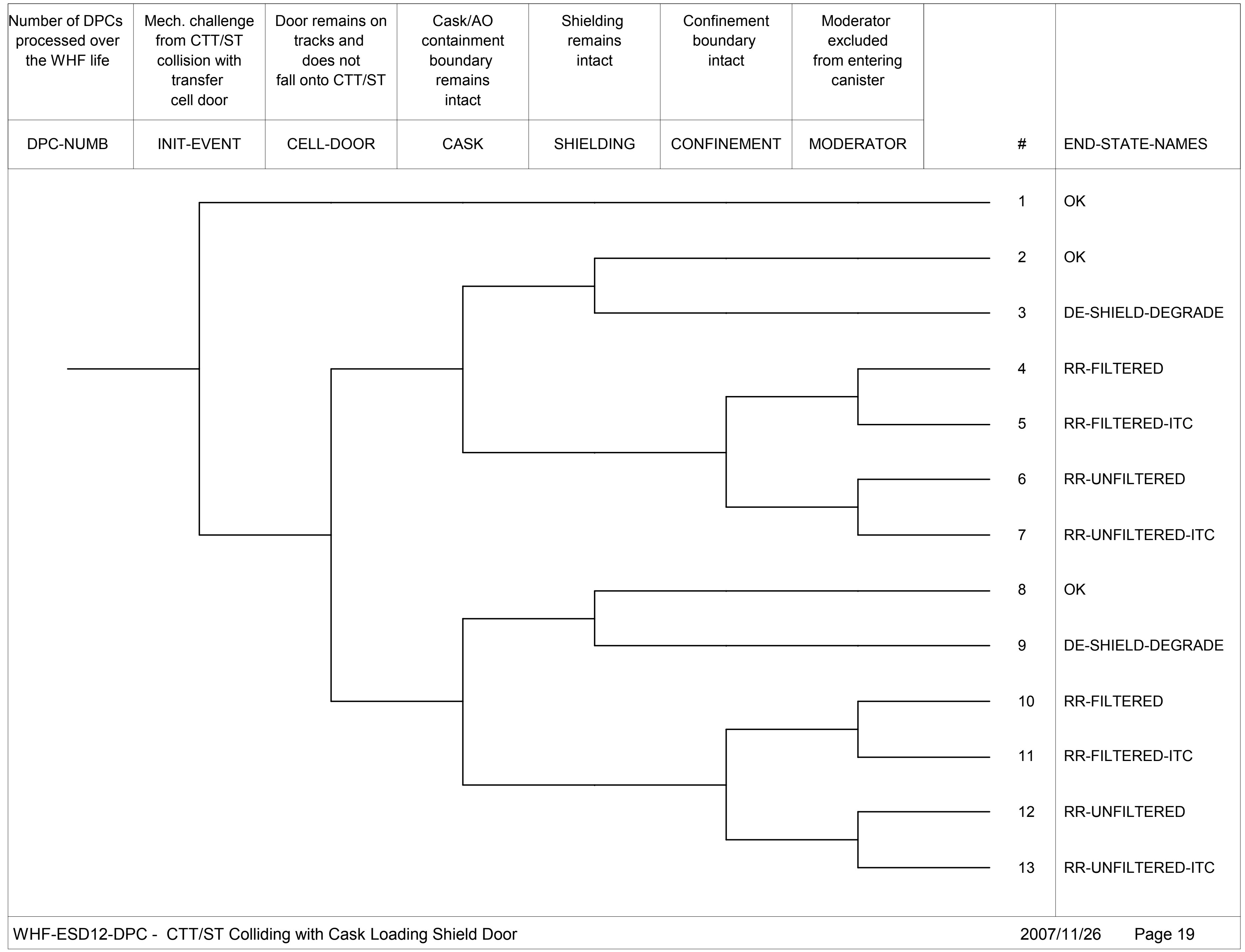
Figure G-18. Event Tree WHF-ESD11-AODPC – Transfer of Aging Overpack/DPC on Site Transporter from Site Transporter Vestibule to Cask Loading Room



NOTE: AO = aging overpack; DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; ST = site transporter; T = transfer; TAD = transportation, aging, and disposal canister; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

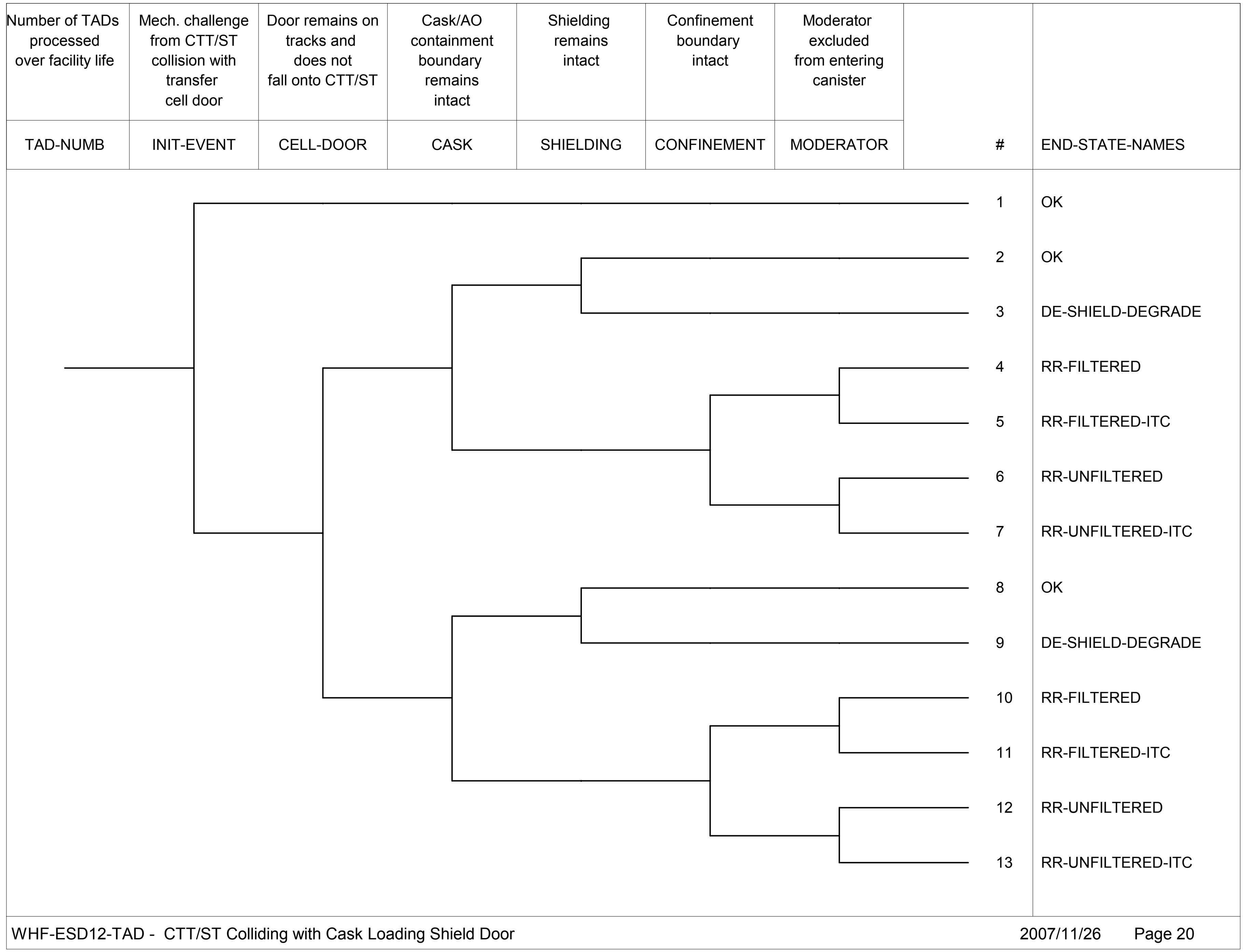
Figure G-19. Event Tree WHF-ESD11-AOTAD – Transfer of Aging Overpack/DPC on Site Transporter from Site Transporter Entrance Vestibule to Cask Loading Room



NOTE: AO = aging overpack; CTT = cask transfer trolley; DE = direct exposure; DPC = dual-purpose canister; INIT = initiating; ITC = important to criticality; NUMB = number; RR = radionuclide release; ST = site transporter; WHF = Wet Handling Facility.

Source: Original.

Figure G-20. Event Tree WHF-ESD12-DPC – CTT/Site Transporter Colliding with Cask Loading Shield Door



NOTE: AO = aging overpack; CTT = cask transfer trolley; DE = direct exposure; ESD = event sequence diagram; INIT = initiating; ITC = important to criticality; NUMB = number; RR = radionuclide release; ST = site transporter; TAD = transportation, aging, and disposal canister.

Source: Original.

Figure G-21. Event Tree WHF-ESD12-TAD – CTT/Site Transporter Colliding with Cask Loading Shield Door

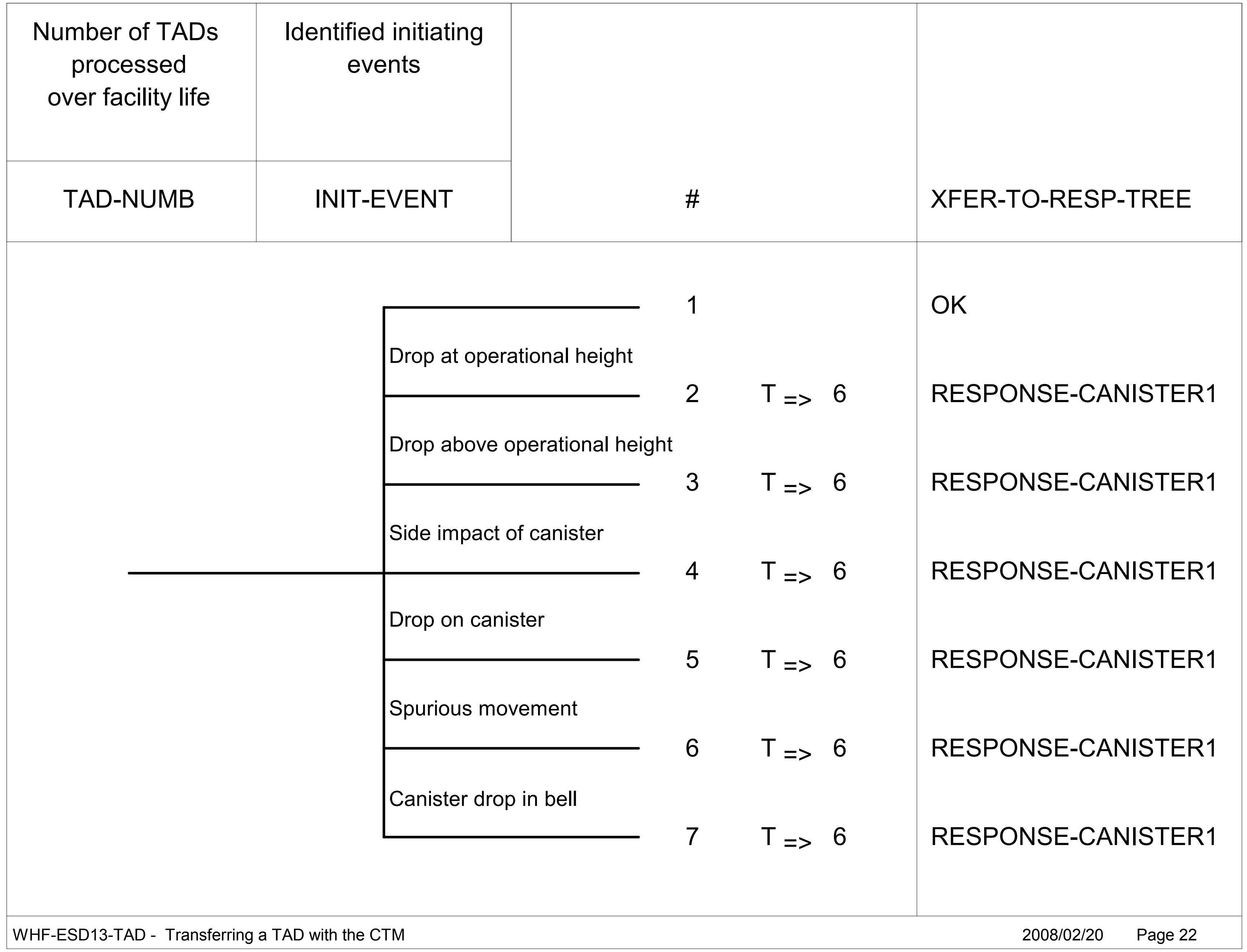
Number of DPCs processed over facility life	Identified initiating events		
DPC-NUMB	INIT-EVENT	#	XFER-TO-RESP-TREE
		1	OK
	Drop at operational height	2 T => 6	RESPONSE-CANISTER1
	Drop above operational height	3 T => 6	RESPONSE-CANISTER1
	Side impact of canister	4 T => 6	RESPONSE-CANISTER1
	Drop on canister	5 T => 6	RESPONSE-CANISTER1
	Spurious movement	6 T => 6	RESPONSE-CANISTER1
	Canister drop inside bell	7 T => 6	RESPONSE-CANISTER1

WHF-ESD13-DPC - Transferring a DPC with the CTM 2008/02/20 Page 21

NOTE: CTM = canister transfer machine; DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; T = transfer; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

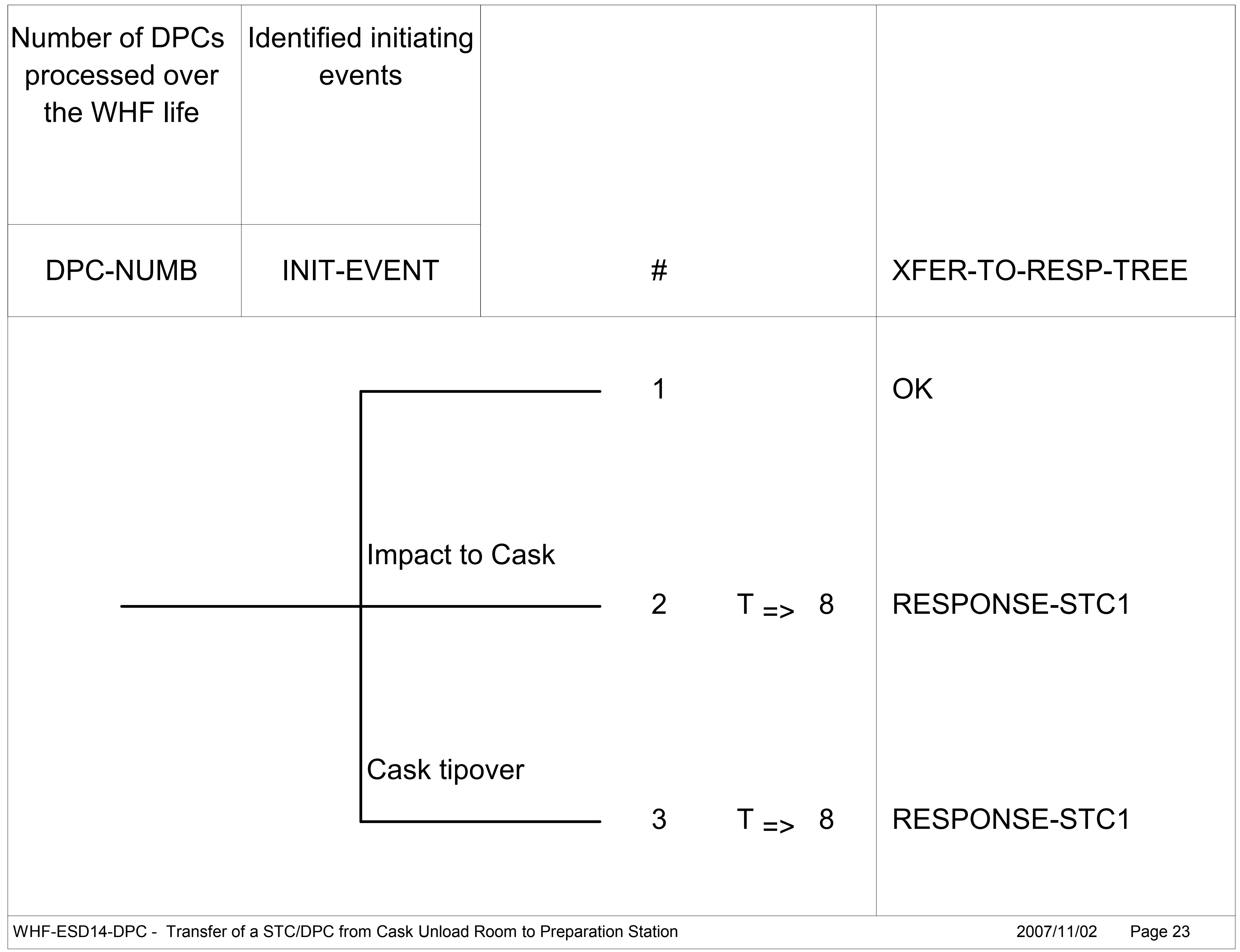
Figure G-22. Event Tree WHF-ESD13-DPC – Transferring a DPC with the CTM



NOTE: CTM = canister transfer machine; DPC = dual-purpose canister; INIT = initiating; NUMB = number; RR = radionuclide release; T = transfer; TAD = transportation, aging, and disposal canister; XFER = transfer.

Source: Original.

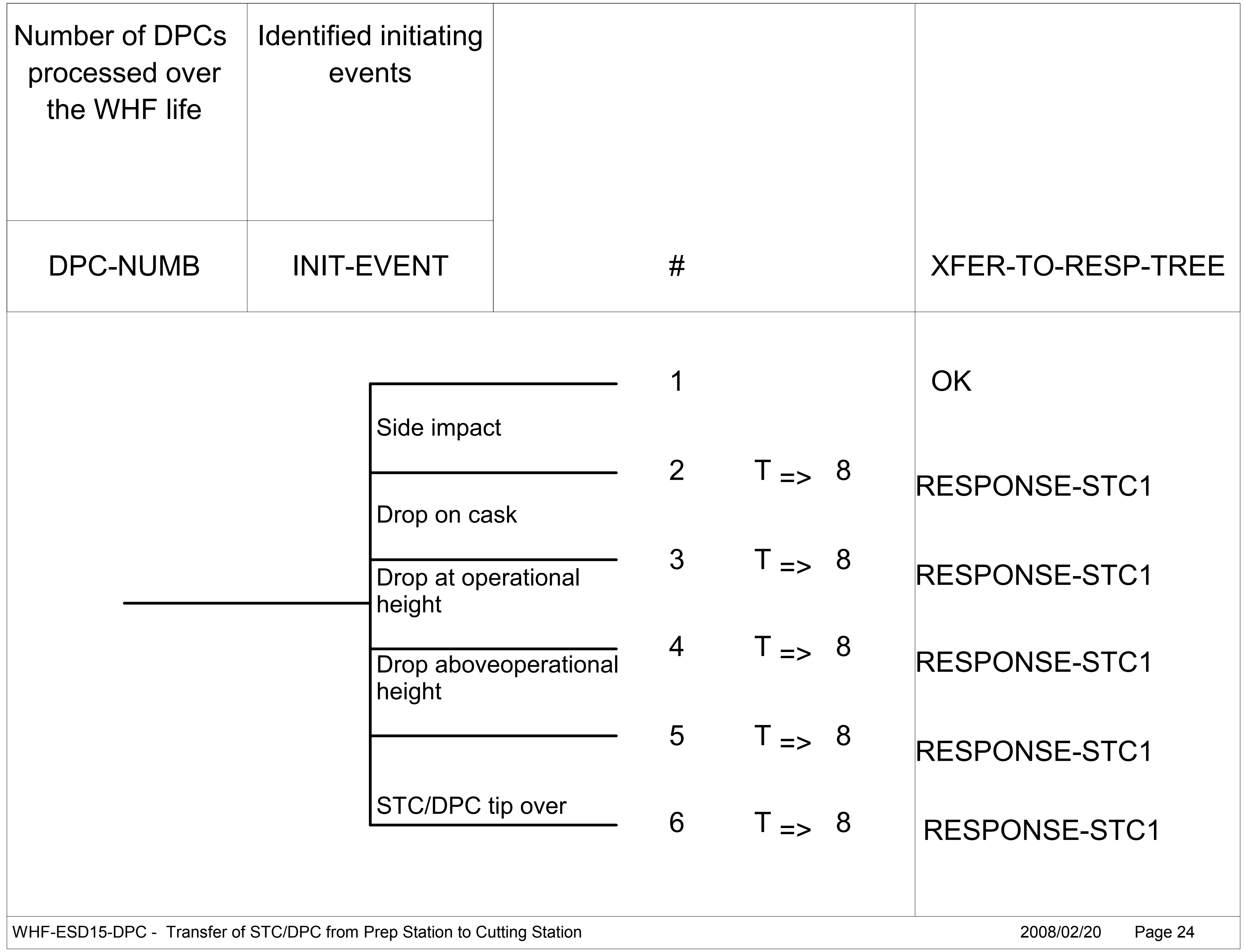
Figure G-23. Event Tree WHF-ESD13-TAD – Transferring a TAD with the CTM



NOTE: DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; STC = shielded transfer cask; T = transfer; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

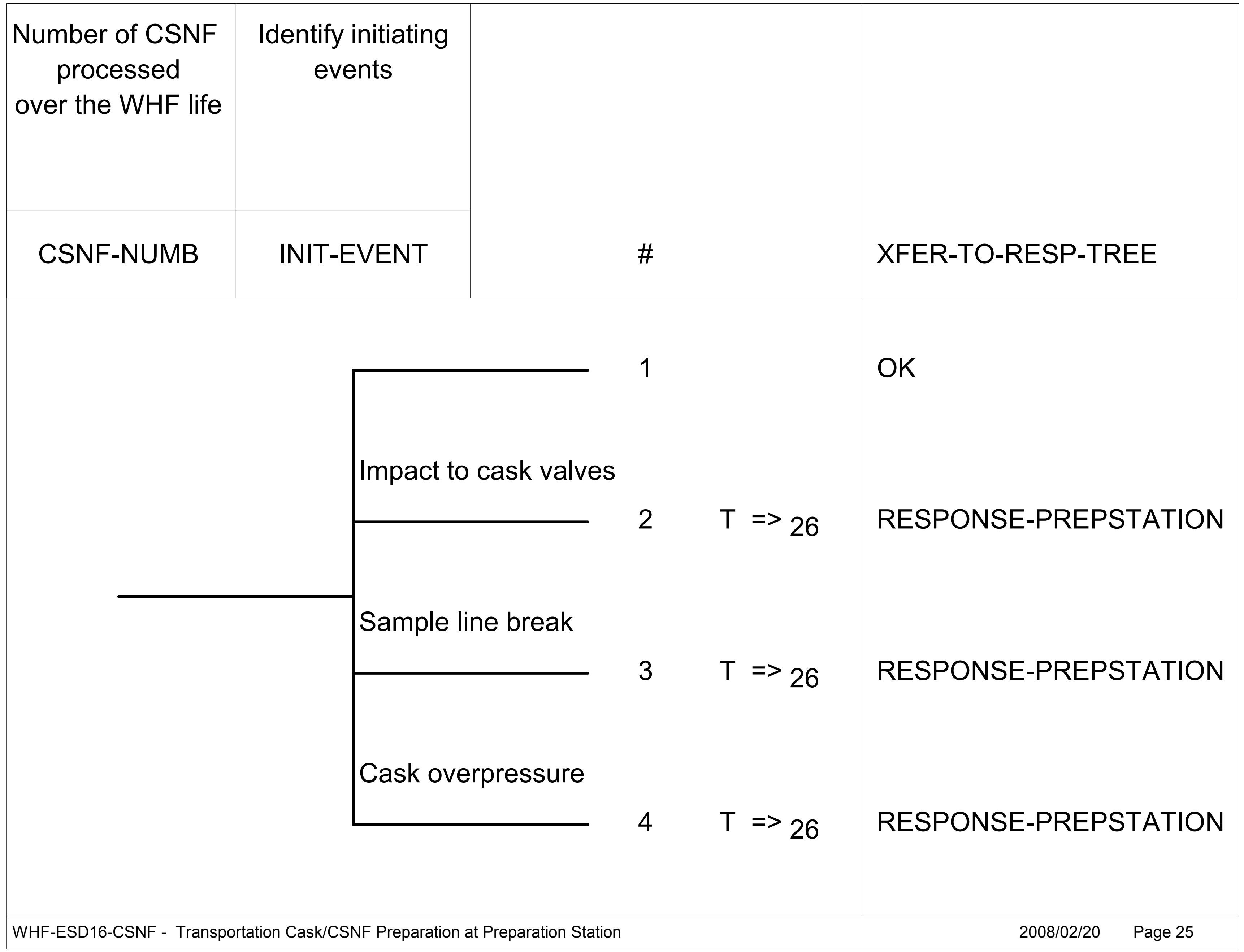
Figure G-24. Event Tree WHF-ESD14-DPC – Transfer of a STC/DPC from Cask Unload Room to Preparation Station



NOTE: DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; STC = shielded transfer cask; T = transfer; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

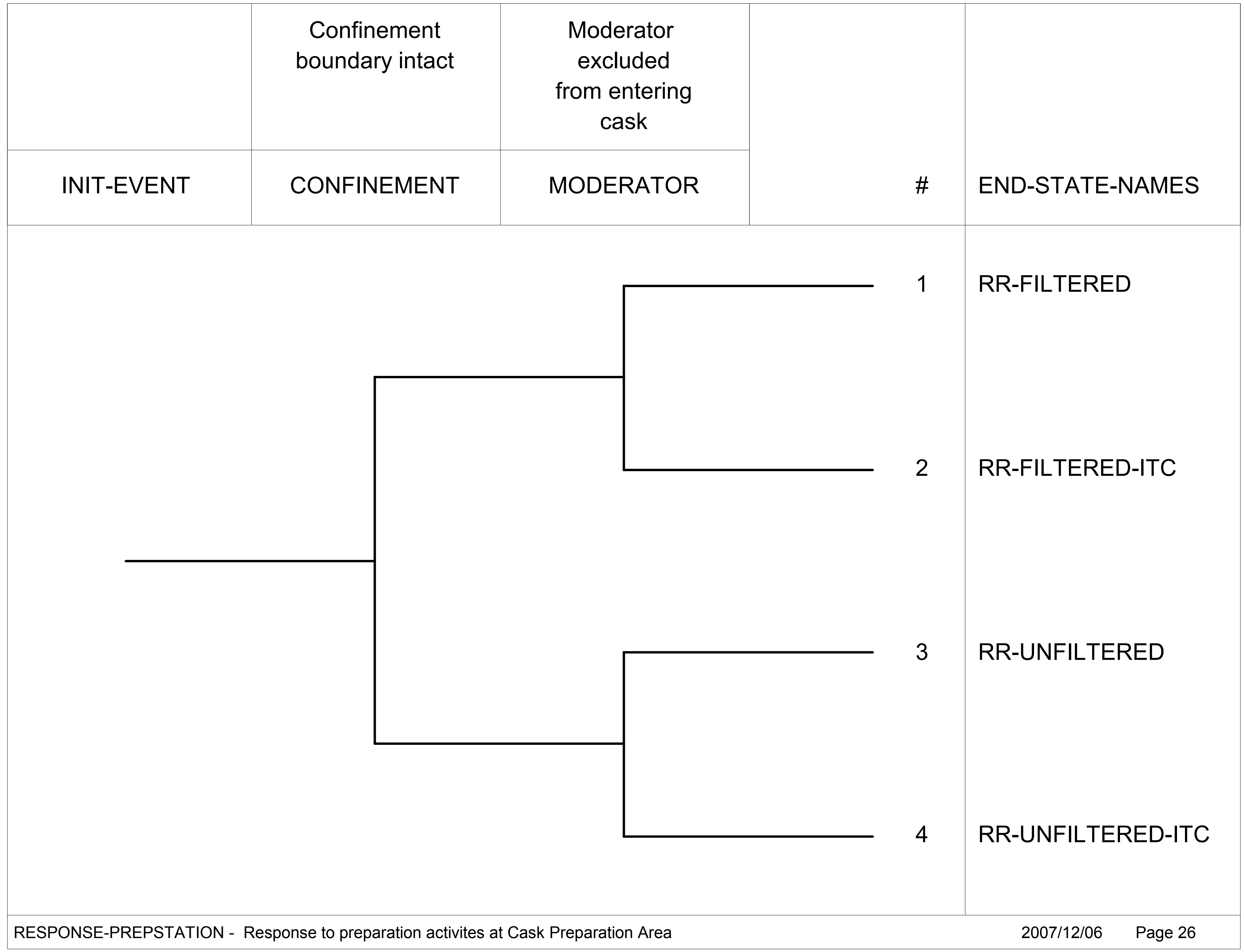
Figure G-25. Event Tree WHF-ESD15-DPC – Transfer of STC/DPC from Preparation Station to Cutting Station



NOTE: CSNF = commercial spent nuclear fuel; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; T = transfer; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

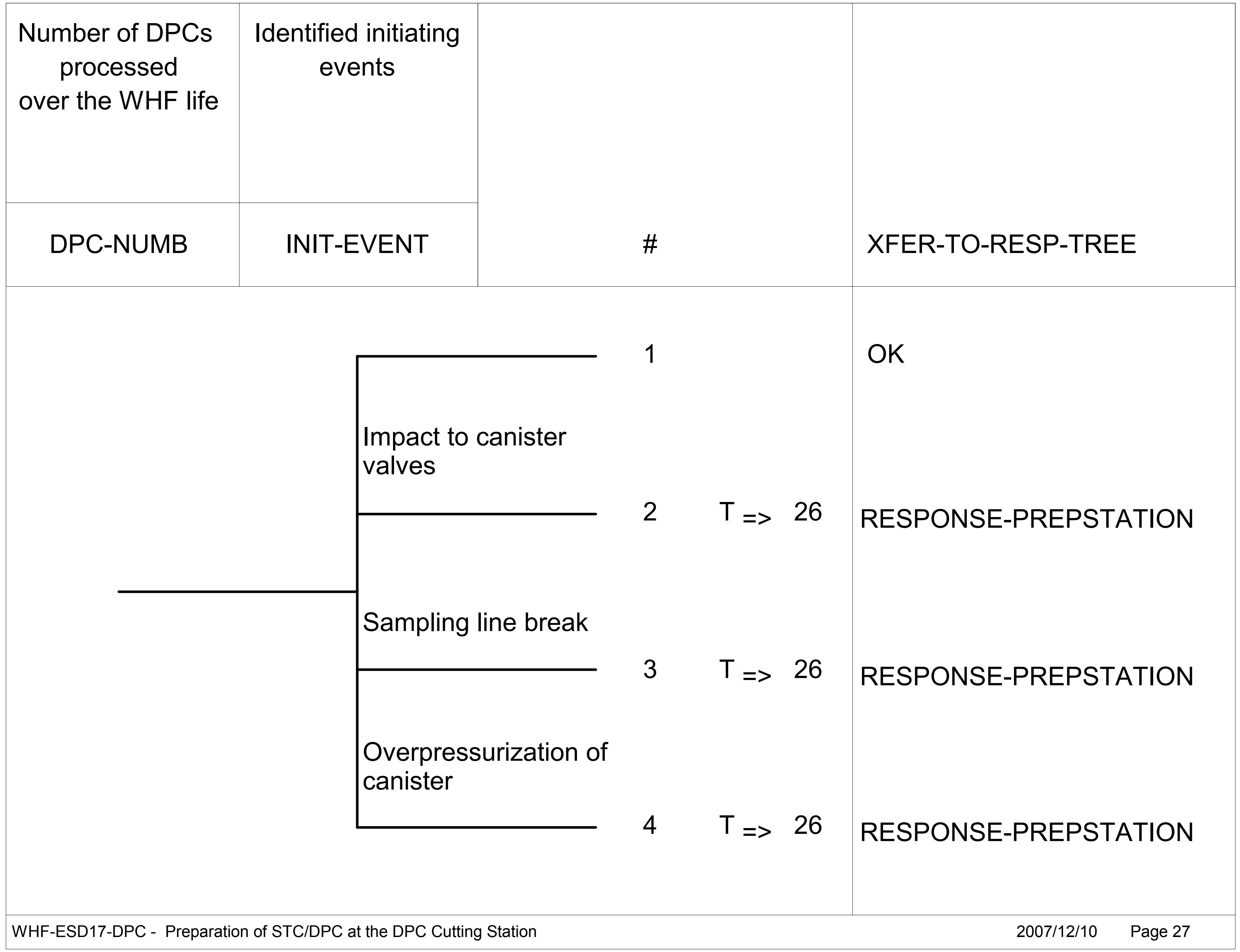
Figure G-26. Event Tree WHF-ESD16-CSNF – Transportation Cask/Commercial SNF Preparation at Preparation Station



NOTE: INIT = initiating; ITC = important to criticality; NUMB = number; PREP = preparation; RR = radionuclide release; RESP = response.

Source: Original.

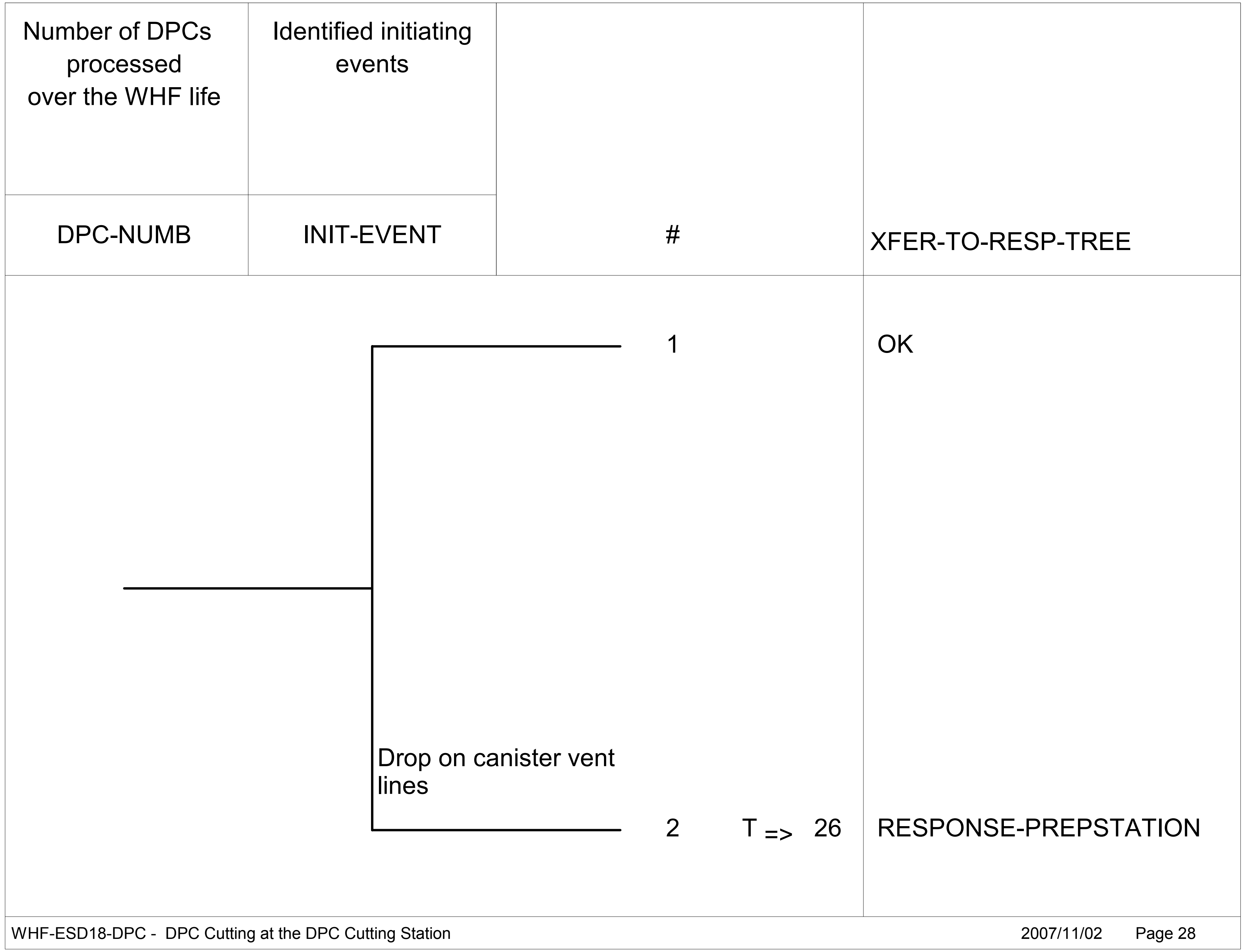
Figure G-27. Event Tree RESPONSE – PREPSTATION – Response to Preparation Activities at Cask Preparation Area



NOTE: DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; NUMB = number; PREP = preparation; RESP = response; STC = shielded transfer cask; T = transfer; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

Figure G-28. Event Tree WHF-ESD17-DPC – Preparation of STC/DPC at the DPC Cutting Station



NOTE: DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; RESP = response; T = transfer; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

Figure G-29. Event Tree WHF-ESD18-DPC – DPC Cutting at the DPC Cutting Station

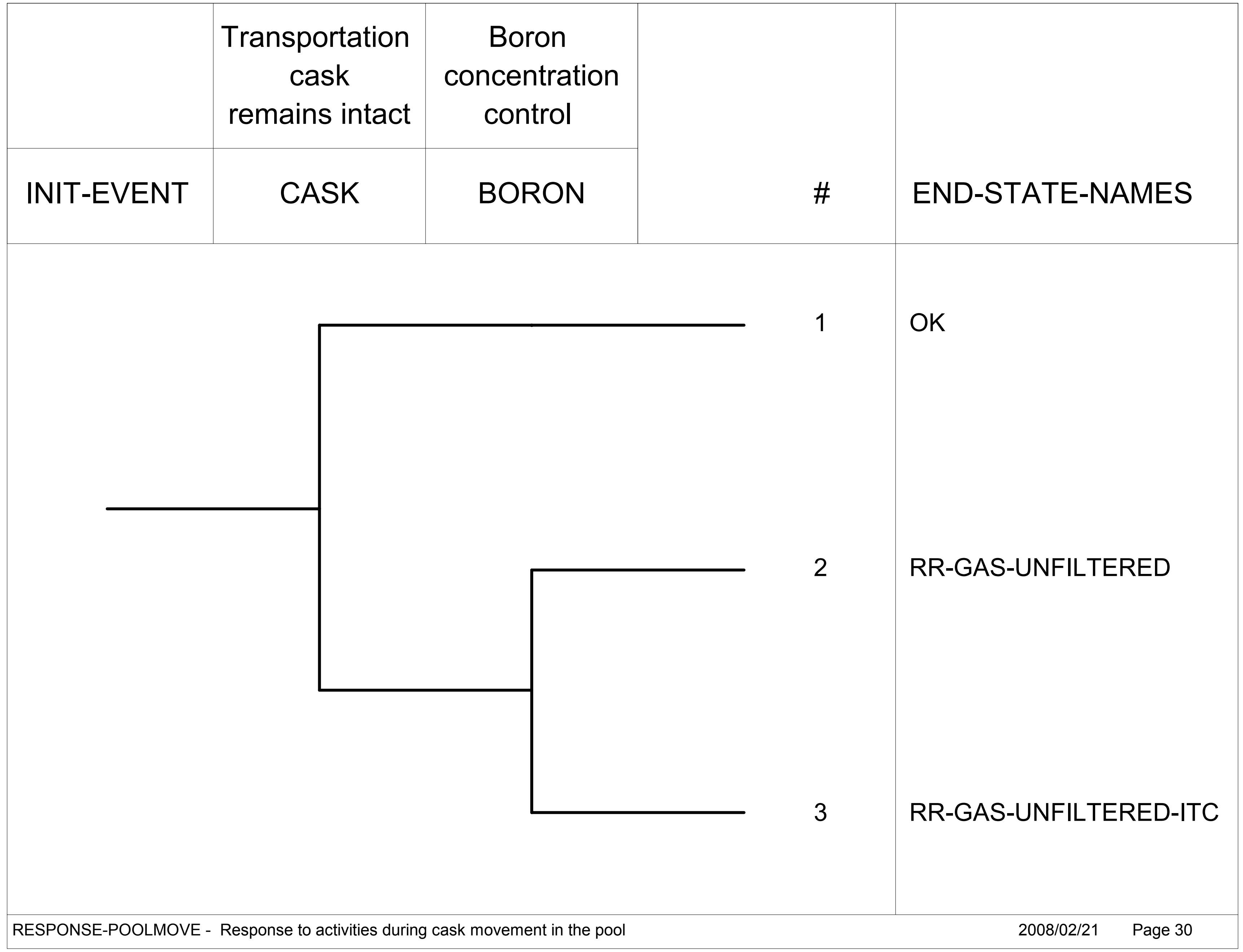
Number of DPCs processed over the WHF life	Identified initiating events	#		XFER-TO-RESP-TREE
DPC-NUMB	INIT-EVENT	#		XFER-TO-RESP-TREE
		1		OK
	Impact to Cask - Pool	2	T => 30	RESPONSE-POOLMOVE
	Drop on Cask - Pool	3	T => 30	RESPONSE-POOLMOVE
	Drop at Operation Height - Pool	4	T => 30	RESPONSE-POOLMOVE
	Drop Above Operation Height - Pool	5	T => 30	RESPONSE-POOLMOVE
	Cask Tips Over - Pool	6	T => 30	RESPONSE-POOLMOVE
	Impact to Cask - Floor	7	T => 8	RESPONSE-STC1
	Drop on Cask - Floor	8	T => 8	RESPONSE-STC1
	Drop at Operation Height - Floor	9	T => 8	RESPONSE-STC1
	Drop Above Operation Height - Floor	10	T => 8	RESPONSE-STC1
	Cask Tips Over - Floor	11	T => 8	RESPONSE-STC1

WHF-ESD19-DPC - Transfer of STC/DPC from Prep Station to Pool Ledge 2008/01/04 Page 29

NOTE: DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; NUMB = number; PREP = preparation; RESP = response; STC = shielded transfer cask; T = transfer; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

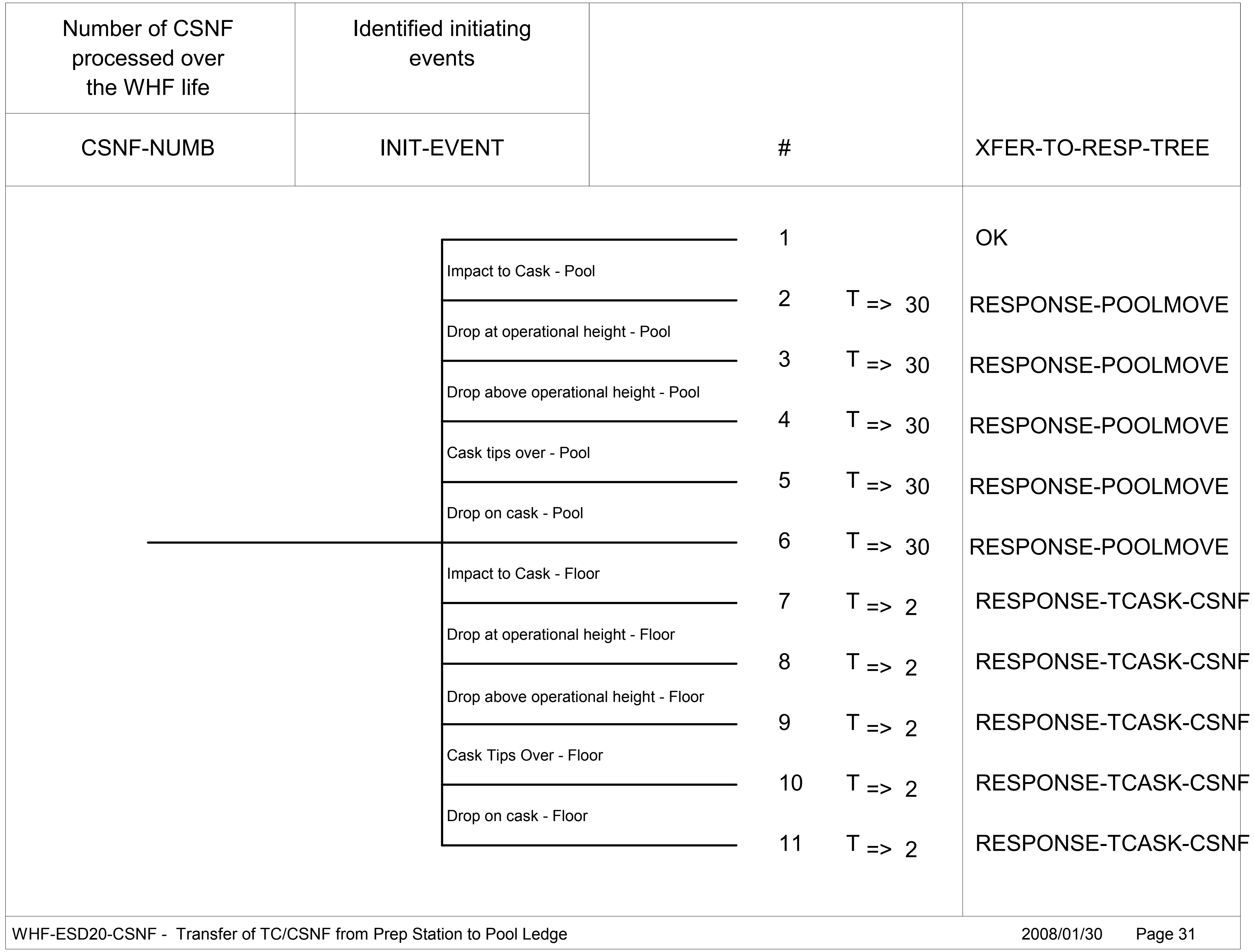
Figure G-30. Event Tree WHF-ESD19-DPC – Transfer of STC/DPC from Preparation Station to Pool Ledge



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

Source: Original.

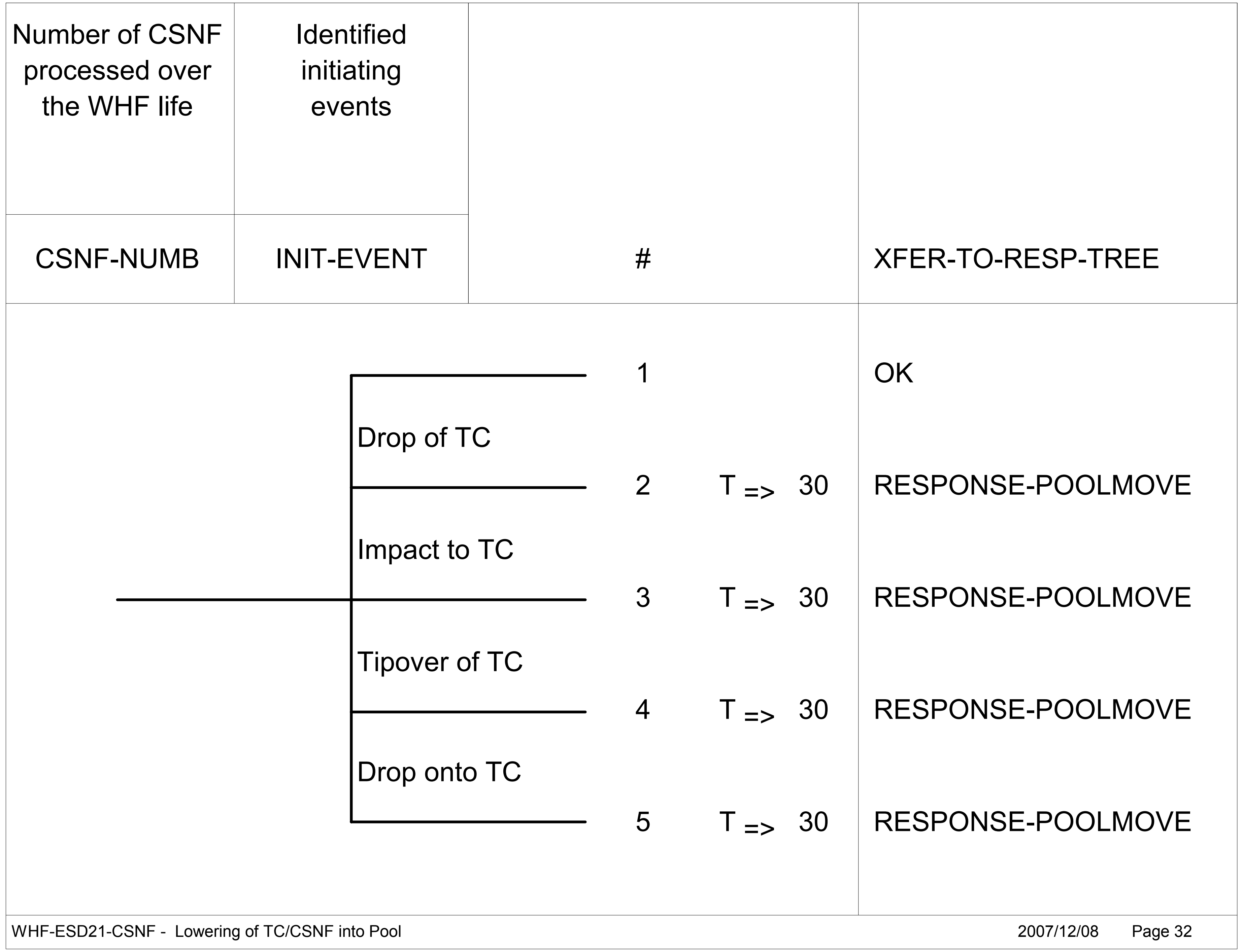
Figure G-31. Event Tree RESPONSE-POOLMOVE – Response to Activities during Cask Movement in the Pool



NOTE: CSNF = commercial spent nuclear fuel; DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; T = transfer; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

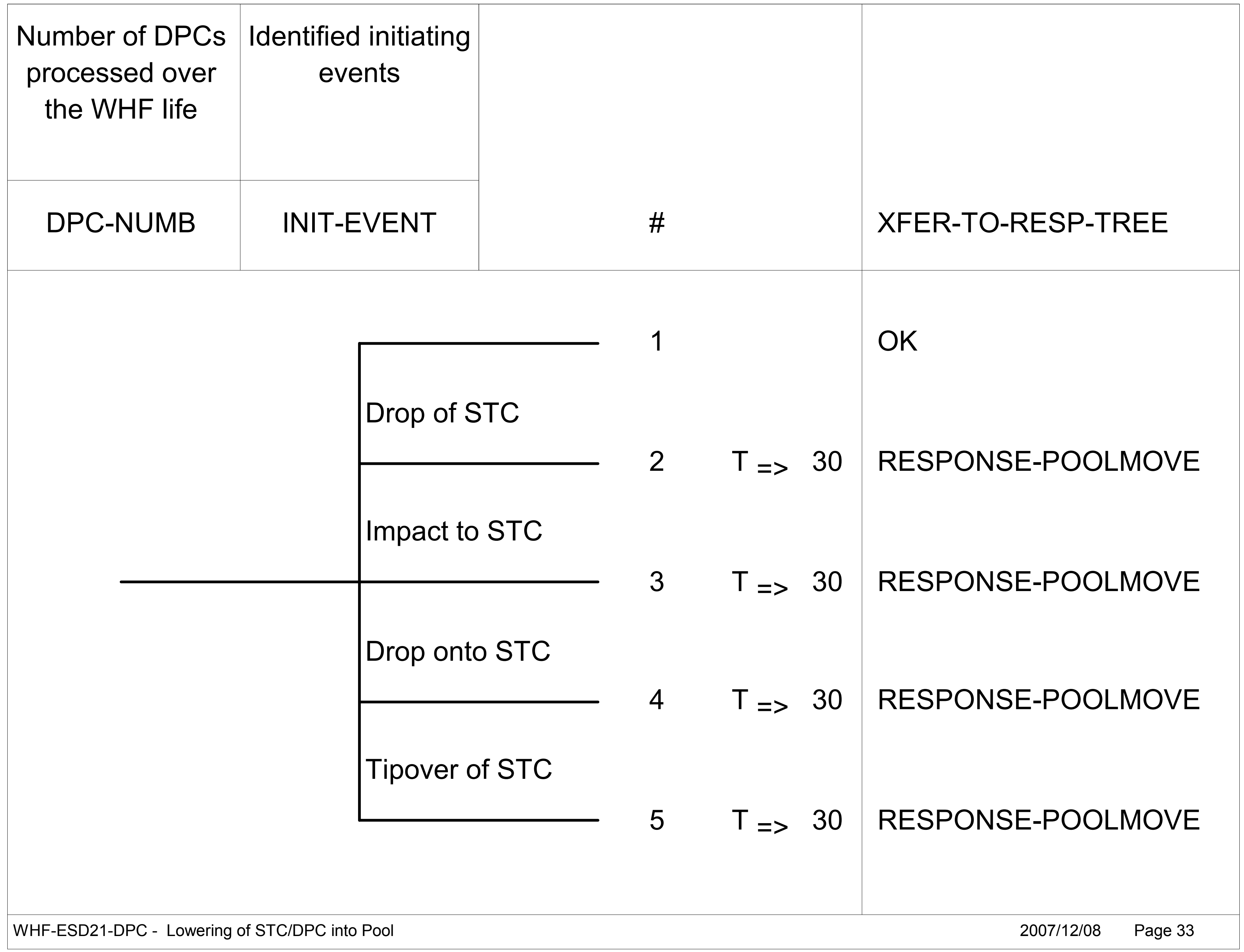
Figure G-32. Event Tree WHF-ESD20-CSNF – Transfer of Transportation Cask/CSNF from Preparation Station to Pool Ledge



NOTE: CSNF = commercial spent nuclear fuel; INIT = initiating; RESP = response; T = transfer; TC = transportation cask; XFER = transfer.

Source: Original.

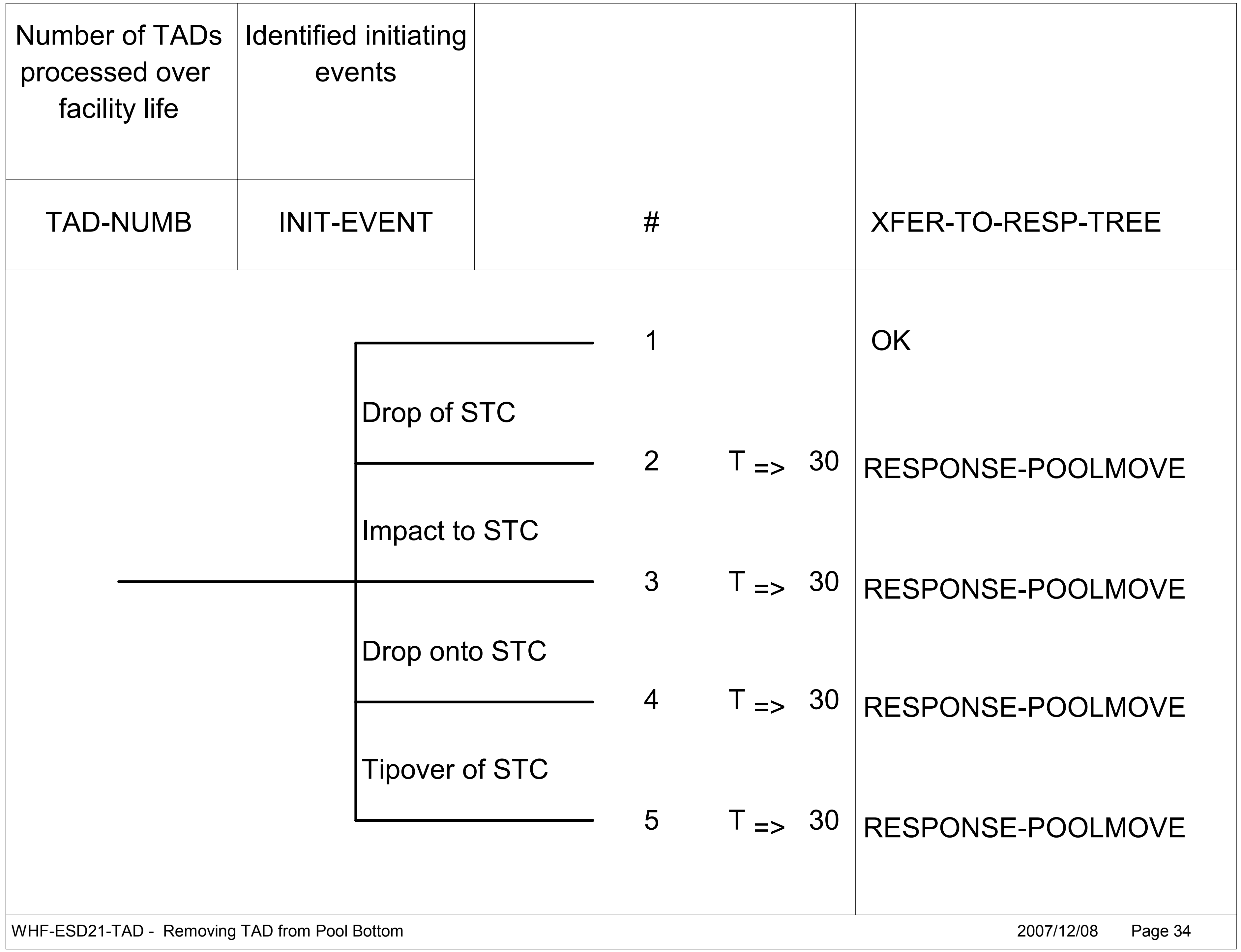
Figure G-33. Event Tree WHF-ESD21-CSNF – Lowering of Transportation Cask/Commercial SNF into Pool



NOTE: DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; STC = shielded transfer cask; T = transfer; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

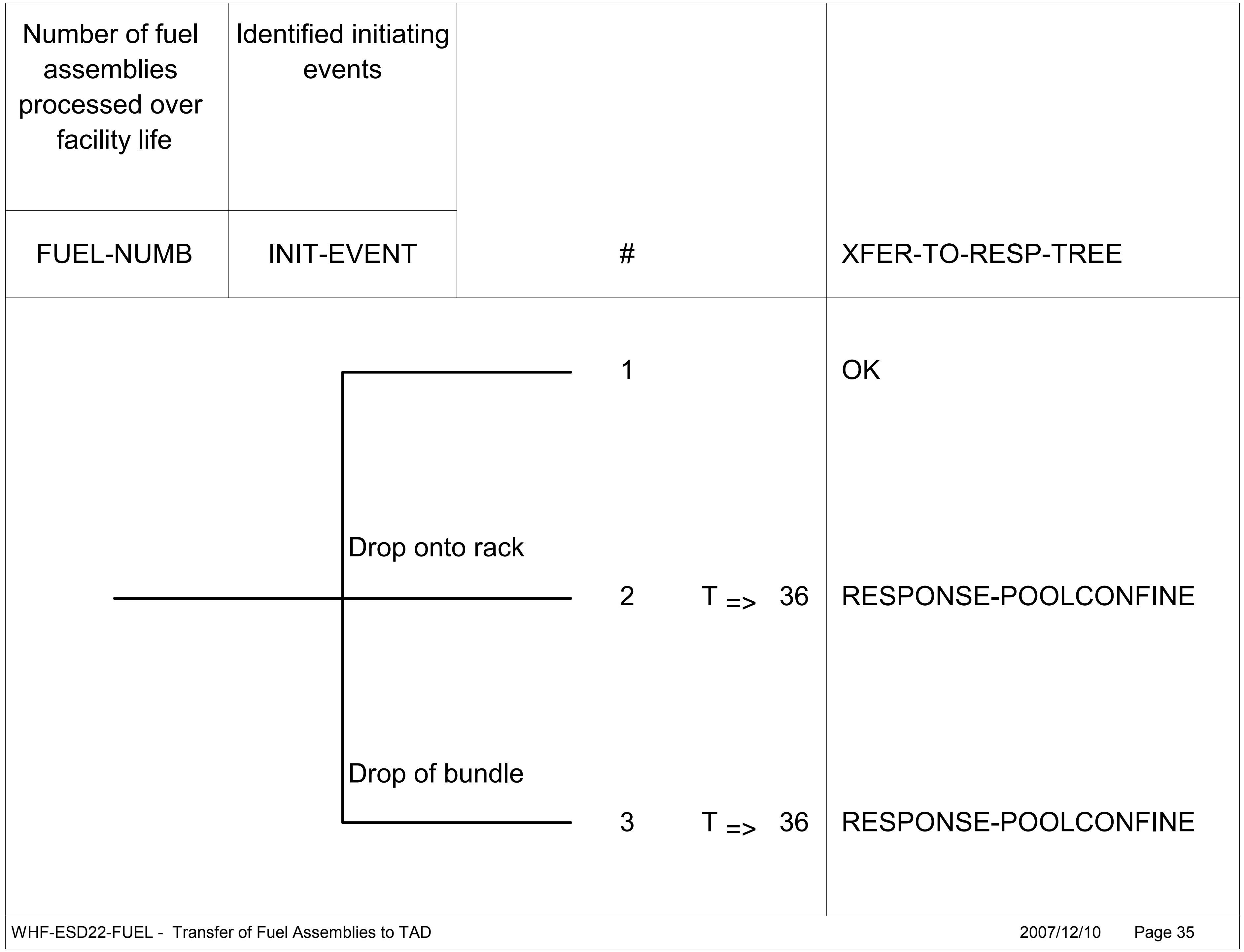
Figure G-34. Event Tree WHF-ESD21-DPC – Lowering of STC/DPC into Pool



NOTE: DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; STC = shielded transfer cask; T = transfer; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

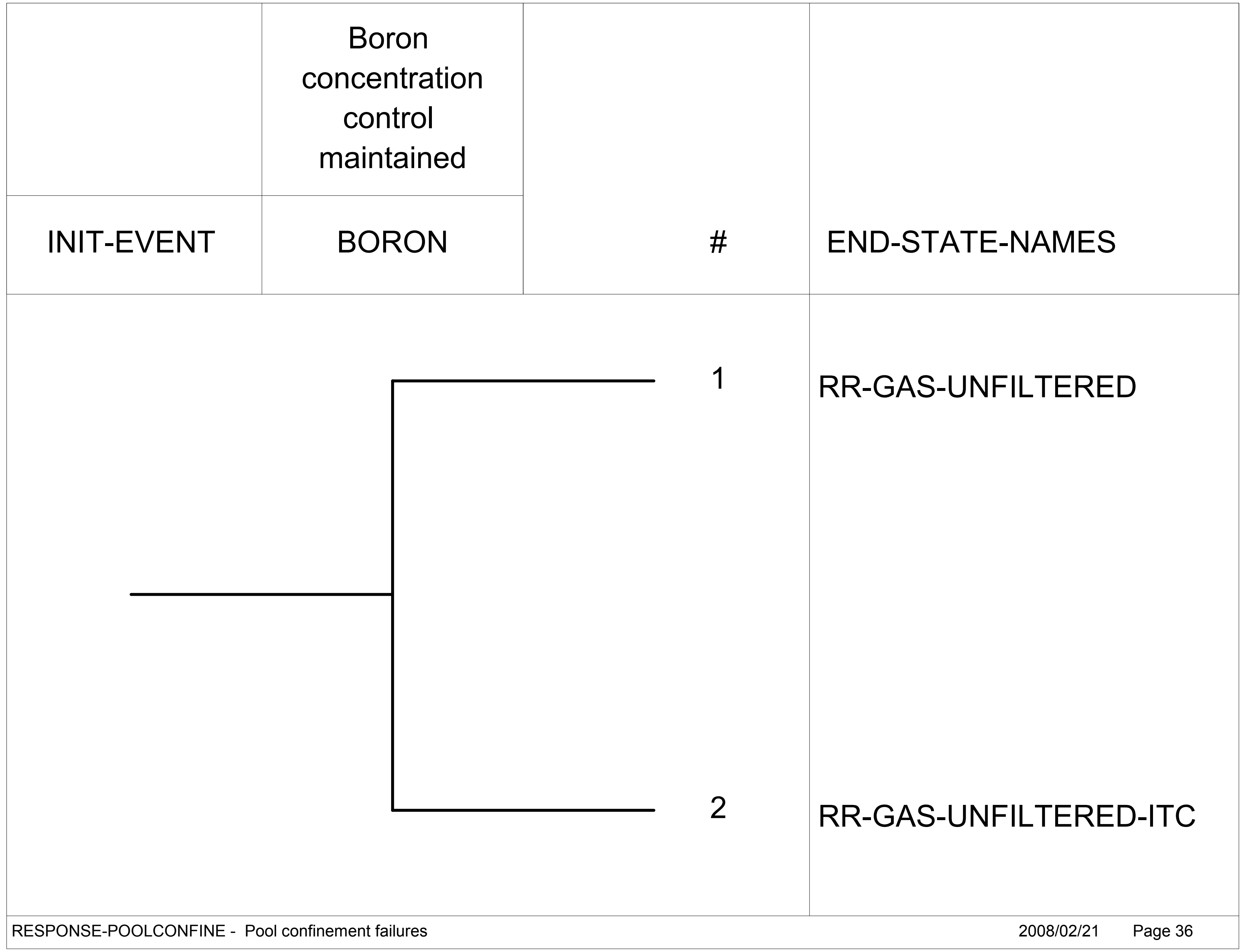
Figure G-35 Event Tree WHF-ESD21-TAD – Removing TAD from Pool Bottom



NOTE: ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; STC = shielded transfer cask; T = transfer; TAD = transportation, aging, and disposal canister; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

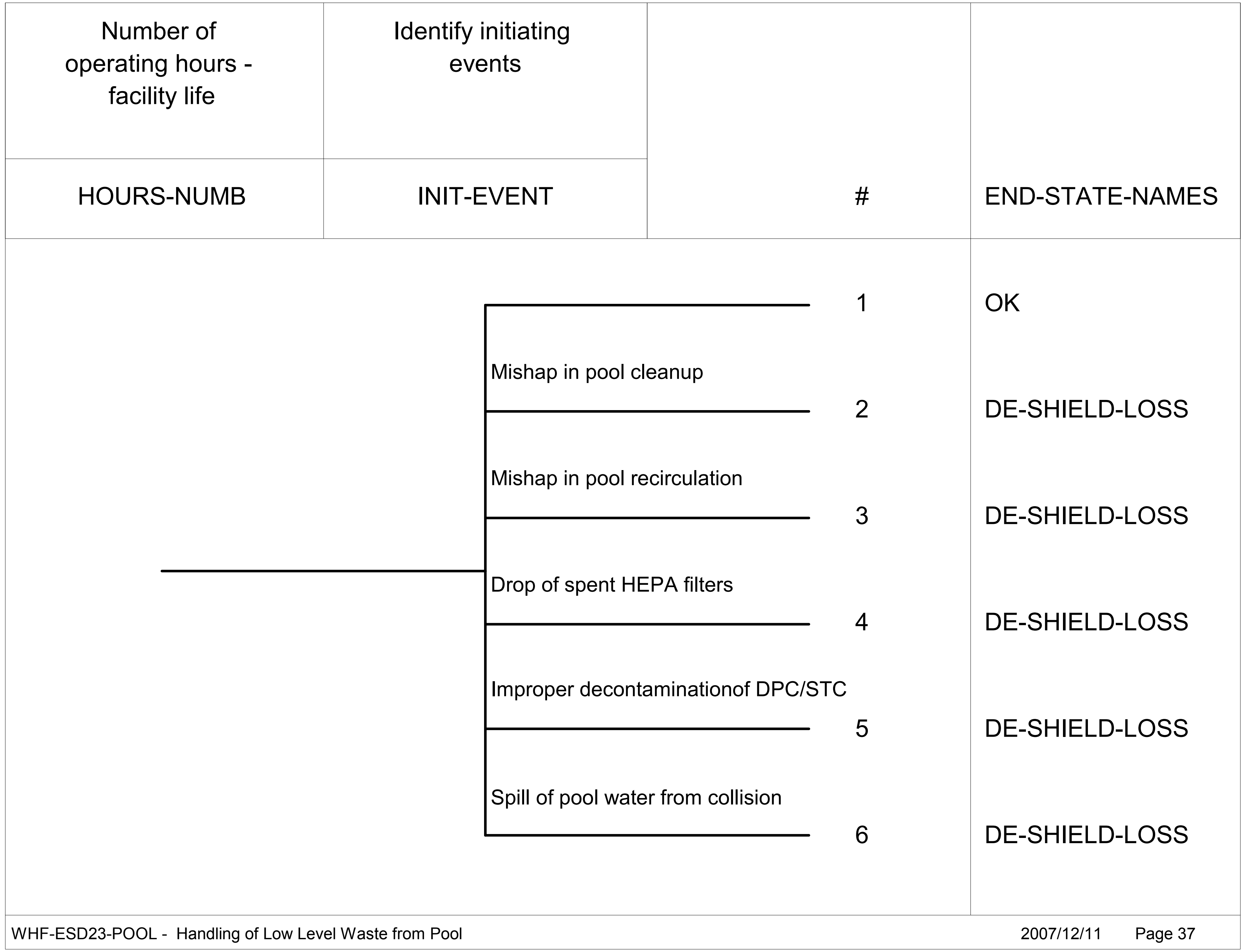
Figure G-36. Event Tree WHF-ESD22-FUEL – Transfer of Fuel Assemblies to TAD



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

Source: Original.

Figure G-37. Event Tree RESPONSE-POOLCONFINE – Pool Confinement Failures



NOTE: DE = direct exposure; DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; NUMB = number; STC = shielded transfer cask; WHF = Wet Handling Facility.

Source: Original.

Figure G-38. Event Tree WHF-ESD23-POOL – Handling of Low-Level Waste from Pool

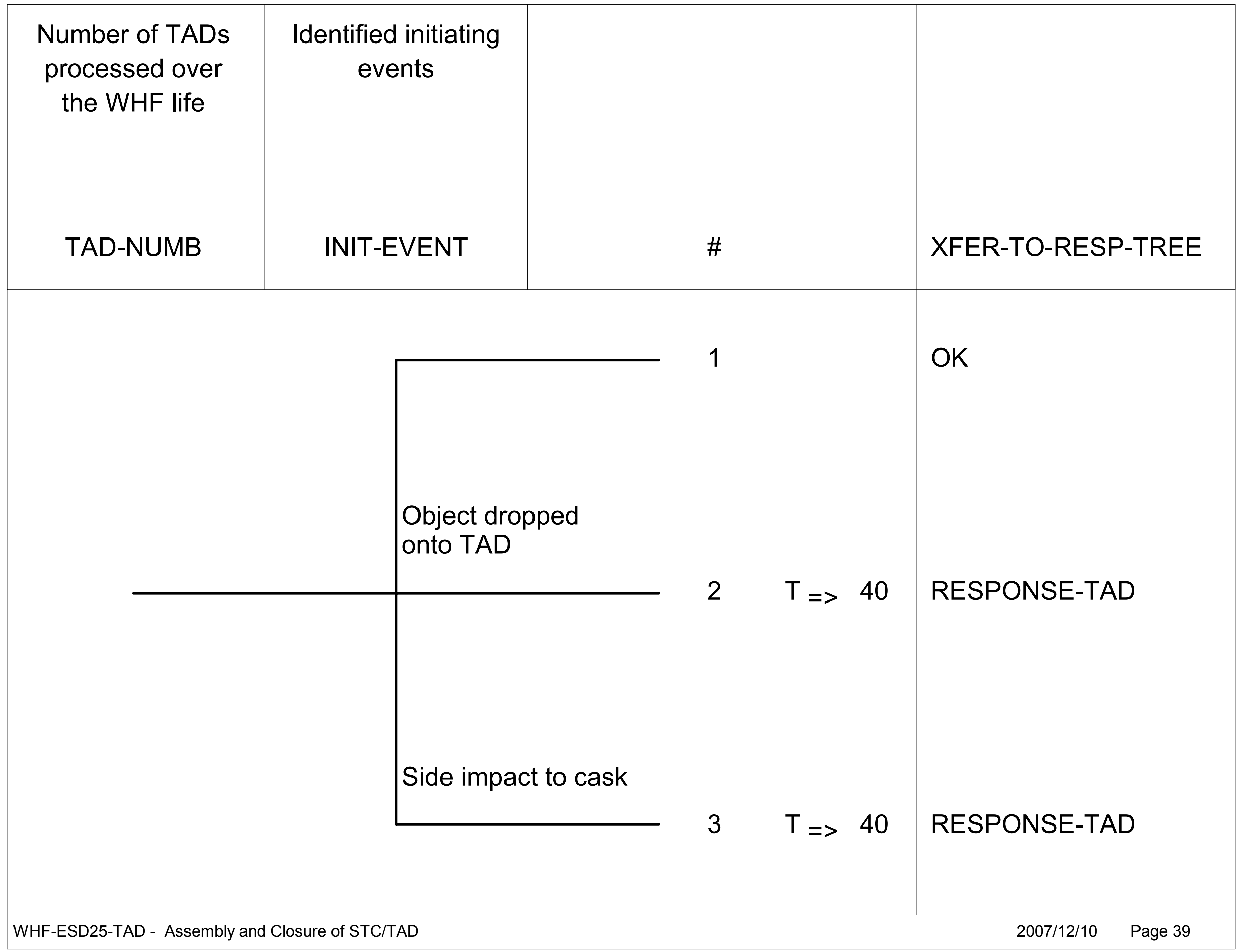
Number of TADs processed over the WHF life	Identified initiating events		
TAD-NUMB	INIT-EVENT	#	XFER-TO-RESP-TREE
		1	OK
	Impact of STC/TAD - Pool	2 T => 30	RESPONSE-POOLMOVE
	Drop at operational height - Pool	3 T => 30	RESPONSE-POOLMOVE
	Drop above operational height - Pool	4 T => 30	RESPONSE-POOLMOVE
	Tip over of STC/TAD - Pool	5 T => 30	RESPONSE-POOLMOVE
	Drop on STC/TAD - Pool	6 T => 30	RESPONSE-POOLMOVE
	Impact of STC/TAD - Floor	7 T => 8	RESPONSE-STC1
	Drop at operational height - Floor	8 T => 8	RESPONSE-STC1
	Drop above operational height - Floor	9 T => 8	RESPONSE-STC1
	Tip over of STC/TAD - Floor	10 T => 8	RESPONSE-STC1
	Drop on STC/TAD - Floor	11 T => 8	RESPONSE-STC1

WHF-ESD24-TAD - Transfer of STC/TAD from Pool Ledge to Prep Area 2007/12/08 Page 38

NOTE: ESD = event sequence diagram; INIT = initiating; PREP = preparation; RESP = response; STC = shielded transfer cask; TAD = transportation, aging, and disposal canister; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

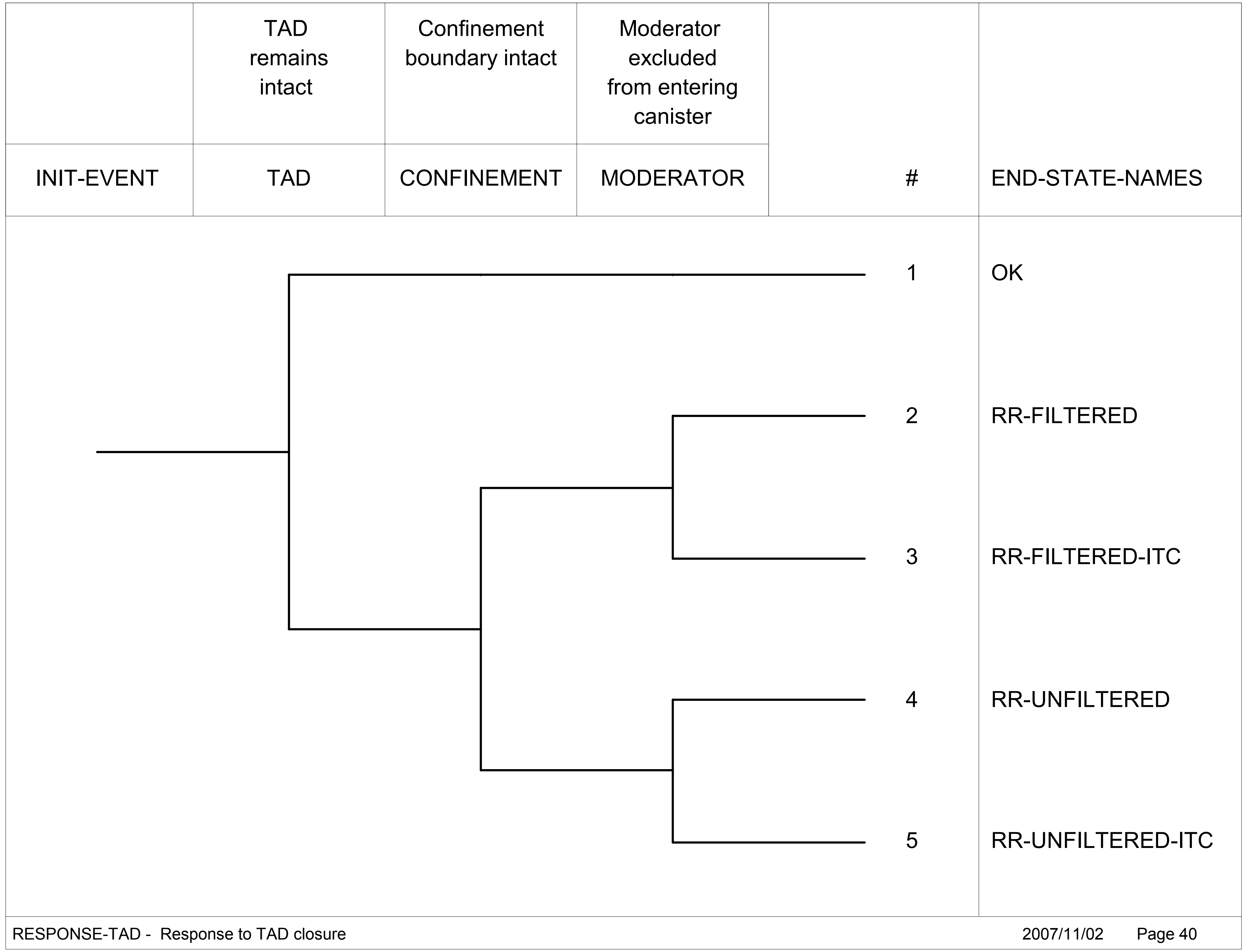
Figure G-39. Event Tree WHF-ESD24-TAD – Transfer of STC/TAD from Pool Ledge to Preparation Area



NOTE: ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; STC = shielded transfer cask; T = transfer; TAD = transportation, aging, and disposal canister; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

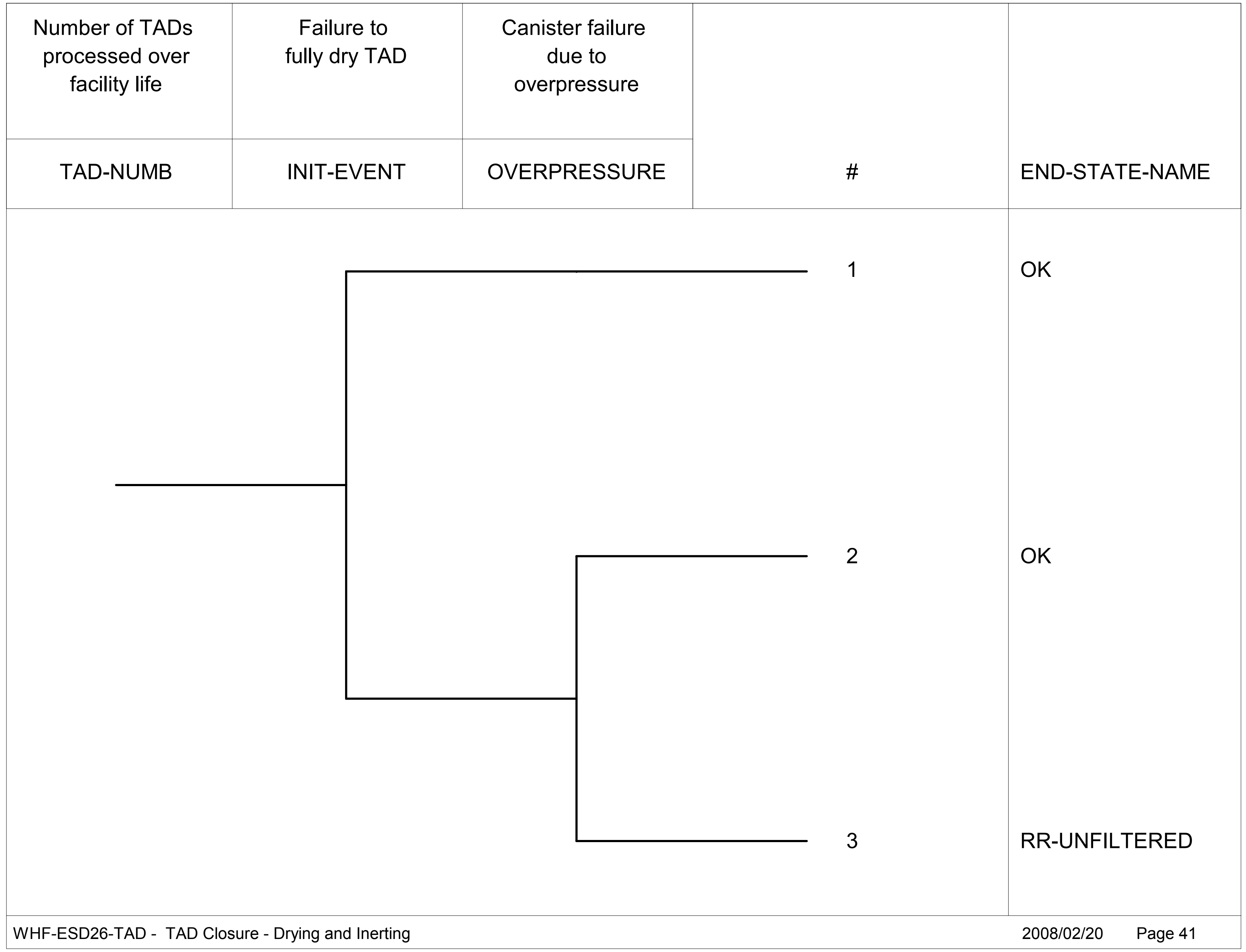
Figure G-40. Event Tree WHF-ESD25-TAD – Assembly and Closure of STC/TAD



NOTE: INIT = initiating; ITC = important to criticality; RR = radionuclide release; TAD = transportation, aging, and disposal canister.

Source: Original.

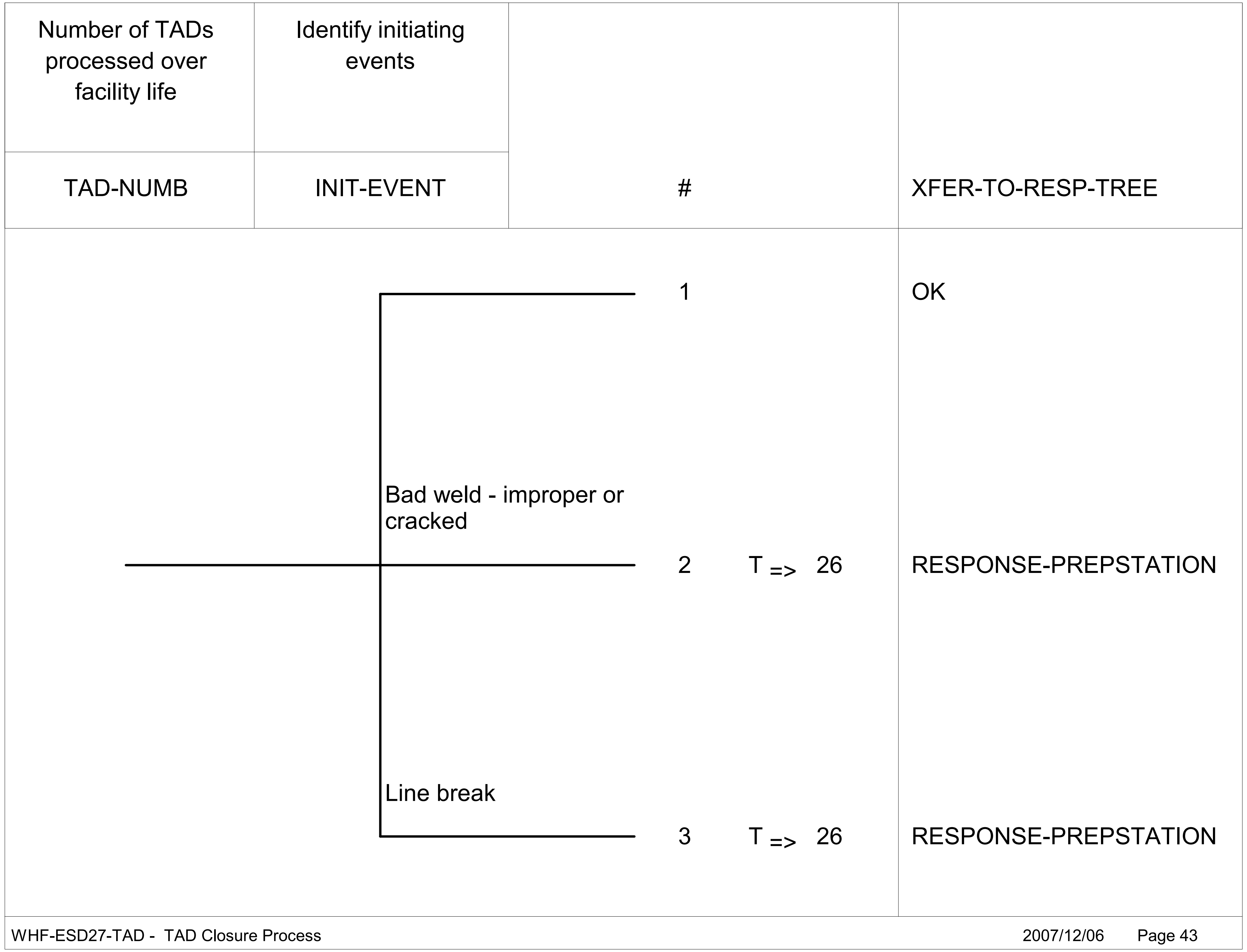
Figure G-41. Event Tree RESPONSE-TAD – Response to TAD Closure



NOTE: ESD = event sequence diagram; INIT = initiating; RESP = response; T = transfer; TAD = transportation, aging, and disposal canister; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

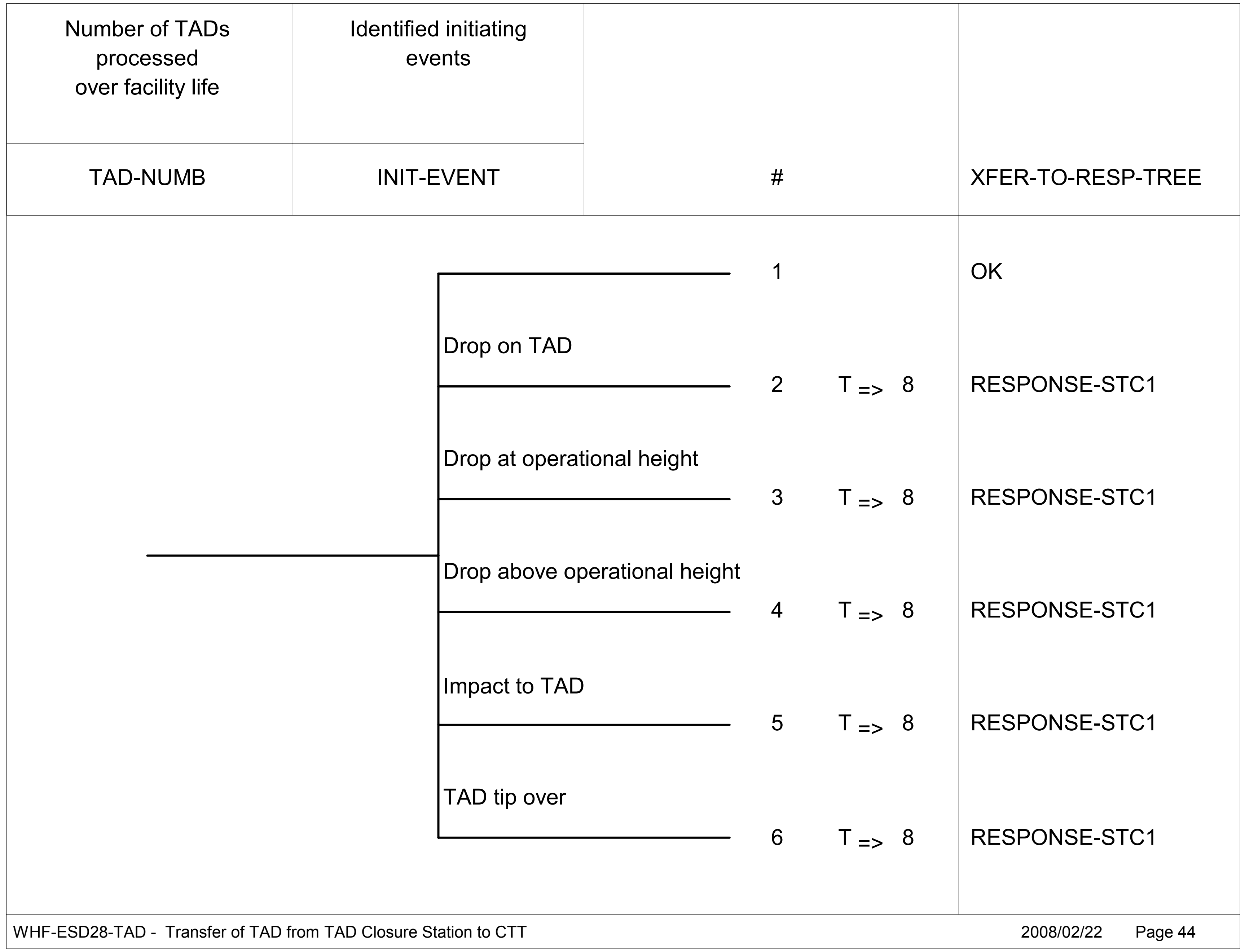
Figure G-42. Event Tree WHF-ESD26-TAD – TAD Closure – Drying and Inerting



NOTE: INIT = initiating; NUMB = number; RESP = response; T = transfer; TAD = transportation, aging, and disposal canister; XFER = transfer.

Source: Original.

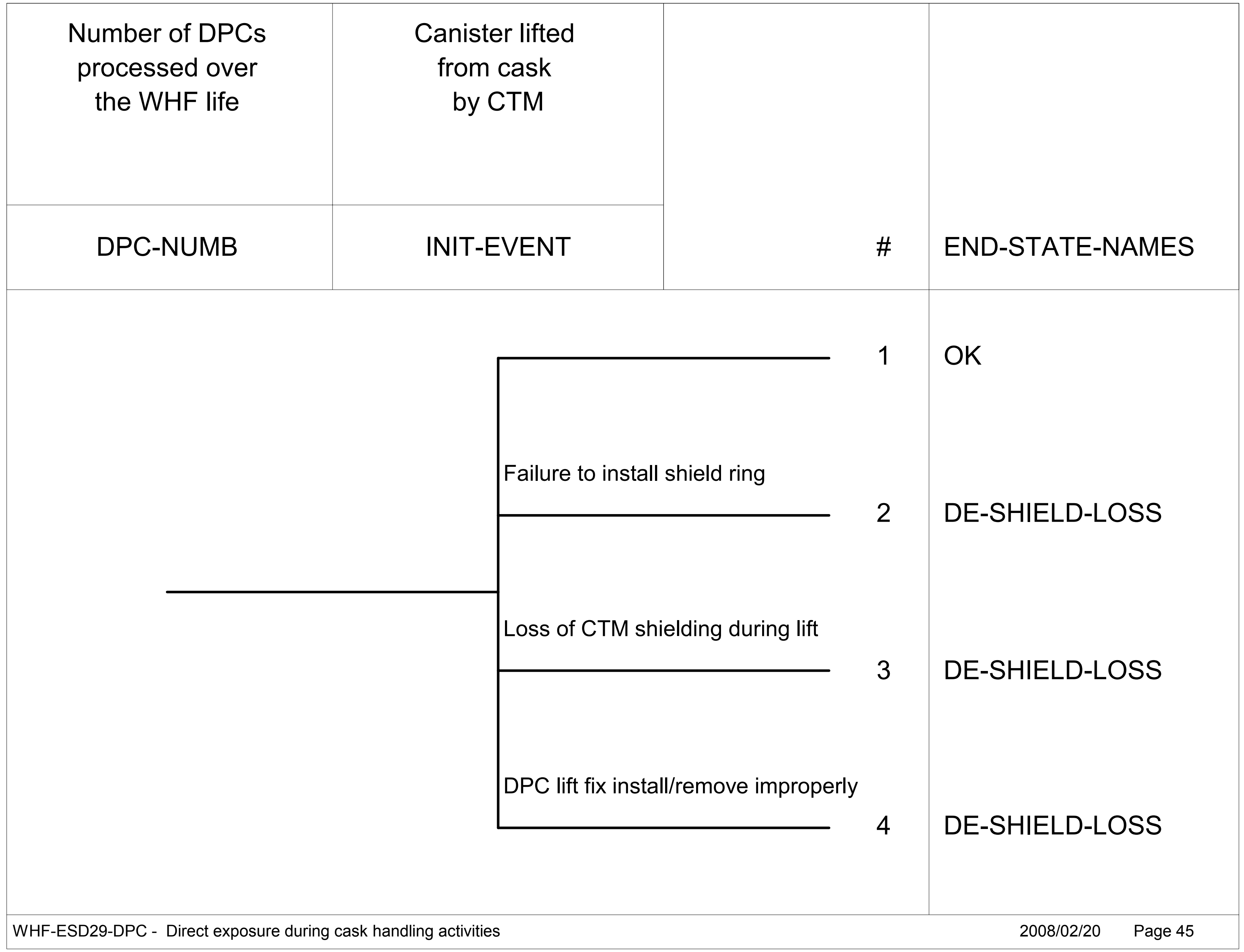
Figure G-43. Event Tree WHF-ESD27-TAD – TAD Canister Closure Process



NOTE: CTT = cask transfer trolley; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; T = transfer; TAD = transportation, aging, and disposal canister; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

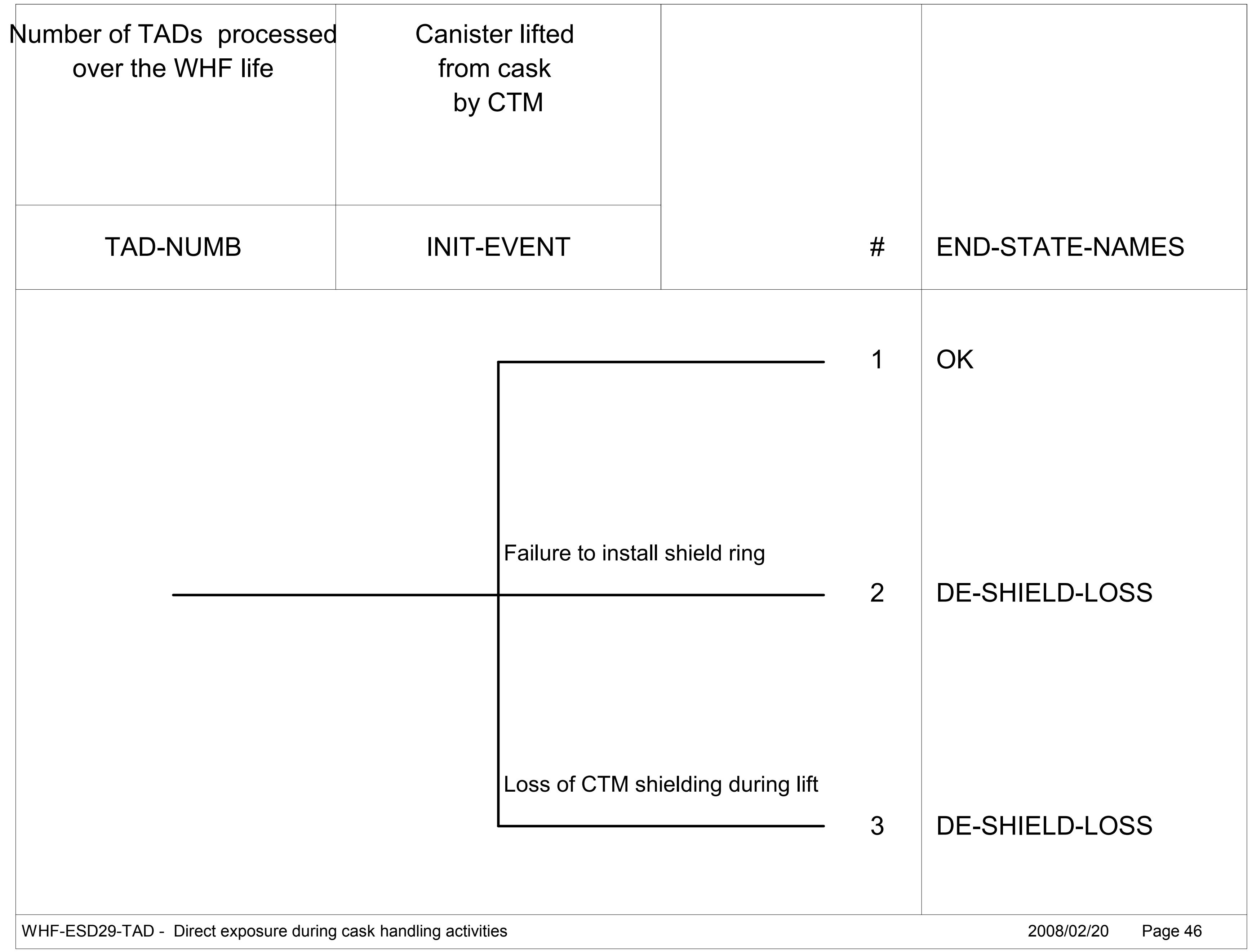
Figure G-44. Event Tree WHF-ESD28-TAD – Transfer of TAD from TAD Closure Station to CTT



NOTE: CTM = canister transfer machine; DE = direct exposure; DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; WHF = Wet Handling Facility.

Source: Original.

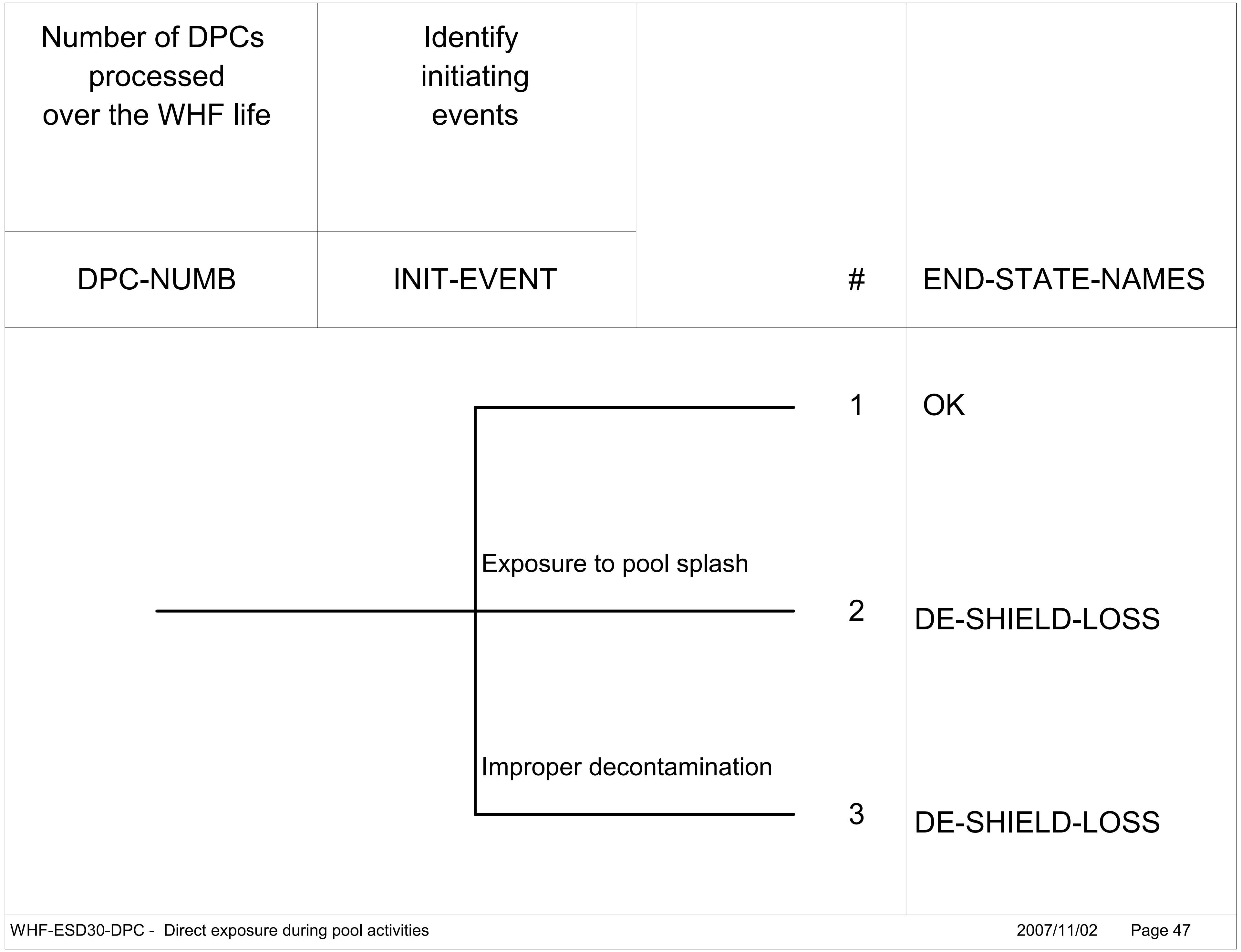
Figure G-45. Event Tree WHF-ESD29-DPC – Direct Exposure During Cask Handling Activities



NOTE: DE = direct exposure; ESD = event sequence diagram; INIT = initiating; TAD = transportation, aging, and disposal canister; WHF = Wet Handling Facility.

Source: Original.

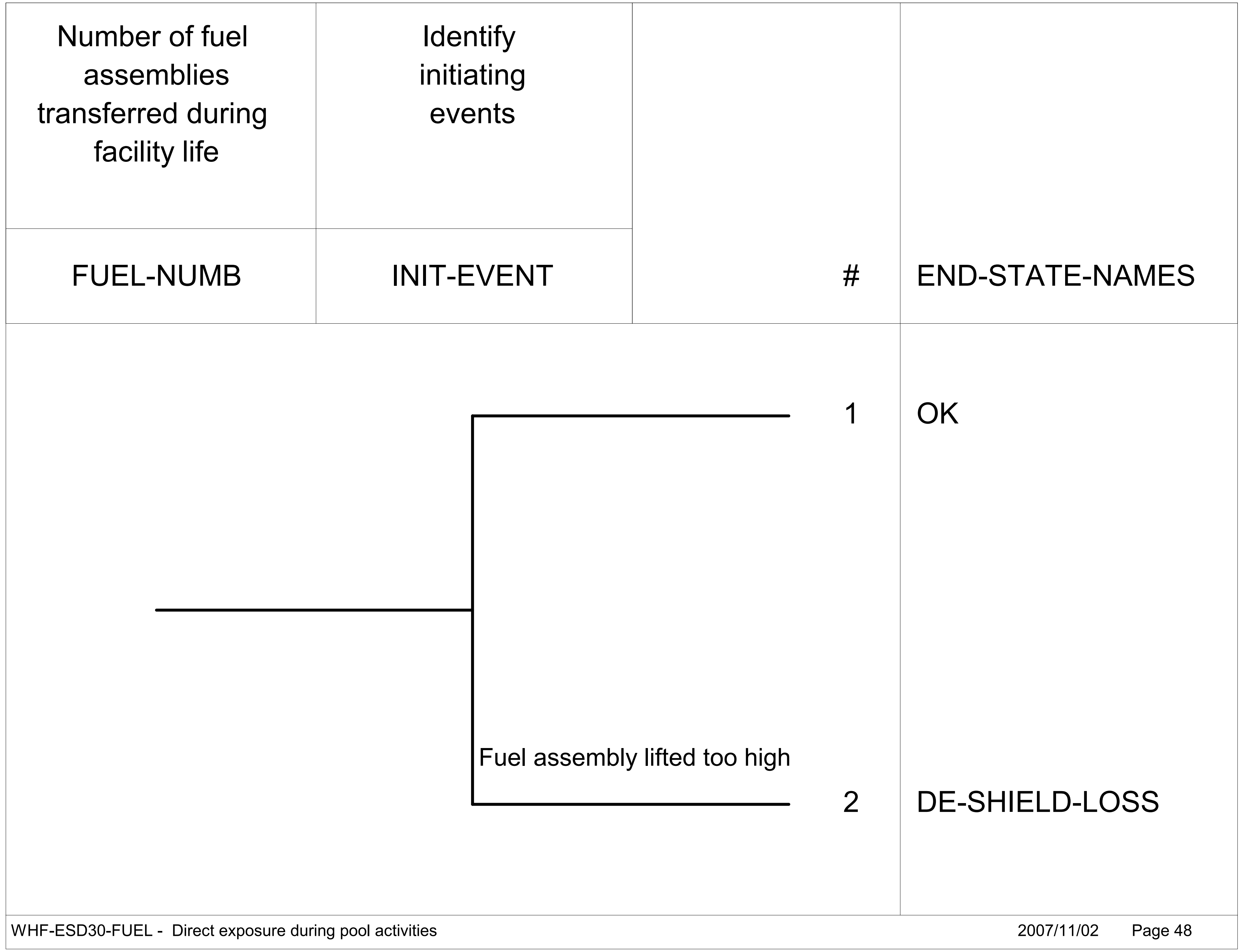
Figure G-46. Event Tree WHF-ESD29-TAD – Direct Exposure During Cask Handling Activities



NOTE: DE = direct exposure; ESD = event sequence diagram; INIT = initiating; NUMB = number; WHF = Wet Handling Facility.

Source: Original.

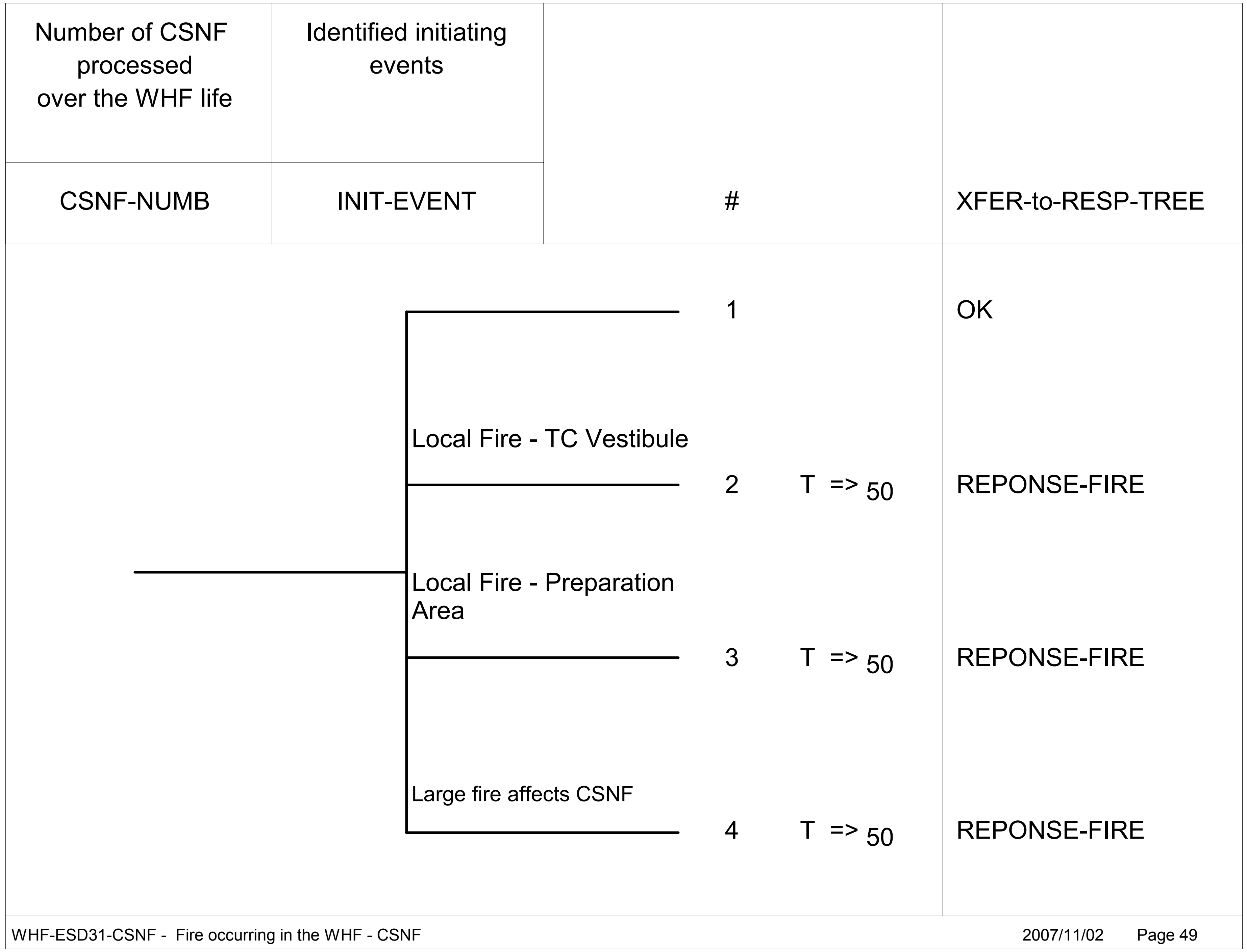
Figure G-47. Event Tree WHF-ESD30-DPC – Direct Exposure During Pool Activities



NOTE: DE = direct exposure; ESD = event sequence diagram; INIT = initiating NUMB = number; WHF = Wet Handling Facility.

Source: Original.

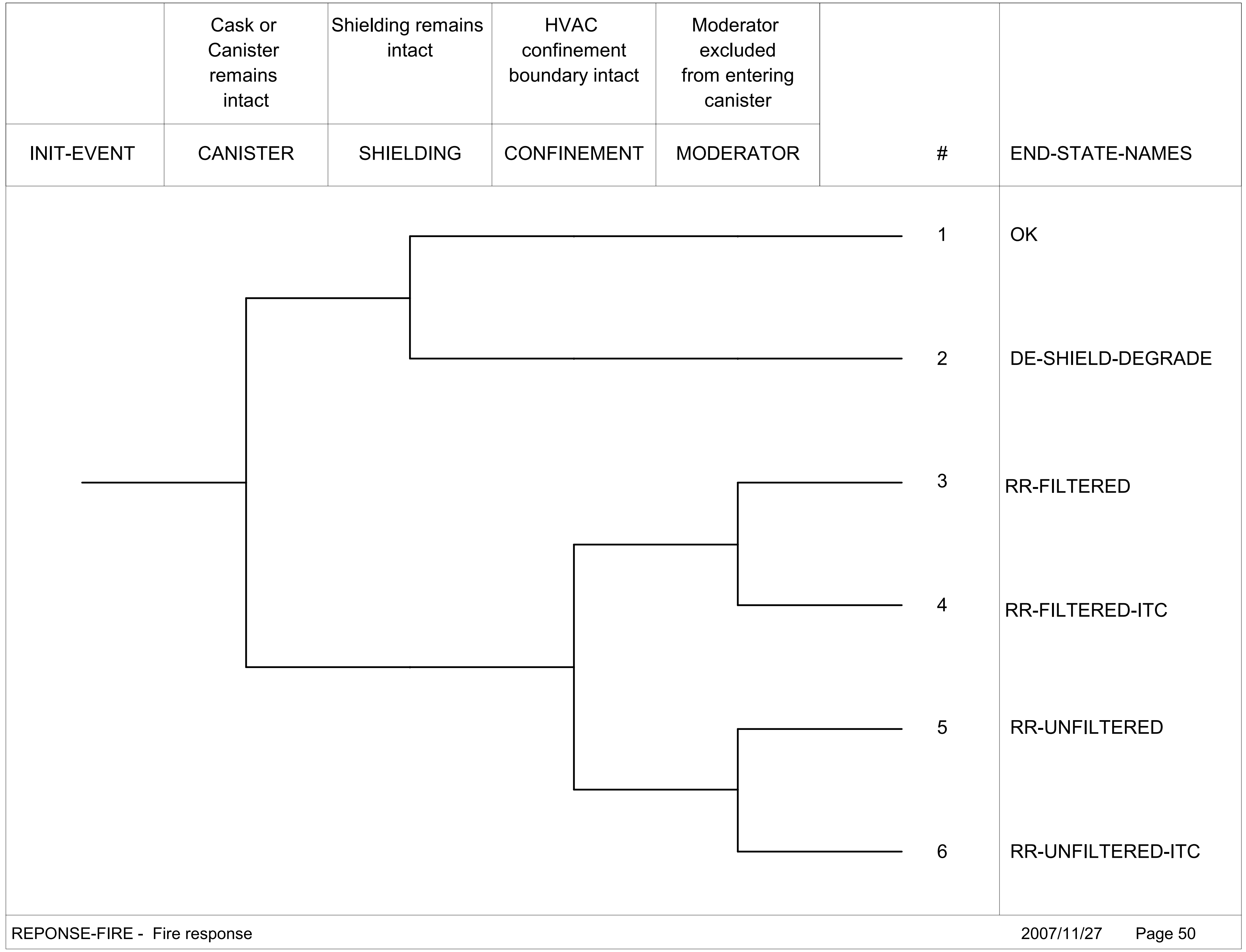
Figure G-48. Event Tree WHF-ESD30-FUEL – Direct Exposure During Pool Activities



NOTE: CSNF = commercial spent nuclear fuel; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; T = transfer; TC = transportation cask; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

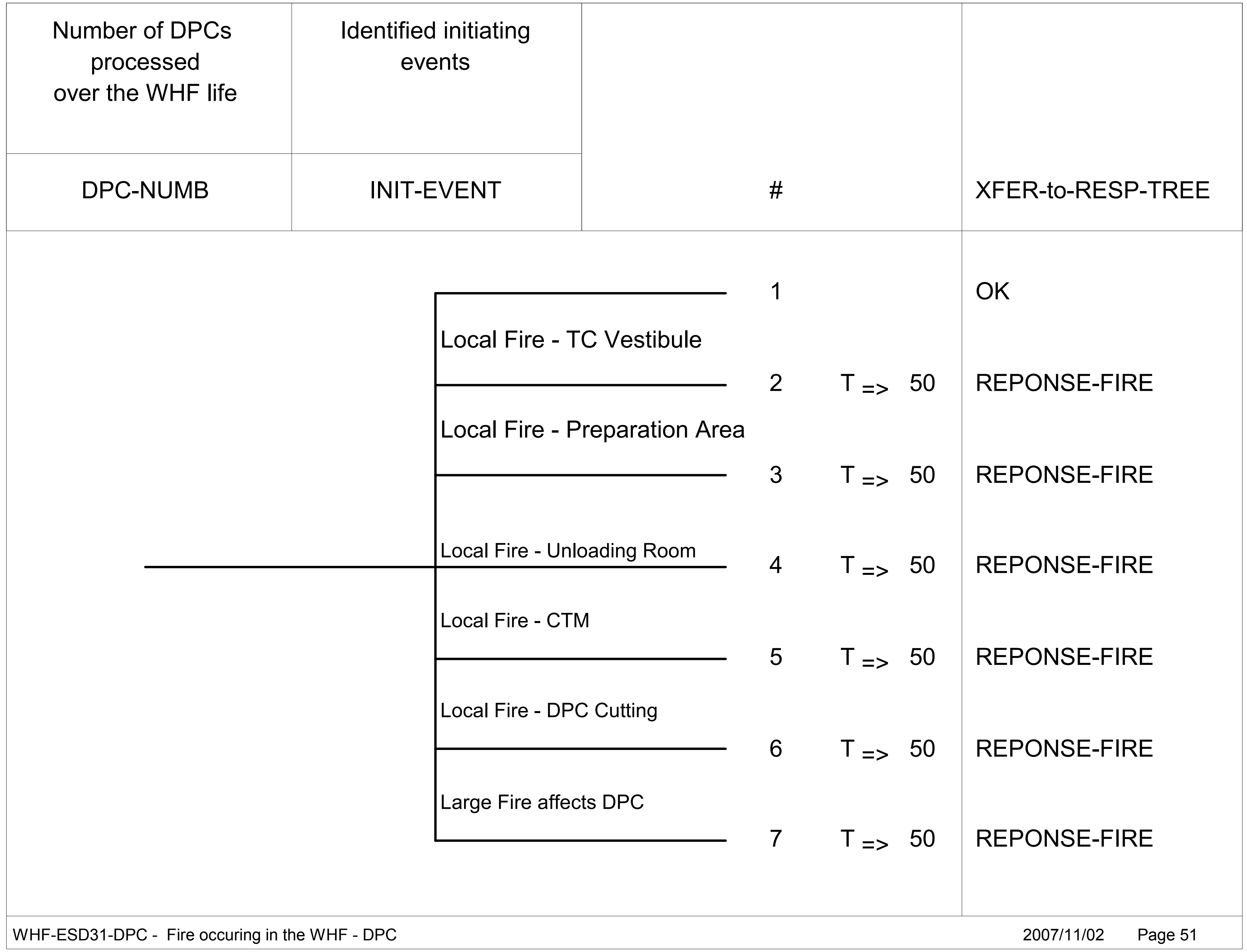
Figure G-49. Event Tree WHF-ESD31-CSNF – Fire Occurring in the WHF-Commercial SNF



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

Source: Original.

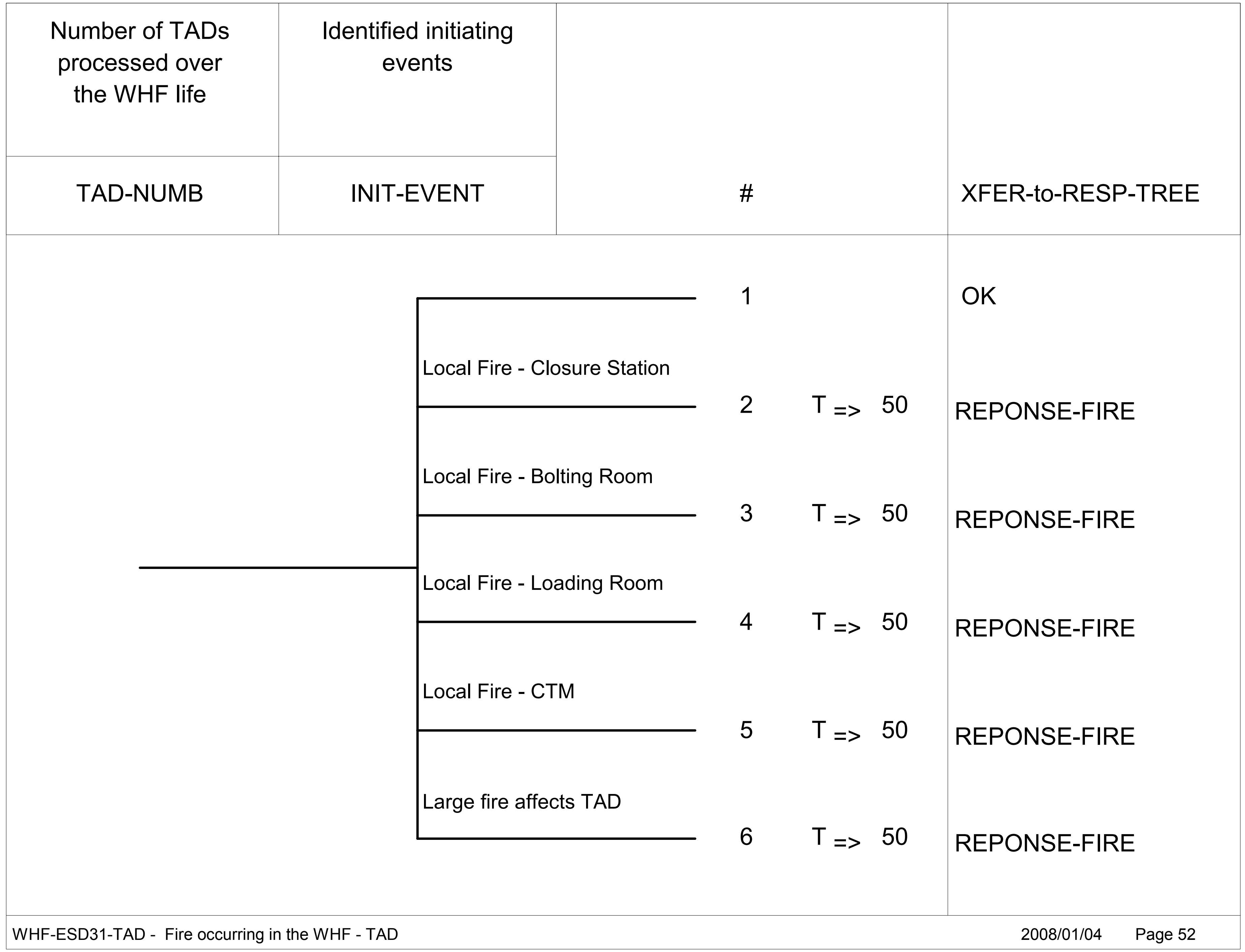
Figure G-50. Event Tree RESPONSE-FIRE – Fire Response



NOTE: CTM = canister transfer machine; DPC = dual-purpose canister; ESD = event sequence diagram; INIT = initiating; RESP = response; T = transfer; TC = transportation cask; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

Figure G-51. Event Tree WHF-ESD31-DPC – Fire Occurring in the WHF-DPC



NOTE: CTM = cask transfer machine; ESD = event sequence diagram; INIT = initiating; NUMB = number; RESP = response; ST = site transporter; T = transfer; TAD = transportation, aging, and disposal canister; WHF = Wet Handling Facility; XFER = transfer.

Source: Original.

Figure G-52. Event Tree WHF-ESD31-TAD – Fire Occurring in the WHF-TAD